Indigenous Knowledge Practices by Farmers in Response to Salinity Intrusion in Coastal Bangladesh

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One of the main causes of soil degradation is salinization which adversely affects crop productivity and threatens the livelihood of resource-constrained small-scale farmers in coastal regions that are sensitive to climate change. Building adaptation plans requires an understanding of farmers' perspectives and indigenous adaptation techniques. This study focuses on soil salinity and its effects on small-scale farmers and their responses to it. The data were analyzed using descriptive statistics, including average and percentage, linear regression, and chi-square test. The findings demonstrated that the studied sites' soil salinity increased with time. The majority of farmers in the study areas believed that salinity had a detrimental effect on crop productivity, availability of freshwater for irrigation, cost of irrigation water, crop area, plant height, and crop size. The methods of indigenous knowledge adaptation varied depending on the locale. Surprisingly, the majority of farmers in extremely salinity-prone regions fell into the low adaptation category, whereas those in somewhat salinity-prone regions fell into the medium adaptation category. The unsuccessful adaptation to rising soil salinity may be a result of their lower educational level, small farm size, reliance on surface water, and lack of access to information and training. Therefore, all parties associated with those influencing elements should collaborate in a comprehensive effort to develop farmers' need-based, site-specific methods to solve the problem of salinity intrusion in the coastal sediments.

Introduction

Climate change-related events, such as drought, cyclones, excessive precipitation, and flooding, have repercussions on rural livelihoods in South Asia's coastal regions (Dastagir, 2015; and Aryal *et al.*, 2020). Several studies have linked drought, precipitation, and flooding to agricultural system failure (Rojas *et al.*, 2016; Myers *et al.*, 2017; Gould *et al.*, 2020; and Meza *et al.*, 2021). However, no adequate attention has been paid to the increased level of soil salinity. The Intergovernmental Panel on Climate Change (IPCC) reports that soil and water salinization are increasing, notably in low-lying coastal areas, river deltas, and estuaries

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(Oppenheimer *et al.*, 2019; and Lam *et al.*, 2022). According to recent studies, salt affects around 1,125 million ha of land worldwide, and every year, 1.5 million ha of land becomes unsuitable for agricultural production due to high soil salinization (Hossain *et al.*, 2019; and Dewi *et al.*, 2022). Soil salinization is regarded as one of the major causes of soil degradation (Shrestha *et al.*, 2021), particularly in coastal areas (Islam *et al.*, 2020).

Bangladesh's coastal areas account for roughly 30% of the total cultivable land, (Salehin *et al.*, 2018) and have been experiencing rising soil salinization at a rate of 0.74% per year since the 1980s (SRDI, 2010). According to Bangladesh's Soil Resource Development Institute (SRDI), approximately 0.328, 0.274, 0.189, 0.161, and 0.101 million ha of land in coastal areas are affected by very slight (S1), slight (S2), moderate (S3), strong (S4), and very strong salinity (S5), respectively (SRDI, 2010). Unimpeded growth in salinity might impair the lives and livelihoods of 13.6 and 14.8 million people by 2050 and 2080, respectively (Aryal *et al.*, 2020).

The causes of salinization in Bangladesh's coastal areas include saline water shrimp and salt farming, river siltation, and climate change-induced saltwater intrusion (Al Mamun *et al.*, 2014; and Aryal *et al.*, 2020). According to a World Bank study, saltwater intrusion caused by a sea-level rise will alone reduce rice (Oryza sativa L) production in Bangladesh by 0.2 million tons (World Bank, 2018). Soil salinity in Bangladesh's coastal regions is anticipated to rise further, posing a severe threat to the region's agricultural system (Hossain and Roy, 2012; Dasgupta *et al.*, 2015; and Khanom, 2016). In the face of the above challenges, the government of Bangladesh prioritized agricultural system sustainability to ensure better livelihood and food security for the people and declared a national agricultural policy linked with sustainable development goals (SDGs) in 2018 (Islam *et al.*, 2020). Sustainable agricultural production, particularly rice production, is critical to achieving SDGs such as no poverty (SDG 1) and zero hunger (SDG 2) (Ashraf *et al.*, 2019). Rice accounts for 75% of cultivable land in the country, generates 48% of rural employment, and accounts for 70% of daily calorie consumption (BRRI, 2018). However, a drop in rice-based agricultural production in Bangladesh's coastal districts due to rising soil salinity ultimately jeopardizes the achievement of the SDGs (Szabo *et al.*, 2016). As a result, the rising soil salinity phenomenon emphasizes the importance of reducing salinity risk through both governmental and local community efforts. Exploring local farmers' perceptions of salinization and their adaptation mechanisms can help address this issue. Understanding farmers' perceptions can be critical in developing need-based adaptation plans (Le Dang *et al.*, 2014).

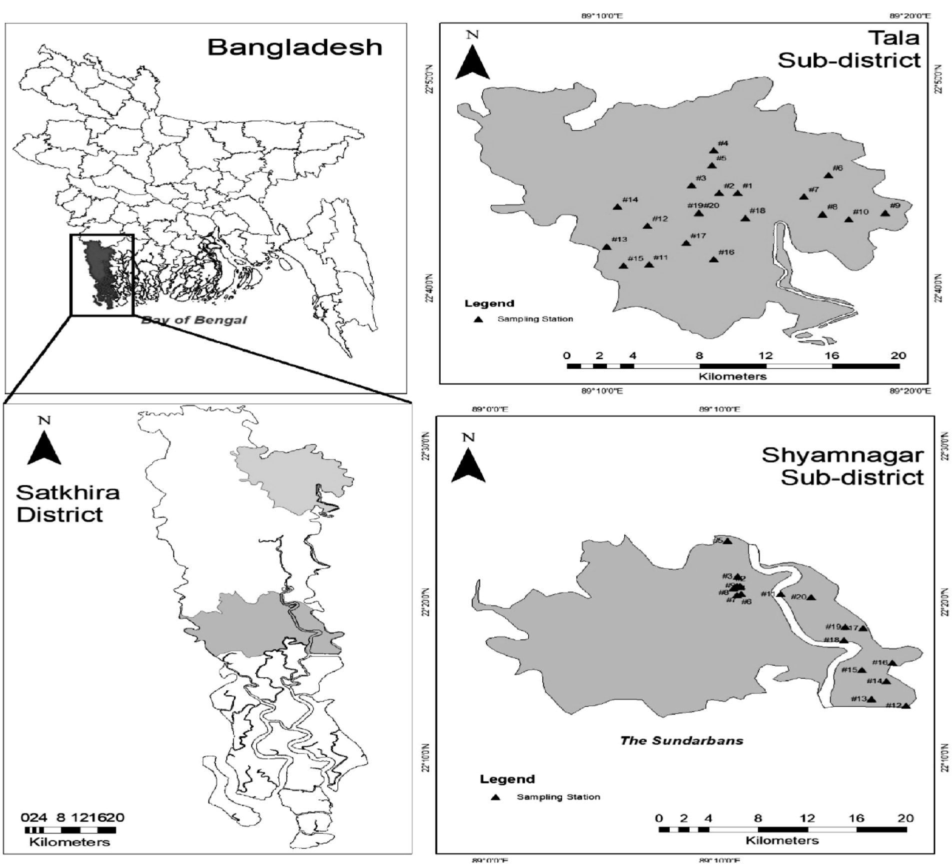
The literature on the impacts of salinity on agriculture and food security in coastal areas is extensive (Bhowmick *et al.*, 2016; Alam *et al.*, 2017; Miah *et al.*, 2020; and Lam *et al.*, 2022). Several researchers have focused on the adaptation strategies used by coastal households (Hossain *et al.*, 2018; and Islam *et al.*, 2020). However, while identifying adaptation strategies, most studies disregard the perspective of small farmers, which can play a critical role in adopting a farmer-need-based policy. A few studies have investigated farmers' perceptions of salinity in coastal regions (Islam *et al.*, 2020, 2021). However, these studies did not compare farmers' perceptions at different salinity levels. Therefore, the present study adds to the current literature by investigating small-scale farmers' perceptions and adaptation strategies at different salinity levels. The findings of this study can assist policymakers in developing appropriate soil salinity adaptation policies based on the needs of small-scale farmers.

Methodology

Study Area

This study was carried out in the southwest coastal zone of Bangladesh due to the high level of soil salinity. The southwest coastal zone is divided into three districts: Khulna, Bagerhat, and Satkhira. This study was conducted in Satkhira district, which is affected by very slight (S1) to very strong salinity (S5) (SRDI, 2010). Satkhira district is characterized by small-scale subsistence agriculture based on a saline, wet rice ecosystem (Ali, 2006; and Faruque *et al.*, 2017). The district includes seven sub-districts, two of which (Shyamnagar and Assasuni) have moderate (S3) to very strong (S5) levels of soil salinity, while the other five (Tala, Debhata, Kalaroa, Kaliganj, and Satkhira Sadar) have very slight (S1) to slight (S2) levels of soil salinity (Figure 1).

Figure 1: Geographical Location of the Study Areas



This study purposively selected one sub-district (Tala) from the very slight salt-affected area and one sub-district (Shyamnagar) from the very strong salt-affected area to examine the variation in farmers' perceptions and adaptation strategies. After consulting with the sub-district agricultural extension office and taking into account the study's time and budget, four villages from each sub-district were selected for the questionnaire survey and Focus Group Discussions (FGDs). For each village, a list of small-scale farmers was compiled, and the desired number of farmers were selected randomly from that list. Farmers with farm sizes ranging from 0.21 ha to 1.00 ha were classified as small-scale farmers (Mottaleb *et al.*, 2016; and Khalil *et al.*, 2017).

Sampling Technique

This study focused on small-scale farmers since small farmers are more susceptible to the adverse impacts of salinity in coastal areas (Jalal *et al.*, 2021). There are 42,053 small farm families in two sub-districts, including 19,653 in Tala sub-district and 22,400 in Shyamnagar sub-district (BBS, 2018). This study's sample size was determined using Yamane's formula (Yamane, 1967). Previous studies have also used this formula to determine the optimal sample size (Swe *et al.*, 2015; Shrestha *et al.*, 2018; and Roy *et al.*, 2022).

$$n = N \div [1 + n(e2)] \qquad \ldots(1)$$

where n is the sample size, N is the population of small farm households in each sub-district, and e is the precision or sampling error (0.10). Equation (1) suggests a sample size of 100 from each sub-district. Therefore, the overall sample size was 220, including a 10% reserve. However, because of the enthusiasm and willingness of the Tala sub-district's households to participate in the survey, we conducted two additional interviews, bringing the overall sample size to 222.

Data Collection

Secondary and primary data were used to analyze soil salinity levels, farmers' perceptions of soil salinity impacts on crop production, and adaptation strategies. Secondary data on soil salinity from 2011 to 2017 were obtained from the SRDI. FGDs, Key Informant Interviews (KIIs) and face-to-face interviews were used to gather primary data (See Appendix). First, an interview schedule was prepared and pre-tested with a small group of farmers. The interview schedule was revised and finalized in response to the farmers' feedback. Face-to-face interviews were conducted to collect information from the farmers using the finalized interview schedule. In addition, soil samples were collected from the study areas at depths ranging from 0 to 15 cm. To estimate surface soil salinity, a total of 40 samples were collected, 20 from each sub-district. The samples were collected and analyzed during March-April 2018.

Data Analysis

Using soil Electrical Conductivity (EC) values for the dry season, a simple linear regression was applied to determine the trend of soil salinity. The following regression equation was used to examine the trend:

$$Y = \alpha + \beta t + u \qquad \ldots(2)$$

where Y is the soil EC value, *a* represents the constant, β is the slope, *t* is the year, and u is the random error term. The soil EC is a measurement of the amount of salt in the soil. It negatively impacts crop yields, crop suitability, plant nutrient availability, and the activity of soil microorganisms, all of which influence key soil processes, including the emission of greenhouse gases such as nitrous oxide, methane, and carbon dioxide. The variations in soil EC are strongly sensitive to the ripening stages of rice planted at different soil salinity levels (Touch *et al.*, 2015). A conductivity meter was used to measure the soil EC. The method used to measure the soil salinity level was based on the study of Hossain *et al.* (2015) on the association between soil salinity and other physicochemical parameters. However, rather than detecting ion species, the main goal of this study was to assess the degree of soil salinity. As a result, only the EC of soil water extract, pH, and salt percentage were measured. Descriptive statistics, such as percentage and frequency, were used to analyze farmers' socio-demographic profiles and perceptions of soil salinity impacts. Following Shrestha and Nepal (2016), farmers' perceptions of soil salinity impacts were classified into four groups: high, moderate, low, and unchanged. The Pearson chi-square (χ^2) test was used to assess if there were any significant variations in farmers' opinions of the effects of soil salinity on crop production.

A four-point Likert scale was used to determine the adoption status of several adaptation strategies. According to FGD and KII, farmers mostly adopted eight adaptation strategies to cope with the adverse impacts of soil salinity. For ranking purposes, a Weighted Average Index (WAI) for each adaptation strategy was constructed (Ndamani and Watanabe, 2016). Farmers' possible responses to each of the adaptation strategies were categorized into four groups: frequently, occasionally, rarely, and not at all, with corresponding scores of 3, 2, 1, and 0, respectively. The WAI was computed using the following formula:

$$WAI = (Ff * 3 + F0 * 2 + Fr * 1 + Fn * 0) / N \qquad \ldots(3)$$

where WAI = weighted average index, *Ff* = number of farmers with the response 'frequently', *Fo* = number of farmers with the response 'occasionally', *Fr* = number of farmers with the response 'rarely', *Fn* = number of farmers with the response 'not at all', and N = total number of farmers. As a result, if a farmer responds that he/she has used all eight adaptation strategies frequently, he/she can receive a maximum score of 24. Farmers were divided into three groups based on the estimated score: high adaptation (17-24), medium adaptation (9-16), and low adaptation (0-8) (Defiesta and Rapera, 2014).

Results

Socioeconomic Characteristics of the Farmers

The socioeconomic characteristics of the farmers are presented in Table 1.

Table 1: Socioeconomic Characteristics of the Farmers

Attribute	Category	Tala Sub-District (n =112)	Shyamnagar Sub-District (n = 110)
Age (year)	Young (18-35)	47 (42.0[a])	35 (31.8[a])
	Middle aged (36-50)	44 (39.3)	52 (47.3)
	Old (above 50)	21 (18.8)	23 (20.9)
Educational status (year of schooling)	No education (0)	17 (15.2)	45 (40.9)
	Primary education (1-5)	46 (41.1)	47 (42.7)
	Secondary education (6-10)	44 (39.3)	15 (13.6)
	Above secondary (> 10)	5 (4.5)	3 (2.7)
Farm size (ha)	0.21-0.47	70 (62.5)	72 (65.5)
	0.48-0.73	30 (26.8)	30 (27.3)
	0.74-1.00	12 (10.7)	8 (7.3)
Source of irrigation	Deep tube well water	17 (15.2)	0 (0)
	Shallow tube well water	84 (75.0)	17 (15.5)
	Surface water	11 (9.8)	93 (84.5)
Engaged in off-farm activities (number)	Yes	44 (39.3)	79 (71.8)
	No	68 (60.7)	31 28.2)
Access to information (score)	Low (< 10)	25 (22.3)	57 (51.8)
	Medium (11-20)	57 (50.9)	45 (40.9)
	High (> 20)	30 (26.8)	8 (7.3)
Training	Yes	38 (33.9)	17 (15.5)
	No	74 (66.1)	93 (84.5)

Note: [a] Figures in parentheses indicate the percentage.

According to the age distribution of the farmers, approximately half of them were middle-aged, while around 20% of the farmers in both study areas were old. The findings indicate that the age distribution in both study areas is similar. The educational level suggests that illiteracy is more prevalent in Shyamnagar sub-district (40.9%) than in Tala sub-district (15.2%). In both areas, approximately 40% of the farmers had primary level of education. Farm size distribution was similar in both study sub-districts. There was a high disparity in irrigation water sources between Tala and Shyamnagar sub-districts. In Shyamnagar, most farmers (84.5%) used surface water, whereas 75% of the farmers in Tala used shallow tube wells to irrigate their land. Shyamnagar had more farmers (71.8%) involved in off-farm income-generating activities than Tala (39.3%). In Tala, 26.8% of the farmers had high access to agricultural-related information, whereas only 7.3% of the farmers had access to such information in Shyamnagar. About 34% of the farmers in Tala received agricultural-related training, whereas only 15.5% of the farmers received training in Shyamnagar.

Distribution and Trend of Soil Salinity

Almost all the soil samples (90%) in Tala fell into the very slight or non-saline category (< 2.0 dS/m), with only 10% falling into the slightly saline category (2.0-4.0 dS/m) (Table 2). On the contrary, 40% of the soil samples from Shyamnagar were characterized as highly saline (12.1-16 dS/m) (Table 3). Shyamnagar also had moderate to high saline (8.1-12.0 dS/m) samples (30%). Figure 2 depicts a trendline with error bars that eventually indicates an increase in soil salinity from 2011 to 2018. The average value of soil EC in Tala sub-district was 1.50 dS/m, while it was 11.44 dS/m in Shyamnagar sub-district, and the mean difference was statistically significant at the 1% level of significance ($p < 0.01$). Therefore, it can be deduced that soil salinity is significantly and substantially higher in Shyamnagar sub-district than Tala sub-district.

Table 2: Distribution of Soil Salinity in Tala Sub-District

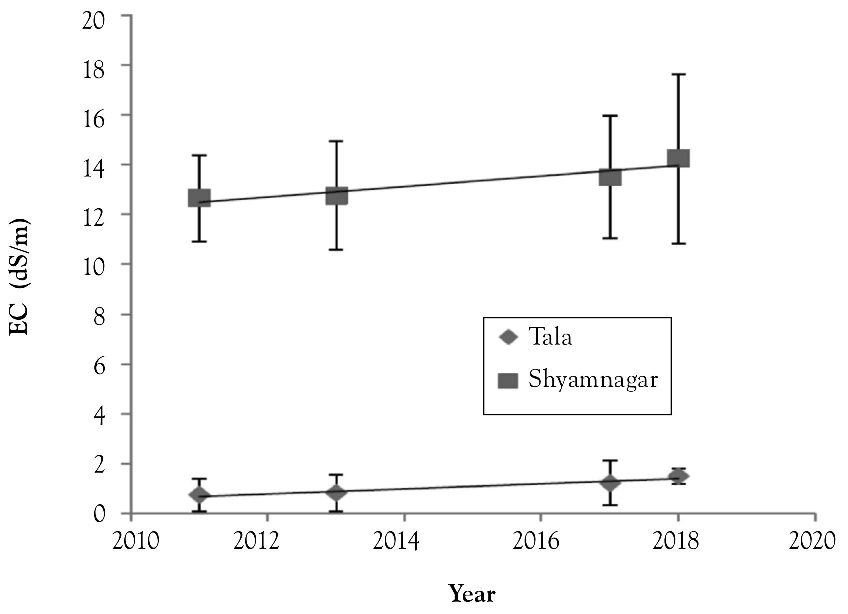
Soil SalinityLevel	Salinity Level (EC, dS/m)	Sample ID (Union Council) Under the Category	Percentage of the Samples Under the Category
Non-saline or very slightly Saline	< 2	Khalishkhali-1, Khalishkhali-2, Khalishkhali-3, Khalishkhali-4, Khalishkhali-5, Magura-1, Magura-2, Magura-3, Magura-4, Magura-5, Islamkathi-1, Islamkathi-2	90%
Slightly saline	2.0-4.0	Islamkathi-3, Islamkathi-4	10%
Slightly to moderately Saline	4.1-8.0	–	–
Moderately to highly saline	8.1-12.0	–	–
8.1-12.0	–	–	–
Highly saline	12.1-16	–	–

Note: '–' indicates not applicable.

Table 3: Distribution of Soil Salinity in Shyamnagar Sub-District			
Soil SalinityLevel	**Salinity Level (EC, dS/m)**	**Sample ID (Union Council) Under the Category**	**Percentage of the Samples Under the Category**
Non-saline or very slightly saline	< 2	–	–
Slightly saline	2.0-4.0	–	–
Slightly to moderately saline	4.1-8.0	Gabura-1, Boro Kupot-1, Poddopukur- 2, Poddopukur-3, Poddopukur-4, Poddopukur-5	30%
Moderately to highly saline	8.1-12.0	Gabura-4, Boro Kupot-5, Kalibari-2, Kalibari-4, Kalibari-5, Poddopukur-1	30%
Highly saline	12.1-16	Gabura-2, Gabura-3, Gabura-5, Boro Kupot-2, Boro Kupot-3, Boro Kupot-1, Kalibari-3	40%

Note: '–' indicates not applicable.

Figure 2: Trend in Soil Salinity Over Time in the Study Areas



Farmers' Perceptions of Soil Salinity Impacts on Crop Production

About 41% of the farmers in Shyamnagar perceived a moderate drop in crop yield owing to soil salinity, followed by a high level of decrease in crop yield (29.1%), whereas about 57% of the farmers in Tala reported a small decrease in crop yield (Table 4). Only about 5% of Tala farmers perceived on a high decrease in crop yield owing to soil salinity. The results also indicate that there is a highly significant difference ($p < 0.01$) in farmers' perceptions of crop yield reduction between Tala and Shyamnagar sub-districts. More than half of the farmers (51.8%) in Shyamnagar stated that freshwater was highly scarce for irrigation, while only 11.6% in Tala stated the same. About 19% of the farmers in Shyamnagar experienced a high decrease in cropping area.

In Shyamnagar, about 15% of the farmers observed no change in cropping area, compared with 30.4% in Tala. About 18% of the farmers in Shyamnagar stated a high level of reduction in the plant height of paddy owing to soil salinity. Reductions in plant height ($p < 0.05$) and crop size ($p < 0.01$) were found to be significantly different between Tala and Shyamnagar. More than 66% of the farmers in Shyamnagar opined that an increase in soil salinity caused a moderate to high increase in irrigation costs. On the other hand, most farmers in Tala experienced a minor rise in irrigation costs because of soil salinity. The perceptions of rising irrigation costs varied significantly across the study areas.

Indigenous Knowledge-Based Adaptation Strategies

The adaptation strategies adopted by the farmers in response to the soil salinity challenges are presented using WAI for generating rank order for two sub-districts separately (Table 5). In Tala, 'mixed cropping' and 'homestead gardening' were ranked first (WAI: 2.20) and second (WAI: 2.17) among eight adaptation strategies, respectively. In Shyamnagar, these two strategies were considered the least important adaptation strategies, with WAI 220 of 0.42 and 0.38, respectively. Farmers in Shyamnagar used 'multiple irrigations' and 'giving up planting of certain crops' as major adaptation strategies. Adaptation strategies such as 'raised seedbed' and 'shifting to shrimp culture' were the least practiced in Tala, whereas they were rated fourth and fifth in Shyamnagar based on the WAI score. Introducing 'saline-tolerant rice varieties' ranked third (WAI: 1.91) in Tala and sixth (WAI: 0.50) in Shyamnagar. The level of adaptation strategies used to limit the impacts of soil salinity varied significantly (as evidenced by the significant chi-square value) across the study areas (Table 6). The majority of the farmers in Tala (73.2%) fell into the medium adaptation category. However, approximately 52% of farmers in Shyamnagar fell into the low adaptation category, followed by medium adaptation (47.2%).

Table 4: Small-Scale Farmers' Perceptions of Salinity Impacts on Crop Production (n = 222)					
Statements	**Degree of Change**	**Total Sub District (n =112)**	**Shyamnagar Sub-District (n= 110)**	**Pearson Chi-Square Value**	**p-Value**
Crop yield reduction	Unchanged	23 (20.5[a])	2 (1.8[a])	57.442	0.001**
	Small	64 (57.1)	31 (28.2)		
	Moderate	19 (17.0)	45 (40.9)		
	High	6 (5.4)	32 (29.1)		
Unavailability of freshwater for irrigation	Unchanged	8 (7.1)	2 (1.8)	61.973	0.001**
	Small	58 (51.8)	12 (10.9)		
	Moderate	33 (29.5)	39 (35.5)		
	High	13 (11.6)	57 (51.8)		
Crop area reduction	Unchanged	34 (30.4)	16 (14.5)	20.265	0.001**
	Small	56 (50.0)	47 (42.7)		
	Moderate	18 (16.1)	26 (23.6)		
	High	4 (3.6)	21 (19.1)		
Plant (paddy) height reduction	Unchanged	30 (26.8)	17 (15.5)	11.446	0.010*
	Small	56 (50.0)	51 (46.4)		
	Moderate	20 (17.9)	22 (20.0)		
	High	6 (5.4)	20 (18.2)		
Crop (paddy) size reduction	Unchanged	24 (21.4)	19 (17.3)	13.845	0.003*
	Small	54 (48.2)	37 (33.6)		
	Moderate	29 (25.9)	33 (30.0)		
	High	5 (4.5)	21 (19.1)		
Leaf tip burn	Unchanged	42 (37.5)	27 (24.5)	15.875	0.001**
	Small	44 (39.3)	30 (27.3)		
	Moderate	18 (16.1)	31(28.2)		
	High	8 (7.1)	22 (20.0)		
Irrigation cost	Unchanged	8 (7.1)	7 (6.4)	10.143	0.017*
	Small	51 (45.5)	30 (27.3)		
	Moderate	32 (28.6)	36 (32.7)		
	High	21 (18.8)	37 (33.6)		
Fertilizer cost	Unchanged	49 (43.8)	26 (23.6)	35.194	0.001**
	Small	53 (47.3)	36 (32.7)		
	Moderate	6 (5.4)	30 (27.3)		
	High	4 (3.6)	18 (16.4)		

Note: [a] Figures in parentheses indicate the percentage; * = Significance at the 5% level; ** = Significance at the 1% level .

Table 5: Indigenous Adaptation Strategies by the Farmers in the Study Areas						
Adaptation Strategies	Degree of Practice				WAI	Rank
	Frequent	Occasional	Rare	Not At All		
Tala (n = 112)						
Mixed cropping	34	48	19	11	2.20	1
Homestead gardening	31	52	20	9	2.17	2
Salt-tolerant rice varieties	25	47	22	18	1.91	3
Synthetic fertilizer application	28	31	30	23	1.76	4
Give-up planting certain crops	25	28	31	28	1.62	5
Applying multiple irrigation	23	28	33	28	1.58	6
Raised seedbed	8	27	55	22	1.33	7
Shifting to shrimp culture	5	4	35	68	0.58	8
Shyamnagar (n = 110)						
Applying multiple irrigation	40	38	24	8	2.20	1
Give-up planting certain crops	40	37	24	9	2.18	2
Synthetic fertilizer application	30	43	30	7	2.06	3
Raised seedbed	28	33	26	23	1.76	4
Shifting to shrimp culture	18	13	38	41	1.18	5
Salt-tolerant rice varieties	4	5	28	73	0.50	6
Mixed cropping	0	6	30	74	0.42	7
Homestead gardening	1	2	31	76	0.38	8

Table 6: Small-Scale Farmers' Adaptation Level (n = 222)				
Level of Adaptation	**Tala Sub-District (n = 112)**	**Shyamnagar Sub-District (n = 110)**	**Pearson Chi-Square Value**	**p-Value**
Low adaptation (0-8)	14 (12.5a)	57 (51.8[a])	45.980	0.001**
Medium adaptation (9-16)	82 (73.2)	52 (47.3)	–	–
High adaptation (17-24)	16 (14.3)	1 (0.9)	–	–
Total	**112 (100)**	**110 (100)**	–	–

Note: [a] Figures in parentheses indicate the percentage; ** Significance at the 1% level.

Discussion

The socioeconomic features of the farmers revealed that a majority of them are middle-aged. The findings also revealed that Tala farmers had a higher education level than Shyamnagar farmers, which may play an important role in the adoption of numerous adaptation strategies. Previous studies have also found that educated farmers are more likely to detect the uncertainty associated with any negative shock (Deresa *et al.*, 2009; and Asrat and Simane, 2018). Education is also more likely to improve farmers' abilities and understanding of adaptation options, inducing them to adapt (Zulfiqar *et al.*, 2021). A majority of the farmers in Shyamnagar were also involved in off-farm activities. This could be because the level of salinity in Shyamnagar is substantially higher than in Tala sub-district (Tables 2 and 3), preventing farmers from focusing solely on agriculture. Moreover, one-third of Tala's farmers obtained agriculture-related training, which may influence them to adopt agriculture-based adaptation strategies. Previous research revealed that training is essential for increasing the long-term application of land-based adaptation strategies (Beshir *et al.*, 2012; and Guteta and Abegaz, 2016).

According to the findings of soil EC values, farmers in Shyamnagar 244 sub-district faced moderate to high soil salinity problems (Table 3). The soil salinity level was substantially higher in Shyamnagar sub-district than Tala sub-district (Figure 2). Moreover, the trend showed a further increase in salinity in both sub-districts. Salinity issues may emerge when the EC value rises by 2 to 4 dS/m (Maas and Grattan, 1999). The findings suggest that location-specific measures are required to address the salinity issue. When the EC value exceeds 8.0 dS/m, saline-tolerant varieties perform well (Abrol *et al.*, 1988).

So far, Bangladesh has only developed a few salt-tolerant rice varieties (BRRI Dhan 53, 54, 55, and Bina Dhan 10) that can withstand salinity of up to 8-10 dS/m (Ahmed *et al.*, 2016). One variety, BRRI Dhan 61, can withstand salinity levels as high as 12-14 dS/m. However, the majority of the soil in Shyamnagar has a salinity level of 12-16 dS/m. This could be one of the reasons why farmers in Shyamnagar are abandoning crop production, increasing irrigation, and converting to shrimp farming (Table 5). As a result, more research from national research agencies is required to develop high salt-tolerant varieties that may be distributed in high saline areas. The farmers' perceptions of moderate to high yield reduction in Shyamnagar (Table 4) were consistent with the high level of soil salinity in this sub-district (Table 3).

According to farmers' perceptions, crop yield and area are decreasing dramatically, particularly in high saline-prone areas such as Shyamnagar (Table 4). According to Alam *et al.* (2017), dry season agriculture is becoming more difficult in southwestern coastal areas of Bangladesh due to saltwater intrusion. Previous studies have demonstrated that saltwater intrusion in coastal areas reduces crop yield by lowering land quality (Sarwar, 2013; and Khanom, 2016). Soil salinity remedies are also limited, expensive, and time-consuming. As a result, small-scale farmers in high salt-affected areas are forced to abandon crop production or harvest with lower yields. Having minimal or low crop output puts pressure on household income and purchasing power. This occurrence may have severe consequences for small-scale farmers whose income is dependent on farm production.

Our findings also revealed that agricultural land is shrinking in moderate to high saline areas, and farmers are shifting to shrimp cultivation as an adaptation strategy, which is consistent with the findings of other studies (Johnson *et al.*, 2016; and Islam *et al.*, 2019). Shrimp farming is profitable (Ahmed, 2013; and Ray *et al.*, 2021), yet it has a number of detrimental effects on agricultural land. As a result of the creation of shrimp farms, nearby lands become unsuitable for cultivation, and surface water for everyday use becomes unsuitable as well (Uddin and Nasrin, 2013). Because of the large profits, many farmers in saline-prone areas have converted their rice fields to shrimp farms (Ray *et al.*, 2021). On the other hand, disease outbreaks have placed shrimp farming in jeopardy (Rahman *et al.*, 2020). As a result, small farmers face significant losses, putting additional strain on their financial situation. In addition, unplanned shrimp farming has some environmental consequences, such as increased salt in soils and a public health risk (Abdullah *et al.*, 2019; and Islam *et al.*, 2019). As a result, awareness-raising efforts in salt-affected areas are needed to educate farmers about the detrimental consequences of unplanned shrimp farming. More research and extension efforts are also required to develop and distribute saline-tolerant crop varieties in saline-prone coastal areas.

Irrigation water is another critical factor in crop production, particularly during the dry season. Without sufficient irrigation water, crops will not produce a satisfactory yield (Mancosu *et al.*, 2015). Our findings indicated that a shallow tube well is the primary source of irrigation water in low/non-saline areas, such as Tala. However, in moderately to highly saline areas, almost all cultivable land is irrigated using surface water, which is prone to contamination with saline water. Similar findings were derived for the Shyamnagar sub-district (Table 1). The farmers in saline-prone areas also faced high irrigation costs (Table 4). Irrigation water scarcity adversely influences crop water uptake, and ultimately, yield is reduced. This has an additional impact on food availability in terms of productivity among small-scale farmers. Farmers reported that plant (paddy) height and size were declining in both areas. Salinity reduces leaf area, resulting in decreased plant and leaf growth (Gupta and Huang, 2014). When the soil EC value rises to 4 to 8 dS/m or more, crops typically exhibit moderate growth, leaf tip burn, foliage burn, or chlorosis (Maas, 2019). Because of soil salinity, farmers must irrigate their land with freshwater on a regular basis during the dry season. This frequent irrigation raises production costs (Shrivastava and Kumar, 2015). Similar findings were observed in the study areas, as the farmers reported an increase in their irrigation costs to compensate for a reduction in paddy height and crop vigor along with leaf tip burn (Table 4). The reported irrigation cost increase was higher in the Shyamnagar sub-district. A similar scenario exists in the case of rising fertilizer costs. Farmers use more fertilizer to ameliorate saline soils in high saline areas. The farmers from high saline areas believe that the yield loss due to soil salinity could be compensated with the application of a higher fertilizer dose. This raises the expense of fertilizer usage even further. Agriculture is the primary source of income for most small-scale farmers in Bangladesh. On the other hand, the increasing expenses of irrigation and fertilizer owing to soil salinity will reduce their profitability. This may have a negative impact on their poverty and food security. The fertilizer cost increase was reported higher by the Shyamnagar respondents. Although soil salinity issues are evident in the study areas, small-scale farmers' adaptation measures lag behind expectations, and the situation is particularly dire in high saline areas, such as Shyamnagar. Despite the evidence of high soil salinity and farmers' accurate perceptions of high salinity in Shyamnagar, the adaptation level is low. Therefore, it can be deduced that higher prevalence and perceptions of salinity do not automatically lead to adaptation (as in Shyamnagar). Suitable supporting policies are required to make the conditions feasible for adaptation. The low level of adaptation may not improve the livelihood of small-scale farmers. This result is consistent with the findings of Billah *et al.* (2015), who found that the adaptation level of small-scale farmers ranges from low to medium. This could be because small farmers have limited resources and may be unaware of the benefits of adaptation strategies.

Farmers in the high salt-affected area (Shyamnagar) adopted multiple irrigations as their main adaptation strategy. The amount of salt that accumulates on the surface soil of agricultural land can be leached from the root zone by frequent irrigation. Multiple irrigations help remove salt from the area by leaching or disposal through effective and well-maintained drainage systems (Dinar *et al.*, 1993; and Clarke *et al.*, 2015). Farmers in Shyamnagar reported that they irrigated their land multiple times to ameliorate saline soils. When salt-affected soils are irrigated frequently, higher soil moisture content prevents salt accumulation in the surface soils (Mustafa and Akhtar, 2019). However, frequent irrigation incurs a high cost and might impair farmers' profitability. Furthermore, farmers in the high saline area were unable to grow certain high-yielding rice varieties (HYV aus/aman) due to increased soil salinity and were forced to cultivate a limited number of local varieties, resulting in a poorer yield and return (Haque, 2006; and Habiba *et al.*, 2014). On the other hand, farmers in slightly/non-saline areas were growing HYV rice and reaping a higher yield (Timsina *et al.*, 2018). Therefore, concerned authorities should take the required steps to develop and disseminate salt-tolerant varieties in salt-affected coastal areas.

The findings also indicated that homestead gardening was the least common adaptation strategy in the high saline area (Shyamnagar). During the FGDs, the farmers mentioned that growing vegetables in homestead areas is very challenging. However, previous studies suggested that farmers in high-saline areas can grow vegetables on their homesteads for consumption during the dry season when the salinity intensifies (Uddin and Nasrin, 2013). A few other studies have also demonstrated that homestead gardening can be used to boost the income and food consumption status of resource-poor farmers in Bangladesh (Ferdous *et al.*, 2016; Akter *et al.*, 2021). Homestead gardening was one of the key adaptation strategies used by farmers in the slightly saline area (Tala). According to the socioeconomic features, farmers in slightly saline areas are more educated, have better access to agricultural information, and have received training (Table 1), which may influence them to use homestead gardening as an adaptation strategy. Therefore, educating coastal farmers about the benefits of homestead gardening through training and extension activities can help increase the use of homestead gardening as an adaptation strategy.

The use of chemical fertilizers has been identified as a major adaptation strategy in both study areas. Previous studies have also suggested that chemical fertilizer application might be employed as an adaptation strategy to deal with both salinity and drought stresses (Dah-Gbeto and Villamor, 2016; Khanom, 2016; and Thiam *et al.*, 2019). Although fertilizers contribute to increased productivity, several recent studies indicate that their contribution to increased productivity has not improved over time (Kishore *et al.*, 2021). Furthermore, farmers' lack of awareness and reliance on excessive use of synthetic fertilizers, as well as the minimal implementation of soil testing-based fertilizer recommendations, have harmed Bangladesh's soil composition Barua *et al.* (2022). As a result, to reduce the harmful effects of synthetic fertilizer use, the focus should be placed on using recommended fertilizer doses. Raised seedbed technology was used by farmers in high-saline areas (Shyamnagar) as an adaptation strategy. Several studies have also revealed that planting in a raised bed is effective for dealing with soil salinity problems and can reduce crop water requirements by 30% (Devkota *et a*l., 2015; and Velmurugan *et a*l., 2015). Raised bed farming has the potential to enhance farmers' income and livelihood (Miah *et al.*, 2015). Hands-on training and publicizing the positive effects of raised bed technology through mass media can help raise awareness of this promising technology. According to the findings, farmers in low-saline areas (Tala) used mixed cropping technology as their main adaptation strategy. Mixed cropping has the ability to improve soil nutrient status, reduce insect and disease incidence, and provide consistent production. More community engagement and long-term approaches are required to make these potential adaptation strategies more familiar, especially in high-saline areas.

Conclusion

Soil salinization in Bangladesh's coastal areas has a negative impact on coastal agriculture and biodiversity. Farmers use a variety of adaptation measures to address the salinity issue. This study examined the soil salinity trend, farmers' perceptions, and adaptation mechanisms in southwestern coastal areas of Bangladesh using primary data obtained from farmers and soil samples collected from various locations. The analysis of soil samples revealed that salinity is gradually increasing in the study areas. Farmers' perceptions of salinity impacts were consistent with the level of salinity in each area. Soil sample analyses and farmers' perceptions revealed higher soil salinity in Shyamnagar sub-district than Tala sub-district. Farmers regarded soil salinity as a constraint on crop area and production in both study areas. It also raised the expense of irrigation and fertilizer application. Farmers used a variety of adaptation strategies to ameliorate soil salinity. However, adaptation strategies differed by area, necessitating an area-specific policy. Despite accurately perceiving a higher salinity level in Shyamnagar, the farmers in higher salinity-prone study areas had low adaptation status. This may be attributable to a low adaptive capacity owing to lower educational status, small farm size, use of surface water, and lack of access to information and training, which may have contributed to lower adaptation by farmers despite facing higher soil salinity. The findings also indicated an urgent need to increase knowledge and training facilities, particularly in high-saline areas.

Developing crop varieties that can withstand salt water and soil conditions will be a critical step in addressing soil salinity problems. A comprehensive development effort involving all stakeholders should be undertaken. Policies for coastal area development should promote the use of promising technologies, such as homestead gardening and raised seedbed farming, which have the potential to increase productivity and income. Location-specific farmers' need-based measures are required to deal with the negative effects of salinity.

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Appendix

Indigenous Knowledge Practices by Farmers for Crop Production in Response to Salinity Intrusion in Coastal Bangladesh

Household Survey Questionnaire

Demographic Profile of the Households

Household ID No.					
Area	District	Upazila	Union	Village Serial No.	Household Serial No.

Section A

Demographic, Socioeconomic and Livelihood Details of the Respondent and Household Information

1. Name of respondent:______________________________
2. Age of respondent:______________________________
3. Gender:

   ☐ Male ☐ Female
4. Name of household head:____
5. Relation to household head:

   ☐ Self ☐ Wife ☐ Son ☐ Daughter ☐ Brother ☐ Sister

   ☐ Father ☐ Mother ☐ Other, specify ________
6. Marital status:

   ☐ Single ☐ Married ☐ Widowed ☐ Separated ☐ Divorced

   ☐ Other, specify ___________
7. Place of birth:

   ☐ This village ☐ Elsewhere in the district

   ☐ Elsewhere in the country, specify district ____________________________

   ☐ Abroad, specify country ___________
8. Education level:

   ☐ Illiterate ☐ Do sign ☐ 1st Class to class 5 ☐ Class 6 to class 8

Appendix (Cont.)

☐ Class 9 to class 10 ☐ S.S.C ☐ H.S.C ☐ Graduate

☐ Postgraduate ☐ Engineer/Doctor ☐ Technician/Vocational

☐ Other specify _______________

9. Religion:

☐ Christian ☐ Muslim ☐ Buddhist ☐ Hindu ☐ Other, specify __________

10. Household head/respondent's occupation (multiple options):

☐ Farming ☐ Livestock raising ☐ Fishing ☐ Trading

☐ Salary (work GO/NGO/Private Sector), specify ________

☐ Other non-farm income, specify ______ ☐ Farm labor

☐ Other labor, specify ________ ☐ Housework ☐ Student

☐ Unemployed ☐ Other, specify ________

11. Address:

Name of House/Identity (If Applicable)			Para		
Village/Mouza			Union		
Upazila	Shamnagar	District	Shatkhira	Division	Khulna

12. Household composition: ☐ Adult men (aged 18-65)

☐ Adult women (aged 18-65) ☐ Boys (<18) ☐ Girls (<18)

☐ Elderly men (>65) ☐ Elderly women (>65)

Land Ownership, Farm Management and Crop Agriculture

13. Do you (or does your household) 'own' land?

Yes ☐ No ☐

a. If yes, for what do you use your land (multiple options)?

☐ House ☐ Crop cultivation ☐ Livestock raising ☐ Renting out

☐ Fallowing ☐ Nothing ☐ Other, specify ________

b. If yes, please estimate the total land size? ________ (decimal)

14. Do you farm?

☐ Yes ☐ No (if no, go to 1.3 section)

Appendix (Cont.)

15. What is the size of the land that you cultivate this year?———(decimal) (Note: 33 decimal=1 biga)

Issue/Items	Types of Land (in Decimal)				
	Homestead Land	Crop Agricultural Land	Fish Farm/ Ponds	Land Leased in/ Out	Fallow Land and Other
Amount					

16. Is some of the land you farm irrigated?

☐ Yes ☐ No

a. If yes, how much? _________ (decimal)

17. Do you use animal traction or a tractor to cultivate your land?

☐ Yes ☐ No

a. If yes, do you own, hire, or borrow these implements (multiple options)?

☐ Own ☐ Hire ☐ Borrow ☐ Other, specify _________

18. Do you employ people to work on your land?

☐ Yes ☐ No

a. If yes, please estimate the total number of 'person days' per year _______

Livestock, Fishing, and Forest

19. Do you or other household members own livestock?

☐ Yes ☐ No

a. If yes, please indicate the number of

☐ Cows ☐ Buffaloes ☐ Goats and sheep ☐ Pigs ☐ Fowls
☐ Others, specify

b. What is the main purpose of your livestock (choose one)?

☐ Household consumption ☐ Sale ☐ Traction ☐ Other, specify ______

20. Please estimate the income you derived from livestock raising in the last 12 months.

Sales——————— and Own consumption.......................................

21. Do you or any other household members engage in fishing or fish raising?

☐ Yes ☐ No

a. If yes, please specify:

☐ Fishing ☐ Fish raising ☐ Both

b. What is the main purpose of your fishing / fish raising (choose one)?

☐ Household consumption ☐ Sale ☐ Other, specify ______

22. Please estimate the income your household derived from fishing / fish raising in the last 12 months? Sale............................(BDT) and Consumption.....................(BDT)

23. Does your household own commercial trees (fruit, timber, medicinal)?

☐ Yes ☐ No

a. If yes, what is the main purpose of your economic trees (choose one)?

☐ Household consumption ☐ Sale ☐ Other, specify ______

b. Please indicate the number of commercial trees:

☐ <10 ☐ 10-50 ☐ 50-100 ☐ >100

c. Please estimate the income your household got from commercial trees in the last 12 months ____

Other Income Generating Activities

24. Do you or any household members derive income from non-farm activities?

☐ Yes ☐ No

a. If yes, how many household members are engaged in such activities? ________

b. In which activities do they engage (multiple options)?

☐ Petty trading ☐ Larger business ☐ Salary work, specify ________

☐ Daily labor___ ☐ Crafts, specify ____

☐ Processing natural resources, specify___ ☐ Other non-farm income, specify ____

c. Please estimate the total income derived from non-farm activities in the last 12 months? _____

25. Does your household receive remittances from migrant family members, relatives, or friends?

☐ Yes ☐ No

a. If yes, from whom [relation to HH-H] (multiple options)?

☐ Daughter ☐ Son ☐ Brother ☐ Sister ☐ Parents

Appendix (Cont.)

☐ Other, specify ______

b. Where do they live (multiple options)?

☐ Within the district region ☐ Other district, specify __________

☐ Abroad, specify ____________

c. If yes, please estimate the total amount of money (remittance) you received in the last 12 months _____ (BDT)

26. Do you / your household members sometimes labor on other people's farms?

☐ Yes ☐ No

a. If yes, how many household members? ________

b. Please estimate: the total number of 'person days' in the last 12 months _____

c. Please estimate the total annual income derived in the last 12 months _____

27. Do you have any other sources of income besides the ones you mentioned?

☐ Yes ☐ No

a. If yes, please specify the source __________

b. Please specify the total annual income derived in the last 12 months ____

c. Please estimate the amount of money your household usually has at its disposal: Amount ____________ Currency _____________ per (underlined time unit): week / month / year

28. Compared to other households in your village, would you say that your monthly income is

☐ Less than most others ☐ Average ☐ More than most others

Housing and Other Assets

29. Do you 'own' the house you live in?

☐ Yes ☐ No

30. Do you own any other house?

1=Yes, specify how many __________

☐ No

31. Please indicate the building materials of the house you live in:
Roof (multiple options):

Appendix (Cont.)

☐ Roofing tiles ☐ Iron sheets ☐ Concrete

☐ Natural materials, e.g. thatch or earth ☐ Other, specify___________

a. Walls (multiple options):

☐ Cement blocks/concrete ☐ Baked bricks ☐ Sun-dried bricks

☐ Wood ☐ Iron sheets ☐ Other natural materials, specify_______

☐ Other, specify ___

b. Floor (multiple options):

☐ Cement ☐ Earth ☐ Wood ☐ Other, specify __________

32. Compared to the other houses in your village/town, would you say that the house you live in is of:

☐ Better quality ☐ Average quality ☐ Worse quality?

33. Does your house have electricity?

☐ Yes ☐ No

34. Does your household have alternative electricity?

☐ Yes ☐ No

35. What is the source of your drinking water (multiple options)?

☐ Surface water ☐ Well ☐ Borehole/Pump ☐ Pipe

☐ Other, specify _____

36. Does your house have a private latrine or WC?

☐ Yes ☐ No

37. Please indicate whether your household owns the following assets [and how many]:
☐ TV ☐ (Mobile) phone ☐ Bicycle ☐ Motorbike ☐ Car
☐ Fridge ☐ Computer

Food Security

38. How many meals a day do persons in your household eat on a 'regular day'?

☐ Male ☐ Female ☐ Baby

39. Does the meal you eat enough for the daily needs?

☐ Yes ☐ No

40. In the past year, have there been months that you had to eat less?

☐ Yes ☐ No

a. If yes, in which months did this happen (multiple options)?

☐ Jan ☐ Feb ☐ Mar ☐ Apr ☐ May ☐ Jun ☐ Jul ☐ Aug ☐ Sep ☐ Oct ☐ Nov ☐ Dec

b. What was/were the cause(s) of this food shortage? Please specify

41. In the past ten years, has your household experienced any food shortages?

☐ Yes ☐ No

a. If yes, in how many out of ten years?

b. What was/were usually the cause(s) of such shortages?

42. How much of the food your household consumes is bought (i.e., not produced by the household itself)?

☐ Everything ☐ More than half ☐ Approximately half

☐ Less than half ☐ Hardly anything ☐ Nothing

Section B

Perceptions and Information about Climate Change and Salinity

1. What are the main CC (variability and extremes) problems in the locality (please rank the problems in terms of severity and impacts on your lives and livelihoods)

☐ Temperature rise ☐ Erratic rain fall ☐ Change in seasonal patterns

☐ Water logging ☐ Salinity Intrusion ☐ Flood ☐ Fog ☐ Cold wave

2. Which of the above problems have aggravated in the last 10-15 years?

☐ .... ☐ .... ☐ ....

3. How has the salinity problem changed in the locality in the last 20 years?

☐ High level ☐ Moderate ☐ Low ☐ No change

4. Trend and severity of extreme events like low rainfall and high temperatures

☐ Acute problem ☐ Moderate ☐ Low level

5. What are the sectors most impacted by droughts and climate extremes?

a. Crop agriculture

☐ Rice (Aus, Aman and Boro) ☐ Wheat and Maize ☐ Vegetables

☐ Pulses ☐ Fisheries ☐ Poultry

☐ Homestead garden ☐ Agro-forestry

b. Human Health

☐ Food and nutrition ☐ Social security

☐ Disaster preparedness ☐ Ecosystems (mangrove and biodiversity)

Section C

Salinity, Crop Production and Water Supply (state, trend, loss and damage)

1. If you cultivate rice, how many times of the year do you cultivate it?

☐ Once ☐ Twice ☐ didn't cultivate rice

☐ Others please specify....

2. ☐ What is the main source of water for crop cultivation?

☐ Deep Tube Well/Tube-well ☐ Rain ☐ Pond/canal

☐ None ☐ Others, please specify

3. What is the main purpose of your crop production (choose one)?

☐ Household consumption ☐ Sale ☐ Other, specify ______

Section D

Coping with Salinity Problems Caused by Weather-Related Extreme Events

1. In the past twenty years, how many years have you lived in this district?

2. Did your household do anything to deal with salinity intrusion as caused by tidal flooding on production of crops and water supplies?

☐ Yes ☐ No (if no, skip the next two questions)

3. If yes, what did you do?

4. If yes, do you feel that despite these measures, your household still experiences negative effects from salinity problem caused by cyclone or tidal floods (multiple options)?

Appendix (Cont.)

☐ No ☐ Yes, measures are not sufficient

☐ Yes, measures have costs/negative effects ☐ Yes, other reason

a. If yes, Please explain:

5. If not, why not (multiple options)?

☐ I didn't know what to do

☐ Lack of financial resources (to do what?)

☐ Lack of skills/knowledge (to do what?)

☐ Lack of other resources (to do what?)

☐ It's not a priority/not very important to us

☐ Not my task/responsibility

☐ Other, specify

☐ Please explain:

6. If not, what negative effects (loss, damage, and costs) did your household experience from salinity intrusion effects caused by low rainfalls or tidal floods because no measures were taken?

7. Did you ask for food or money from other people to deal with the impacts of salinity and water scarcity caused by low rainfall events?

☐ No ☐ Yes, from a relative ☐ Neighbor ☐ Friend

☐ Other, specify ————

8. Did you or household members try to earn extra income to deal with salinity effects?

☐ No ☐ Yes, intensified existing activities, specify_____

☐ Engaged in new activities, specify______

9. Did you or household members migrate more to deal with salinity problems caused by tidal floods, low rainfall and groundwater scarcity events ?

☐ No ☐ Yes, I migrated ☐ Yes, other household member(s) migrated

☐ Yes, whole household migrated

a. If yes, what is the duration?

☐ Short-term (<6 months) ☐ Longer-term (>6 months)

b. If yes, where to?

Appendix (Cont.)

☐ Within region ☐ Other region, specify _____ ☐ Abroad, specify

c. Was the migration destination rural or urban?

☐ Rural ☐ Urban

10. Did you sell properties to deal with salinity impact caused by water scarcity ?

☐ No ☐ Yes, land ☐ Livestock ☐ House

☐ Productive assets, specify __________ ☐ Means of transport, specify _____

☐ Luxury items, specify ___________ ☐ Other, specify _____________

11. If measures were taken, were these things you did to deal with salinity effects enough to avoid the negative effects on crop production and ground water supply

☐ No, still severe negative effects

☐ No, still moderate negative effects

☐ Yes, it allows us to carry on

☐ Yes, it has even improved our situation

Please explain:

12. Do you feel that your household is more or less likely to suffer from the impacts of salinity intrusion due to climate change than other households in your community?

☐ More ☐ Average ☐ Less

a. Why?

13. Do you think that the impact of this salinity intrusion problem affects men and women differently? Please explain.

14. Do you think men and women play different roles in dealing with these salinity threats? Please explain.

☐ In case of drinking wate ________________

☐ In case of soil ________________________

☐ In case of Agriculture ___________________

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