

UNIVERSITY OF NEW ENGLAND

**ADAPTATION TIPPING POINTS OF SALINITY MANAGEMENT FOR BORO
SEASON RICE CULTIVATION IN THE COASTAL AREAS OF BANGLADESH**

A dissertation submitted by

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DECLARATION OF ORIGINALITY

I, Md Aminul Islam, hereby declare that all research herein is entirely my own work. The work has not been submitted for any other degree or professional qualification. I certify that, to the best of my knowledge, I have acknowledged all the help I received and cited all the sources I used in this thesis. Although Chapters 2, 3 and 4 have joint authorship, the work contained in these chapters is solely my own. Co-authorship represents support in terms of comments, suggestions, advice and discussion aspects of the research.

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ABSTRACT

Soil salinization is a pernicious problem in the coastal areas of Bangladesh that presents substantial challenges to agricultural productivity and difficulties in addressing the sustainable development goals (SDGs). While the biophysical nature of salinity is well understood, dealing with the uncertainties that emerge from the differential nature of its impact on agricultural livelihoods remains unexplored. In order to address the uncertainties in adaptation decisions, this study applied the adaptation tipping points (ATPs) approach to determine the yield loss threshold in a coastal saline environment, and to show the potential signal for tipping points of dry season rice cultivation in the coastal areas. To apply the ATP approach in the agricultural system, this study developed three sequential steps, and showed its potential for an ATP-driven research-extension policy agenda. Using a semi-structured survey, data were collected from 280 farmers (rice farmers; n=109, shrimp farmers; n=107, salt farmers; n=64) who were randomly selected from two coastal sub-districts (Assasuni from Satkhira district (south-west) and Banskhali from Chittagong district (south-east)). In a follow-up survey, in-field salinity measurement data were collected from the rice field of the selected farmers (n=36), and how farmers' perceived these salinity level in their rice field were recorded. Then, the literature based salinity classification of these measured salinity data and farmers' perceptions about the same salinity measured data were compared. To complement the semi-structured survey data, key informant interviews and focus group discussions were also conducted.

In the first step (Chapter 2), this study explored the rice farmers' understanding of the salinity problem and their locally practised adaptation strategies to inform the policymakers as to when farmers are concerned about the salinity problem. Rice farmers perceived the reproductive stages of rice plants as being the most vulnerable to salinity. The findings also demonstrated that farmers perceived a field as being affected by high salinity levels when the levels were lower than the scientific literature recommends. In response to the salinity problem, most of the rice farmers undertake early transplanting and apply irrigation to overcome its harmful effects in Boro season rice cultivation. The study demonstrated that farmers' adaptation strategies (e.g. early transplanting) potentially avoid high salinity during the reproductive stages of rice development in Boro season (dry season), indicating that farmers understand the salinity

problem and are concerned about the harmful effects of salinity on rice production. Farmers' actions to cope with salinity are pre-emptive of when salinity would have severe effects on rice plant growth and yield.

In the second step (Chapter 3), this study examined differential framing of the salinity problem (i.e. perceptions of diverse types of farmers) in order to understand farmers' perceptions of salinity and the underlying causes, and adaptation preferences. The findings indicated that farmers overall have perceived an increasing salinity trend over the last 20 years. However, salinity perceptions and underlying causes varied among the different types of farmers (i.e. rice, shrimp and salt farmers). The majority of rice farmers (87%) reported increased salinity, while over half of the salt (52%) and shrimp farmers (52%) perceived that salinity has decreased over the past 20 years. The results also indicated that most of the rice farmers (62%) perceived that anthropogenic factors are the main cause of increased salinity, while the majority of the shrimp and salt farmers focused more on natural factors as being responsible for salinity. The results also indicated that while rice farmers perceived severe yield loss due to high salinity, shrimp and salt farmers perceived that they were not disadvantaged and reported higher production from their farming enterprises. According to the study, the rice farmers preferred salinity-tolerant rice varieties that have greater tolerance at the reproductive stages, while shrimp and salt farmers considered that engineering solutions such as strengthening embankments and canal excavation as the preferred adaptation options to cope with salinity. Thus, this study demonstrated that farmers' perceptions of salinity are directly related to the ways in which their livelihoods are being impacted by salinity.

In the third step (Chapter 4), this study applied the adaptation tipping points (ATPs) approach to investigate threshold yield loss from the perspectives of all types farmers affected by salinity, which could signal plausible discontinuation of growing rice in the Boro season (i.e. Dry season). Adaptation tipping points are defined as the points where the current strategies may fail to achieve their objectives. This study considered promoting saline-tolerant rice varieties in the dry season as a management strategy, with a policy objective of coping capacity under a high saline environment. The findings revealed that despite government actions to promote dry season rice cultivation, local farmers have not expanded rice growing in the Boro season, and

salinity-induced lower rice yields were found to be the prime reason behind this lack of expansion. This study has shown the existence of a farmer-derived threshold yield loss in the coastal dry season rice farming system that is based on their experience and observations. However, yield loss thresholds varied among the different types of farmers, with rice farmers tolerating a greater rice threshold yield loss (23%) compared to shrimp and salt farmers (at 16% and 14% of threshold yield loss, respectively). Thus, differential perceptions of the salinity affected yield loss thresholds suggest government actions to support and encourage integrated land management for rice, shrimp and salt farming rather than research and extension efforts that are focused on dry season rice expansion alone. These actions could strengthen sustainable livelihood options to ensure food security, and contribute to the achievement of the sustainable development goals for instance, no poverty (SDG-1), zero hunger (SDG-2) and good health and well-being (SDG-3).

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Chapter 1

Introduction and Background

1.1 Overview

Soil salinization is a pernicious problem in the coastal areas of Bangladesh that presents substantial challenges to agricultural productivity and difficulties in addressing the sustainable development goals (SDGs). While the biophysical nature of salinity is understood, a less explored area is how to deal with the variable nature of the impact of salinity on agricultural productivity, especially on diverse livelihoods that may be impacted differentially. Such variability creates uncertainty for the policymakers who need to make adaptation decisions. This chapter introduces key background information on the salinization problem, and the statement of the research problem. This chapter also introduces the research approach that is followed to achieve the key research goals, and background information on the coastal areas of Bangladesh, with special attention to the study area. Finally, this chapter presents the thesis structure.

1.2 Background of the study

Achieving sustainability in overall development has remained a key policy priority of the Bangladesh Government since independence. More recently, the government has demonstrated a continued commitment to sustainability with its adoption of the UN sustainable development goals (SDGs) (Alam, 2018). To operationalise the SDGs targets, the government has adopted these goals in most of the prioritised policy documents, such as the five-year plans (FYP), national agriculture policy (NAP), national food policy (NFP), national perspective plan (NPP) and Bangladesh climate change action plan (BCCAP) (Ashraf et al., 2019; Selim et al., 2018; GED, 2018). Among the SDGs, eradication of poverty (SDG-1), zero hunger (SDG-2) and good health and well-being (SDG-3) are clearly linked to sustained agricultural production. The agricultural sector of Bangladesh remains the key driver for overall development of the country since independence, and contributes 13% to the gross domestic product (GDP) of the national economy (NSDS, 2013; BBS, 2018). In the agricultural sector, rice production plays the principal role as it is cultivated on more than 75% of the cultivable land of the country, and provides around 50% of total rural employment and 75% of total daily calorie intake of its citizen (BRRI, 2019; BBS, 2018).

In Bangladesh, rice is grown in three distinct seasons, namely Aus, Aman and Boro, which are pre-monsoon, monsoon and dry season, respectively. Of these three rice seasons, Boro (dry

season henceforth) contributes around 54% of the total rice production (BBS, 2020). Although the dry season rice is grown in about 83% of the potential rice growing¹ areas of the country, its cultivation in the coastal areas remains very low when compared to the other regions of Bangladesh (Ali, 2006; BBS, 2020). Thus, intensification of dry season rice cultivation in the coastal areas has attracted considerable attention from the policymakers, as these regions represent around 30% of the total area of the country (Baten et al., 2015; Islam, 2004). These areas, however, are also vulnerable, as they are located in a climate change-sensitive region (Yohe et al., 2006). The rice-dominated agricultural sector of Bangladesh is increasingly exposed to natural disasters such as cyclones, drought, flood and salinization, which have short and long-term implications for the nation's food security and the achievement of the SDGs (Alam, 2018; UNDP, 2018; GED, 2018). Among these disasters, salinization in the coastal areas is considered a key constraint to expansion of dry season rice cultivation, which could have an impact on the pace of achievement of the SDGs targets (Alam, 2018; MoA, 2013). To address the salinization problems, government planning is predominantly focused on technical solutions such as development of saline-tolerant rice varieties, and expansion of these technologies at the farm level (MoA, 2013). However, salinization in the coastal areas resulted from both natural and anthropogenic drivers that have developed over several decades and, as such, are not only temporally and spatially variable but also exhibit differential impacts and responses in coastal communities (Clarke et al., 2015; Islam et al., 2020; SRDI, 2010).

If government intends to achieve the sustainable development goals (SDGs), when planning for rice intensification in the coastal areas of Bangladesh, it is therefore necessary to consider the salinity perspective of the three major farming enterprises of rice, shrimp and salt farming in the coastal areas and the locally preferred strategies for adapting to the increasingly saline environment. Furthermore, the uncertainty posed by contested land use practices necessitates a comprehensive understanding of the threshold yield loss of dry season rice from the perspectives of all farmer types, as this understanding can guide policymakers in expanding

¹ Potential rice area is considered to be the rice cultivation area during the wet season.

dry season rice production through salinity adaptation planning and prioritising research needs that ultimately will help in achieving the SDGs.

1.3 Statement of the research problem

Soil salinization is a widespread phenomenon and a common problem in coastal areas worldwide. It is also considered one of the major causes of soil degradation (Setia et al., 2013). In Bangladesh, soil salinization is the major constraint to agricultural intensification in the coastal areas, as these areas are affected by various magnitudes of salinity (MoA, 2013; SRDI, 2010). Soil salinization in these areas has increased at a faster rate over the last few decades, and the salt-affected area had grown to 1.06 Mha in 2009 from 0.83 Mha in 1973 (Seal and Baten, 2012; SRDI, 2010). Low-lying coastal areas of Bangladesh are expected to be inundated by seawater due to being in climate change-sensitive geographical locations, which could have potential impacts on salt intrusion into the coastal inland regions (Hasan et al., 2020). It is also predicted that upstream withdrawal of river water, reduced stream flows in dry season, over-extraction of ground water and climate change-induced reduction in precipitation during the dry season are likely to contribute to increased soil salinization (Khan et al. 2011; Vineis et al. 2011). A study conducted in the Bangladesh Delta reported a 39% increase in soil salinity by 2050 due to climate change-induced changes such as sea level rise, which could lead to extensive salinization of cropland and could make dry season rice cultivation even more challenging (Dasgupta et al., 2015).

Despite these threats of salinity, achieving the SDGs through sustaining rice-dominated agriculture in these regions is the most important concern of the policymakers, as the food security of Bangladesh is synonymous with sustained rice production (Alam, 2018; Selim et al., 2018). Although most of the guiding policy documents that address SDGs recognise coastal salinity as the primary constraint to intensification of dry season rice cultivation, the potential adaptation measures have focused on promotion of saline-tolerant crop varieties and the scaling up of local innovations to cope with salinity problems (BCCSAP, 2009; NAP, 2018; NAPA, 2009; NSDS, 2013). Thus, adaptation decisions that are aimed at addressing the expected salinization problem in the coastal regions of Bangladesh have been predominantly influenced by the priorities of research organisations, and have consisted mainly of developing saline-tolerant crop varieties (MoA, 2013; NAP, 2018). However, the literature also indicates that the salinity problem

in the coastal areas exhibits considerable temporal and spatial variation (CCC, 2009; Clarke et al., 2015; Lázár et al., 2015). Thus, salinity perceptions can vary among the different types of farmers who live in close proximity in the coastal areas and use land resources for their livelihoods. Few studies conducted in the coastal saline environment in the Mekong Delta argued the existence of differential perceptions of the salinity intrusion among the rice and shrimp farmers (Khong et al., 2020; Nguyen et al., 2020; Nguyen et al., 2019). However, local farmers' perceptions of salinity and their locally preferred adaptation strategies have received little attention in policy formulation and research priorities for addressing the salinity problem in coastal regions.

Numerous studies that have been conducted in different parts of the world have demonstrated the usefulness of understanding farmers' perceptions of climate change for the development of adaptation strategies that can reduce the risk and for informing policymakers on successful adaptation planning in the agricultural sectors (Below et al., 2012; Bryan et al., 2013; Deressa et al., 2009; Maddison, 2007). It has also been argued that understanding farmers' perceptions of any hazard, and how it varies across various scales can also be useful for planning successful adaptation strategies (Niles et al., 2016; Weber and Stern, 2011). However, research work based on the farmers' salinity perceptions and the potential of their resulting actions to cope with salinity have attracted little attention in the existing literature.

Although rice-dominated agriculture has gained the most policy attention, it is also well understood that coastal resources have the potential to contribute to achieving the SDGs by contributing to all components of food security and socioeconomic development (Selim et al., 2018). For example, rice farming can ensure grain sufficiency, while shrimp aquaculture and the salt industry can generate household incomes that can provide better livelihoods to the coastal communities (Al Mamun et al., 2014; Lázár et al., 2015). Shrimp farming is a substantial economic activity in the coastal areas of Bangladesh, and has been rapidly expanding due to the availability of suitable brackish water (Afroz and Alam, 2013; Swapan and Gavin, 2011). Bangladesh is the fifth largest shrimp producer in the world, producing around 4.5 million tonnes of shrimp annually, which generates US\$380 million annually and directly employs 1.5 million people (FRSS, 2018). Additionally, around 2 million household livelihoods are associated with shrimp feed industries (Dhar et al., 2020; FRSS, 2018; Uddin et al., 2019). In addition, salt farming in the south-

western coastal areas of Bangladesh is considered to be a potential economic activity that is reported to be highly profitable when compared to rice farming (Al Mamun et al., 2014; Hossain et al., 2006). However, there are environmental and social issues associated with shrimp and salt farming; for instance, these farming activities are reported to accelerate salt intrusion into rice fields, destruction of aquatic habitat for plants, fish and other aquatic animals, and the destruction of mangrove ecosystems (Chowdhury et al., 2011; Hossain et al., 2013; Islam and Tabeta, 2019).

Thus, adaptation decisions to deal with the salinization problem in the coastal areas of Bangladesh are characterised as a wicked problem, as it involves various types of farmers who are benefited or affected by this problem in diverse ways (Adamo, 2011; Lázár et al., 2015). In addition, policymakers have been presented with contested solutions with diversified ideas. For example, the innovation of saline-tolerant rice varieties by the Ministry of Agriculture (MoA) influenced policymakers to promote dry season rice expansion even though these varieties have certain limitations in their adaptation to the salinity (Islam et al., 2020; Rabbani et al., 2013). Shrimp and salt farming industries in the coastal saline environment are important economic activities and are supported by government agencies such as the Ministry of Fisheries and Livestock (MoFL) and the Bangladesh Small and Cottage Industries Corporation (BSCIC), but environmental consequences have also been reported as a result of these farming practices (Abdullah et al., 2017; Battacharya et al., 1999). Given these contested livelihood options, the expected salinity threats and the limitations of the saline-tolerant varieties, policymakers are becoming more uncertain about their adaptation decisions, as this problem affects a number of livelihood options in socially diverse ways (Dewulf et al., 2005). Despite the factors mentioned earlier, uncertainties can also originate from societal perspectives, such as the preferences of local farmers for livelihood options and socioeconomic developments in the coastal areas that can change over time (Haasnoot et al., 2013; Offermans, 2010). To address these uncertainties, understanding how local farmers (i.e. rice, shrimp and salt farmers) perceive the salinity problem in their farming enterprises is yet to be considered in great depth.

1.4 Conceptual research approach

The adaptation tipping points (ATPs) approach is applied in this study to address uncertainties in the adaptation decisions that are intended to address salinization and dry season rice intensification planning in the coastal areas of Bangladesh. ATPs are defined as the points where the magnitude of change due to climate change or sea level rise is such that the current management strategy will no longer be able to meet the objectives for which these were undertaken (Werners et al., 2015). This is a bottom-up approach to assessing the vulnerability of a system and differs from the classical top-down approach to an adaptation decision in the sense that it is less dependent on climate projections (Ludwig et al., 2014), as it addresses the problem from the bottom end (i.e. perceptions of people who are affected by the problem).

To apply the ATP approach, it is necessary to first identify how, in this case, the salinity problem is perceived by the different types of farmers living in the coastal areas, and to assess their locally preferred strategies for coping with salinity. After achieving an understanding of the farmers' perceptions of salinity, the next step is to investigate the threshold yield loss of rice farming as perceived by the different types of farmers living in close proximity that would signal the tipping points for salinity management of dry season rice farming.

Examination of salinity perceptions and farmers' adaptation strategies from their perspective is based on the two vital components of adaptation in agricultural systems to any environmental stress such as perception and adoption. These two components indicate that, firstly, farmers need to be aware that there are changes in the environmental factors (for example perceptions about the stress), and that they have a willingness to implement different strategies to address those changes (i.e. adaptation actions) (Maddison, 2007).

The theoretical basis of the threshold yield in coastal saline environments signifies the situations in the farming system (e.g. level of yield loss) that are perceived by the different types of farmers as being unable to sustain their livelihoods (Werners et al., 2015). In a biophysical system, the threshold is often considered to be the point beyond which yield loss is irreversible (Russill and Nyssa, 2009), but in the social-environmental system, it represents the level at which members of a society (e.g. different types of farmers) perceive it as undesirable for their livelihood options (Werners et al., 2013). The threshold of a system also highlights the scales for

operationalising adaptation planning, such as the decision level (e.g. policy objectives) and the physical level (e.g. where the policy is implemented) (Clar et al., 2013; Howden et al., 2007). Threshold identification has been suggested as a means for obtaining an integrated and more comprehensive framework to inform policymakers so that they have a better understanding of risk assessments and adaptation decisions (Briske et al., 2010). Thus, determination of the salinity-affected threshold yield loss will signal the tipping points of dry season rice cultivation through adaptation decisions on salinity management in the coastal areas of Bangladesh. The conceptual research approach applied in this study is presented in Fig. 1.1.

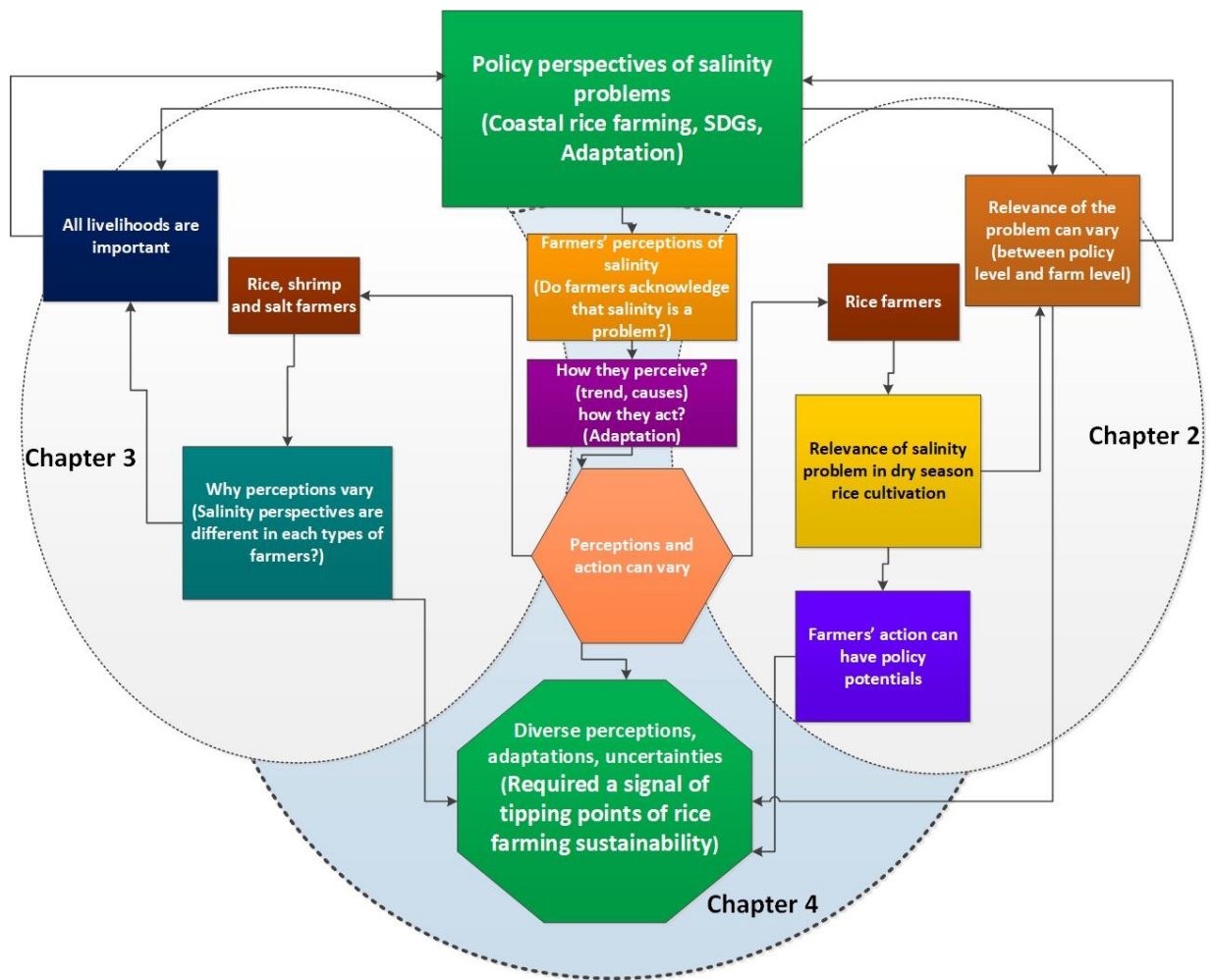


Fig. 1.1. Conceptual research approach.

1.5 Research aim and objectives

Achieving the SDGs remain the key policy objectives of the Bangladesh Government. Among these goals, SDG-1 (no poverty), SDG-2 (zero hunger) and SDG-3 (good health) are explicitly connected with ensuring food security through optimal and sustained agricultural production. In Bangladesh, agricultural production is dominated by rice farming, and among the rice growing seasons, dry season (i.e. Boro) is the largest. This season has attracted the most attention from policymakers, especially the intensification of dry season rice cultivation in the coastal areas. However, salinization in the coastal areas is considered to be the main constraint to intensification of dry season rice cultivation. Nevertheless, the severity of salinization has been shown to be temporally and spatially variable and affects coastal rural communities in diverse ways. Thus, government policy is concerned with ways to intensify rice cultivation in the coastal areas to achieve the SDGs which is becoming more challenging under pernicious salinization problem. However, this policy agenda lacks information on the salinity perspectives of all types of farmers and their locally preferred adaptation strategies to an increasingly saline environment. Furthermore, the uncertainty posed by contested land use practices necessitates a comprehensive understanding of a threshold yield loss of dry season rice from the perspectives of all types of farmers, which can guide policymakers in their adaptation planning for the salinity problem and allow prioritisation of research that will ultimately help in achieving the SDGs.

The general aim of this study is to examine local farmers' perspectives of growing dry season rice under an increasingly saline environment and their preferred adaptation strategies. Based on farmers' perceptions, this study will develop a farmer-derived threshold yield loss that signals the tipping points of dry season rice farming. The specific aims of this research are to study two coastal areas of Bangladesh, the Satkhira and Chittagong regions, to:

- i) Evaluate rice farmers' perceptions of salinity, its causes, recognition and adaptation strategies, and review its potential in policy initiatives (Chapter 2)
- ii) Delineate how farmers' salinity perspectives and their adaptation preferences, vary in and across various farming groups and locations (Chapter 3)

- iii) Assess the threshold yield loss of dry season rice under increasingly coastal saline environment based on farmers' perceptions (Chapter-4)
- iv) Show the potential of farmers' derived threshold yield loss for policy initiatives (Chapter 5)

1.6 Research methodology

1.6.1 General description of the coastal regions of Bangladesh

The coastal zone policy of the Bangladesh Government recognises 19 districts in the south of the country as the coastal region. It represents around 30% of the total area of the country (Sarwar, 2005). Based on the three fundamental criteria such as risk of exposure to cyclones, salinization and tidal influence, the coastal areas of Bangladesh are broadly divided into "Exposed Coast" and "Interior Coast" (ESCAP, 1987; Islam, 2004; Karim and Mimura, 2008). The "Exposed Coast" delineates all three criteria covering 48 upazilas (sub-districts) of 12 districts, while the presence of one or two of these three criteria classifies the area as the "Interior Coast", which consists of 99 upazilas of 7 districts (Karim and Mimura, 2008). These coastal areas are further classified as the Western (south-west), Eastern (south-east) and Central coastal regions based on the location in southern Bangladesh (Fig. 1.2).

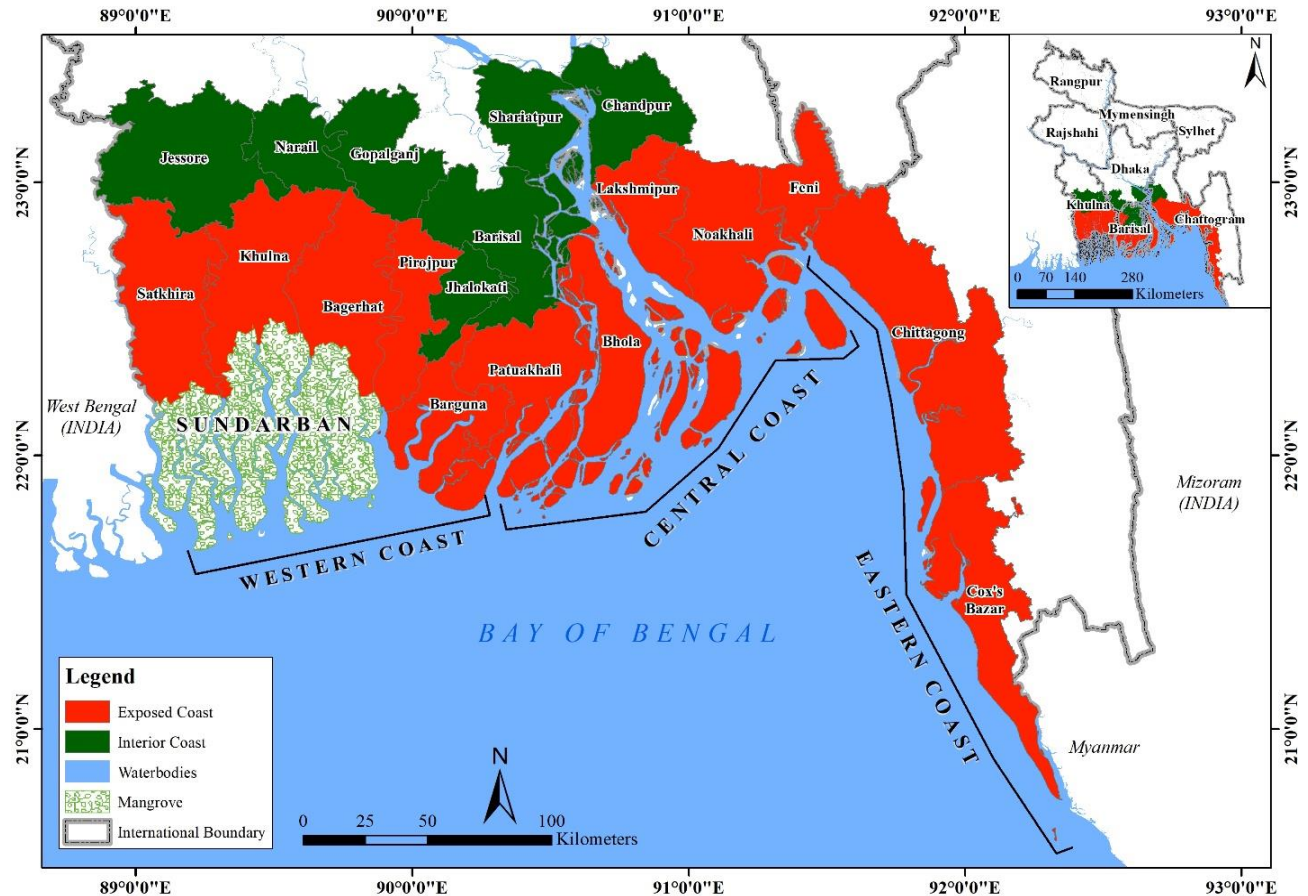


Fig. 1.2. Coastal regions of Bangladesh showing exposed and interior coastal districts

1.6.2 Historical background of salinity in coastal regions of Bangladesh

In coastal regions of Bangladesh, the area affected by salinity has increased rapidly over the last few decades (Baten et al., 2015). A study published by the Soil Resources Development Institute (SRDI) reported that 1056 thousand hectares of land were affected by salinity in 2009, which was around 833 thousand hectares in 1973 (Fig. 1.3). It also reported that the rate of increase in the salinity-affected area was higher in the south-western region (a 21% increase) than the south-eastern region (a 3% increase) when compared to the base year of 1973 (SRDI, 2010). However, the highest trend in increasing salinity has been observed in the central coastal zone (Fig. 1.4). Among the affected areas, a sharp increase in salinity was recorded as a higher electrical conductivity of $EC_e \geq 8.0$ or higher (Fig. 1.5).

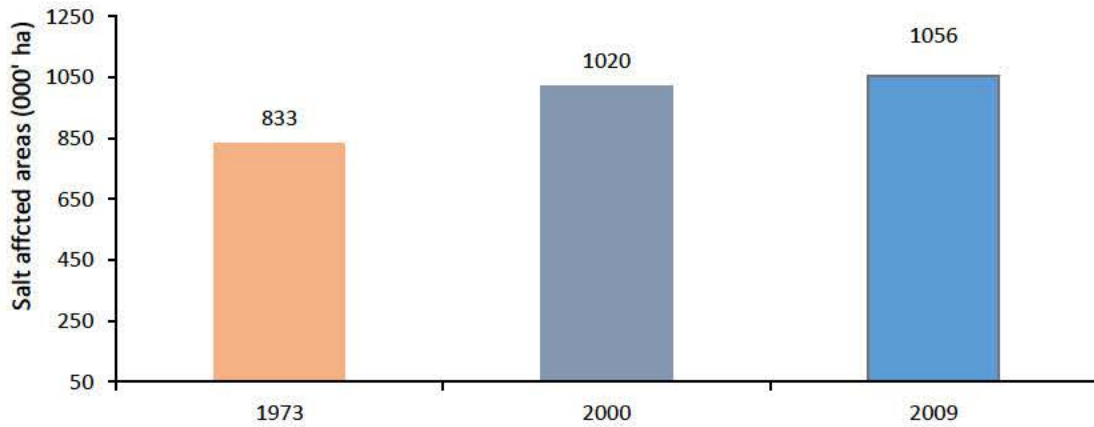


Fig. 1.3. Land area ('000' ha) affected by salinity in the coastal areas of Bangladesh from 1973 to 2009 (SRDI, 2010)

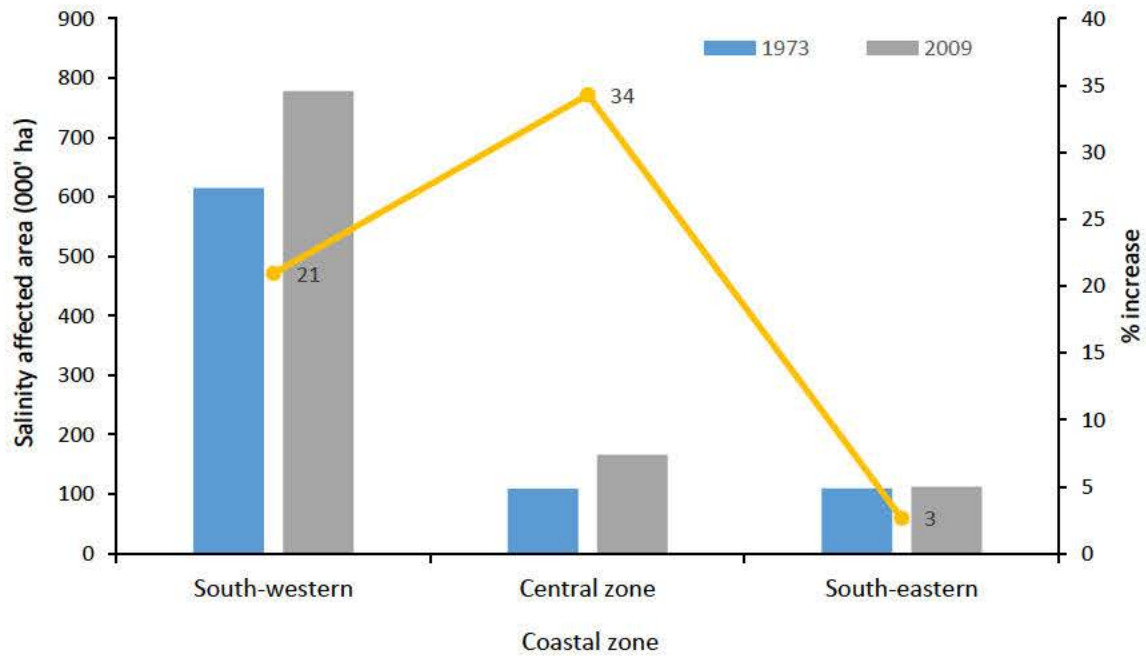


Fig. 1.4. Trends of salinity-affected land areas in different coastal regions of Bangladesh (SRDI, 2010)

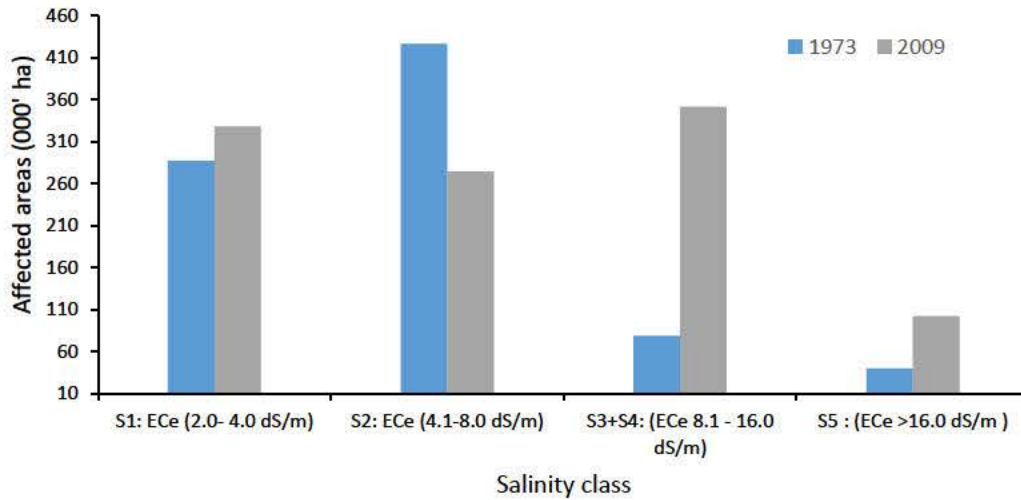


Fig. 1.5. Salt-affected land areas from 1973 to 2009 categorised according to soil salinity class (SRDI, 2010)

1.6.3 Agricultural land use changes (rice, shrimp and salt farming) in the coastal areas of Bangladesh

Salinization in the coastal areas of Bangladesh limit rice cultivation; however, saline environments favour shrimp aquaculture and salt farming. The temporal distribution of these enterprises has been affected by the increases in soil salinity. Before the 1990s, coastal agriculture was dominated by wet season rice farming. However, due to less availability of high-yielding rice varieties, yields were typically low (Ahmed et al., 2010). Over the same period, higher global demand for shrimp secured higher prices, which favoured the growth of this industry (Ahmed et al., 2010). From 1990 to 2015, for all coastal areas, there was an 11% decline in the potential area for dry (Boro) season rice; however, there was a 59% reduction in the south-western coastal region (BBS, 2020). In contrast, shrimp farming areas have increased significantly over the same period. Around 300,000 ha of shrimp farming was reported in the coastal areas in 2015, compared with only 60,000 ha in the 1990s (Table 1.1). The highest increase (650%) in shrimp farming area was in the south-western coastal region, where potential area for Boro rice farming had shown a substantial reduction in land area. Furthermore, salt farming areas in the south-eastern coastal region have increased by 53% since the 1990s (Table 1.1).

Table 1.1. Trends in agricultural land use in the coastal areas of Bangladesh

Coastal region	Potential area for dry season (Boro) rice (000' ha) (% increase/decrease)		Shrimp farming area (000'ha) (% increase/decrease)		Salt farming area (000'ha) (% increase/decrease)	
	1990	2015	1990	2015	1990s	2015
South-west	434	275 (-59%)	32	240 (+650%)	-	-
Central	697	693 (-0.57%)	9	4 (-59%)	-	-
South-east	538	525 (-2.41%)	19	48 (+152%)	18.7	28.6 (+53%)
Total	1669	1493 (-11%)	60	292 (+386%)	18.7	28.6 (+53%)

Source: (BBS, 2020; BSCIC, 2020; FRSS, 2018)

1.6.4 Selection and description of the study locations

The administrative and territorial boundaries of Bangladesh are divided into divisions, districts, sub-districts, unions and wards/villages. Divisions and villages represent the largest and smallest units, respectively (BBS, 2016). Two study locations (sub-districts) were selected from the south-western and south-eastern coastal zones. Then two villages from each of these sub-district were selected for household survey (Fig. 1.6).

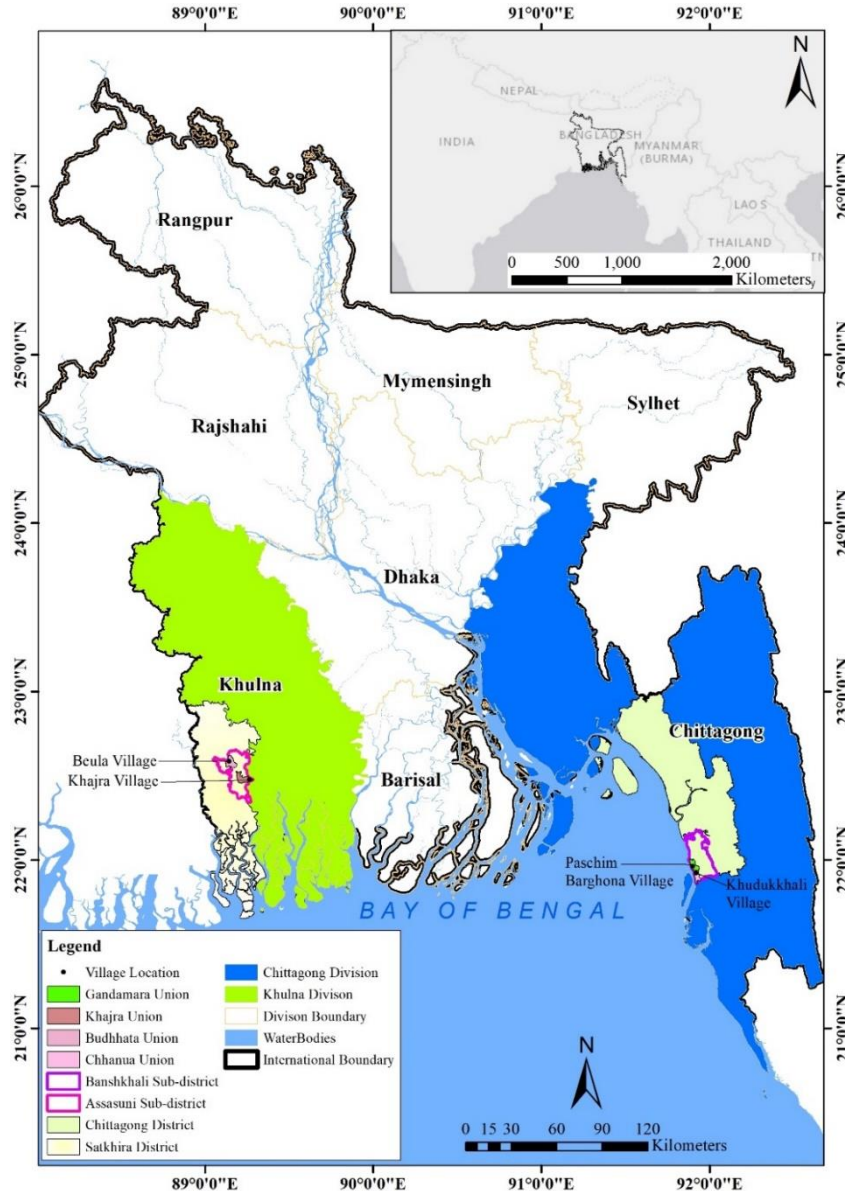


Fig. 1.6. The study locations showing territorial boundaries in the map of Bangladesh

The south-western coastal zone is in a more active delta and is characterised by the Ganges tidal flood plain, which consists of a large number of creeks and channels. The major rivers of this region are the Gorai and its tributaries. In contrast, the south-eastern coastal area falls under the shallow piedmont zone along with the Chittagong hill tracts and is more stable geomorphologically. Major rivers in this south-eastern region are the Sangu, Karnafuli and its tributaries (Banglapedia, 2019; BWDB, 2013). Satkhira district from the south-western coastal region and the Chittagong district from the south-eastern coastal region were selected as the study locations based on the severity of salt intrusion, where 67% and 20% of arable land is saline in Satkhira and Chittagong, respectively (Fig. 1.7) (SRDI, 2010). In addition to the variability in the salinity-affected land, the climatic conditions also differ in these two coastal districts. Average rainfall is at its maximum from July to August in both districts while the lowest rainfall occurs from November to March. However, the average monthly total rainfall is higher in the Chittagong district compared to the Satkhira district (Fig. 1.8) (BMD, 2020). It was reported that the average temperature in both districts starts to increase in March, with May being the warmest month in both districts (Fig. 1.9) (BMD, 2020). Thus, the two different coastal locations with higher and lower salinity areas provide an opportunity to study differential salinity perceptions as well as salinity coping strategies. Assasuni and Banskhalī sub-districts were then selected from the Satkhira and Chittagong districts, respectively. The Assasuni sub-district is located around 40 km south-east of Satkhira District Headquarters. This sub-district is surrounded by four small rivers, namely the Morirchap, Kholpetua, Beta and Kaptaksha, which are connected to the Bay of Bengal. Shrimp aquaculture and cropping are the main livelihoods of most of the families, with round 60% of the agricultural land in Assasuni used for shrimp aquaculture, 33% for rice farming and the remaining proportion of land for vegetables and other crops (Fig. 1.10) (UAO, 2018). Banskhalī sub-district is around 45 km south of the Chittagong District Headquarters. This sub-district is delineated by Cox's Bazar district and the Sangu River to the south and the Bay of Bengal to the west (BBS, 2015; GOB, 2019). Land use is dominated by rice farming, which represents 57% of the agricultural land, with only 24% of the land used for salt farming and shrimp farming and the remainder used for cultivation of vegetables and other crops (Fig. 1.11) (UAO, 2018).

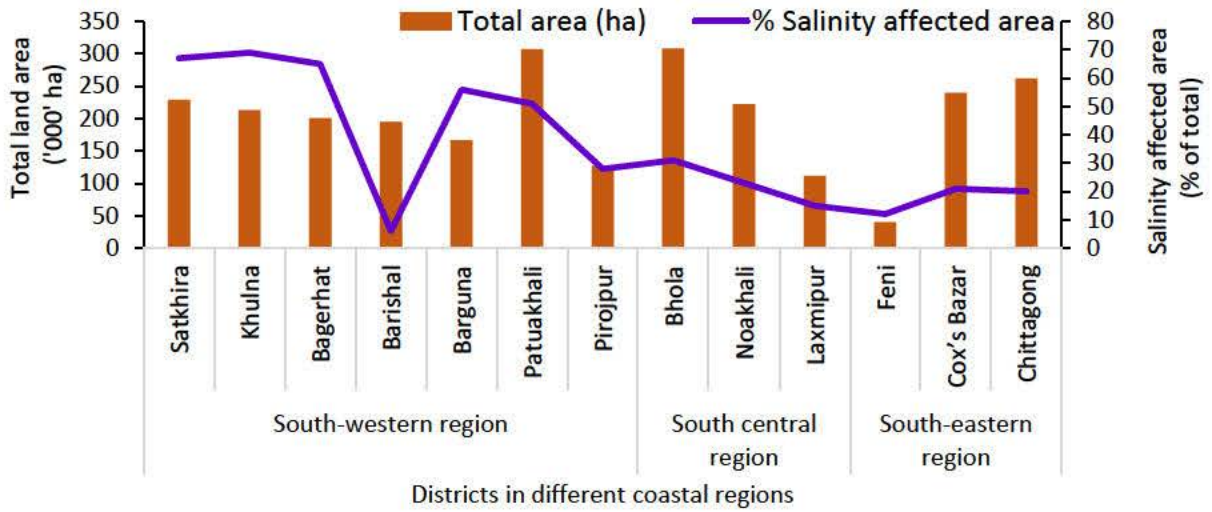


Fig. 1.7. Salinity-affected area ('000' ha) in different coastal districts of Bangladesh (SRDI, 2010)

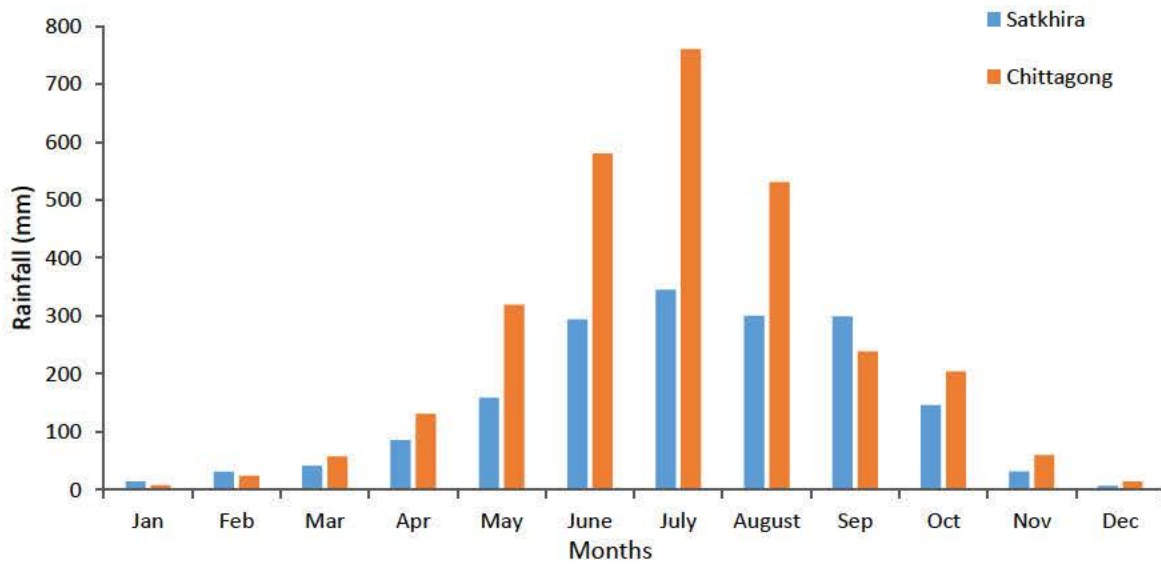


Fig. 1.8. Monthly average rainfall (mm) in Satkhira and Chittagong districts (BMD, 2020)

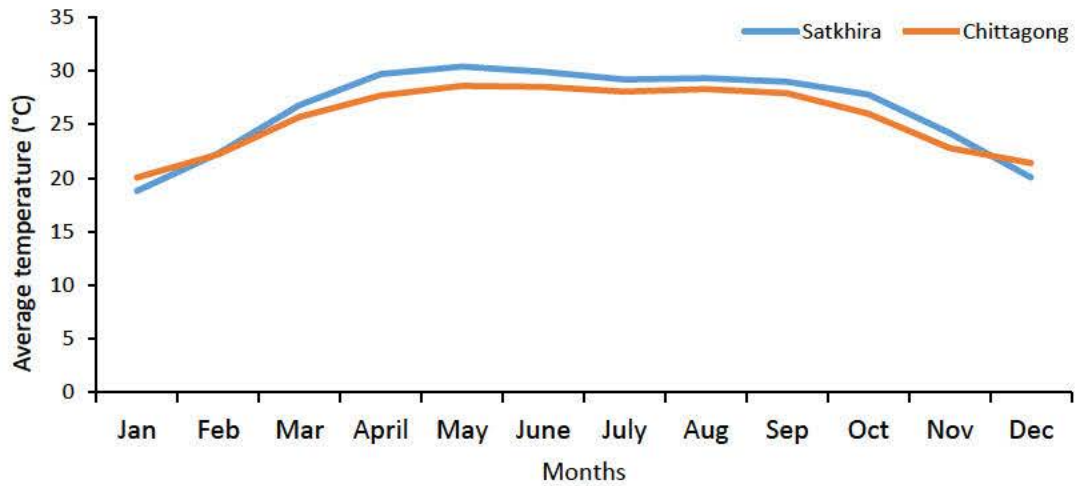


Fig. 1.9. Monthly average air temperature (°C) of the Satkhira and Chittagong districts (BMD, 2020)

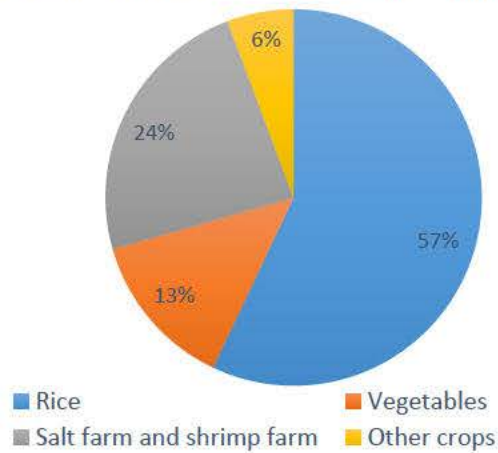


Fig. 1.10. Land use patterns of the Assasuni sub-district (SW)

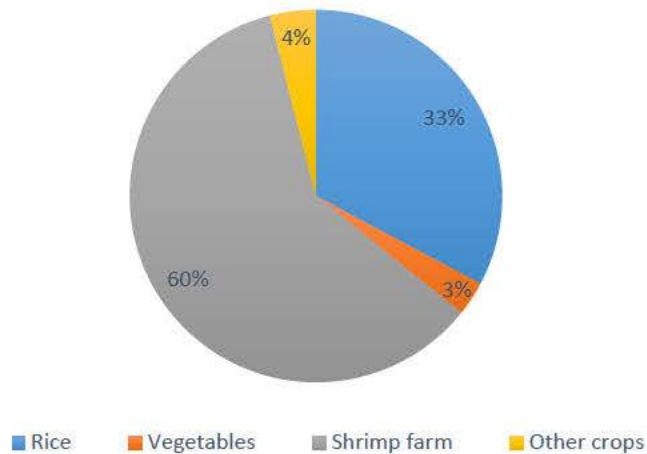


Fig. 1.11. Land use pattern of the Banskhali sub-district (SE region)

Although shrimp farming is a common land use practice in both sub-districts, the pattern is quite different in the two areas. In Assasuni, most of the shrimp farms use brackish water, and these are year-round shrimp, but there are a few areas where shrimp farming alternates with rice farming, where freshwater prawns are farmed in the monsoon and then rice farming during Boro season (Kabir et al., 2016). The latter has started in recent years in areas affected by low salinity levels (Kabir et al., 2016). In Banskhali, shrimp farming generally alternates with salt farming, and is the most extensive land use system. Shrimp are cultivated in the wet season and salt farming occurs in the dry season (Ahmed, 2013; Azad et al., 2009; Pokrant, 2014). Typical rice and shrimp farming practices of the Assasuni sub-district and the rice, shrimp and salt farming practices in Banskhali sub-district are illustrated in Fig. 1.12 and Fig. 1.13, respectively (Islam, 2018/2019).



Single crop land (rice during wet season only and remain fallow during dry season)



Brackish water shrimp farm (year-round production)



Dry season (Boro) rice field



Salinity-affected dry season (Boro) rice field

Fig. 1.12. Rice and shrimp farming practices in Assasuni sub-district (Source: Pictures captured by the author during the field trip, M. A. Islam)



Salt farming (some parts of this land are used for wet season (Aman) rice cultivation)



Salt farming during dry season, and whole field used for brackish water shrimp during wet season



Salt farming (pulling saline water for salt farming)



Rice field (land used for dry and wet season rice cultivation)

Fig. 1.13. Rice, shrimp and salt farming practices in Banskhali sub-district (Source: Pictures captured by the author during the field trip, M. A. Islam).

1.6.5 Methods of data collection and analysis

Both qualitative and quantitative (mixed method) approaches were used for this study to collect data. Primary data were collected through household surveys, focus group discussions and key informant interviews. These were conducted from January to April in 2018 and 2019. Before conducting the interviews, Human Research Ethics Approval (HREA) was sought and

gained from the University of New England, Australia; Approval No. HE17-272. Household surveys were conducted in four coastal villages in the two selected sub-districts. A pre-tested interview schedule for household surveys was used for primary data collection. A total of 280 farmers (rice farmers = 109, shrimp farmers = 107 and salt farmers = 64) from the two sub-districts were randomly selected for face-to-face interview. A multi-stage random sampling procedure was followed to select the survey respondents. In-field salinity measurement data were also collected from the 36 sampled rice farmers' fields from the earlier household survey list. Each rice field was visited twice to collect the salinity data from the standing rice field as well as corresponding farmers' perceptions of salinity of that rice field were recorded. The overall data collection methods of this study are presented in the Fig. 1.14. There were 22 key informant interviews conducted in this study. The key informant interviewees (KIIs) included personnel from extension service providers, agricultural scientists and NGO personnel from the national and local levels. The quantitative data collected from the household survey were analysed using SPSS (version 25) and R statistical software (Horton and Kleinman, 2015; Rovai et al., 2013). Data collected through the KIIs and FGDs were analysed in NVivo 12 plus software (Edhlund and McDougall, 2019). The detailed data collection and analyses procedures are expanded upon in the relevant research chapters, chapters 2 to 4.

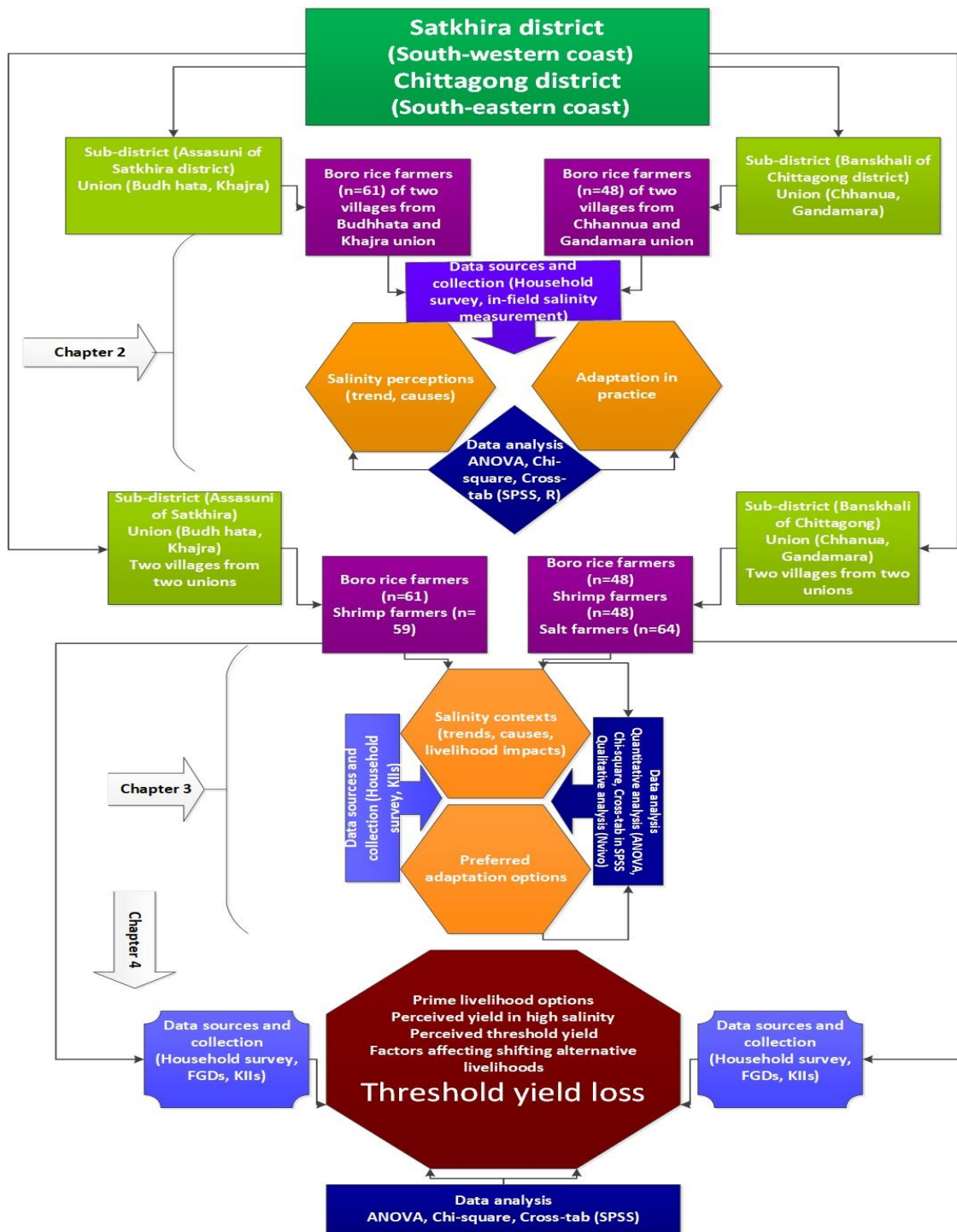


Fig. 1.14. Overall data collection and analysis methods applied in this study

1.7 Thesis structure

This study developed three sequential steps to apply the adaptation tipping points approach to the coastal rice growing system that is experiencing an increasingly saline environment. Each of these steps is presented in the research chapters (Chapter 2 to Chapter 4) to achieve the core research objectives of this study. The first research chapter addresses the understanding of rice farmers' perceptions of salinity, and their adaptation actions to salinity problem with relevance of the findings in the policy initiatives. Understanding the differential farming of the salinity problem (i.e. salinity perspectives of all types of farmers) is presented in chapter 3. The chapter 4 depicts the existence of threshold yield loss of dry season rice cultivation signalling the potential tipping points of dry season rice cultivation through adaptation decisions on salinity management in the coastal areas of Bangladesh. In Chapter 5, the findings of the three research chapters are synthesised, and the potential of the findings for policy initiatives is presented.

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Chapter 2

The importance of farmers' perceptions of salinity and adaptation strategies for ensuring food security: Evidence from the coastal rice growing areas of Bangladesh

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It is presented here with the original contents (published materials) in MS word versions.

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2.1 Abstract

Coastal salinity causes substantial adverse impacts on agricultural productivity and food security. Farmers' choice of salinity adaptation strategies might depend on how they perceive the problem. This research examined rice farmers' perceptions of salinity, adaptation strategies, and its implications for policy initiatives to sustain rice production in the affected coastal areas of Bangladesh. Boro rice growers (n=109) randomly selected from two coastal sub-districts were interviewed using a semi-structured survey. Awareness of salinity and its increase over the past 20 years was widespread amongst rice farmers. A similarly high proportion of farmers (90%) perceived the reproductive (e.g. booting, heading, and flowering) stages as the most sensitive to salinity problems. Salinity (EC) was measured in the farmers' fields and were categorized according to farmers' perceptions and scientific interpretation (e.g. high or low). Farmers perceived a field affected by high salinity at a lower EC reading than the scientific interpretation of the salinity level. Most of the farmers (67%) were undertaking early transplanting and applying irrigation in order to adapt to salinity problems which rise later in rice crop growth during Boro season. Thus, farmers' actions demonstrated that their perceptions of salinity and adaptation responses were pre-emptive of when salinity was most likely to have an impact on rice crop. Farmers' perceptions of salinization and measures to manage salinity need to be considered in research prioritization and policy formulation by the government. This action could potentially secure rice production and thus contribute to the achievement of Sustainable Development Goals (SDG-1, 2 and 3).

Key words: Salinity perception; Rice farmer; Boro season rice; Coastal Bangladesh

2.2 Introduction

Soil salinization is a widespread phenomenon and is considered one of the major causes of soil degradation especially in the coastal areas (Setia et al., 2013). The coastal areas of Bangladesh comprise around 30% of the total cultivable area and have been facing increased soil salinization at a faster rate since the 1980s (SRDI, 2010). The causes of salinization in this area include extensive use of saline water for shrimp and salt farming, siltation of river due to reduced upstream discharge and climate change-induced natural disasters (e.g. lower precipitation, sea water intrusion and regular coastal inundation) (Al Mamun et al., 2014; Chowdhury et al., 2011). The cultivated land in this region has declined specifically during the dry period of the year due to increased soil salinity and lower availability of fresh water (Rahman et al., 2011). Dasgupta et al. (2014) and Hossain et al. (2012) predicted that due to lower dry season river flows, over-extraction of ground water and climate change induced reductions in precipitation, there will likely be further increases in soil salinity in these areas. Thus, increased salinity will have detrimental impacts on the agricultural productivity of this region, especially during the dry season (Khanom, 2016).

One of the major policy objectives of the Bangladesh government is to ensure the sustainability of the agricultural sector, especially food security (Faisal and Parveen, 2004; NAP, 2018). A number of guiding policy documents (e.g. National Adaptation Programme of Action (NAPA) 2009; Bangladesh Climate Change Strategies and Action Plan (BCCSAP) 2009; Perspective Plan of Bangladesh (PPB), 2012; National Sustainable Development Strategies (NSDS), 2013; and National Agricultural Policy (NAP), 2018) have been adopted by the government to ensure agricultural sustainability. The Bangladesh government has recently committed to the United Nations (UN) Sustainable Development Goals (SDGs) (GED, 2018; Selim et al., 2018), and linked to these SDGs in their guiding policy documents. Among the SDGs, eradication of poverty (SDG-1), ensuring food and nutrition security (SDG-2), and maintaining good health for all people (SDG-3) are underpinned by sustainable rice production (Ashraf et al., 2019). Rice is the largest single crop grown in Bangladesh; it occupies about 75% of the cultivable land, generates 48% of rural employment, provides 70% of the daily calorie intake of citizens and contributes 18% to the gross domestic product (BRRI, 2018). Rice is grown in three distinct seasons viz Aus (April-

August); Aman (July-November); and Boro (November-July). Boro is the largest season in terms of production, and is subject to irrigation (BRRRI, 2018). Rice-based agricultural productivity in the coastal areas of Bangladesh has declined due to increasing salinity, which ultimately threatens food security and the attainment of the SDGs (Afroz et al., 2018; Szabo et al., 2016). To address the increasing salinization problem in the coastal regions of Bangladesh, development and promotion of salt tolerant crop varieties and coastal embankments are the top most priority initiatives in the key policy documents (BCCSAP, 2009; NAP, 2018; NAPA, 2009; NSDS, 2013). However, local farmers' perceptions about salinization and their locally preferred responses to the problem have not been taken into account in these policy documents. In fact, local farmers' perceptions have been reported as a key entry point for policymakers to learn about need-based adaptation planning, which in turn can increase the adaptive capacity of smallholder farmers (Blackstock et al., 2010; Le Dang et al., 2014).

In this study, perception is considered as the state in which an individual or community understands the situation in accordance with the practical experience they encounter and takes action to respond to the situation accordingly (Adger et al., 2009; Harvatt et al., 2011). The role of perception is well documented and extensively studied in medicine, psychology, business, and social sciences. Recently, it has also gained attention in climate change adaptation, and disaster management discourse (Alam et al., 2017; Hossain and Roy, 2012; Moni and Hossain, 2010). It is argued that adaptation planning is most effective when local peoples' perceptions of the environmental issues and their prioritized responses to tackle the problems are known to policymakers (Deressa et al., 2011; Weber, 2010). Integration of farmers' perceptions into long-term policy, fitting with agricultural practices at the community level, would legitimize farmers' decisions and place policy in a more credible position (Deressa et al., 2011). Thus, better understanding of local farmers' perceptions is undoubtedly important and would significantly help decision-makers to understand local perspectives as well as relevant policy interventions (Jendoubi et al., 2020).

Although salinity has been considered a disaster, its management has not attracted much attention compared to floods, cyclones, and earthquakes in the existing body of disaster management discourses (Binh, 2010). The event and exposure characteristics of natural disasters

(e.g. floods, cyclones) can be examined because knowledge and historical evidence are available (Thomalla et al., 2006). However, unlike these disasters, salinity is slow-growing and sporadic in nature (Adamo, 2011), and its exposure and vulnerability is variable in spatial-temporal scale as well as across the local community affected by it (Greiner and Parton, 1995). Although most disasters are diverse in nature and affect society in different ways, their risk and management analysis is quite similar (Patt et al., 2005). The basic principles of disaster management (e.g. preparedness, response and recovery) found in the existing body of literature mostly focus on hard engineering and technical solutions (e.g. embankments) to reduce vulnerability (Hall et al., 2004; Patt and Schröter, 2008). However, management of salinity disaster is complicated due to its multi-dimensional nature and gradual progression through hydrological processes and human activities (Hall et al., 2004). Therefore, engineering and technical solutions for salinity management on their own might not be sustainable in the long term. A new approach focused on adaptation strategies that have evolved from living with the salinity disaster in the existing social-ecological system will be more effective in reducing vulnerability and improving the resilience of communities affected (Binh, 2015).

However, a clear understanding of the salinity issue that capture the perceived risks (e.g. the causes and vulnerability of salinity) by farmers is not well understood and is yet to be adequately addressed in the existing literature on disaster management. Recent studies on farmers' perceptions of salinity conducted in Bangladesh and elsewhere in the world have mainly focused on salinity issues in relation to drinking water scarcity and health issues (Abedin et al., 2014; Habiba et al., 2013; Javed et al., 2018; Rahman et al., 2017), land degradation (Kington and Pannell, 2003), and vulnerability (Binh, 2011). To the best of our knowledge, this study is the first attempt at investigating farmers' perceptions of salinity, the way their perceptions influence their actions in adapting salinity during Boro season rice cultivation, and the way these perceptions could inform policymakers working on salinity adaptation and research prioritization. The study will contribute to the existing body of literature on salinity management and analyze how farmers' perceptions and their actions could be well-suited to managing this disaster. In addition, it will also narrow the gaps in the understanding of salinity problems from farmers' perspectives and inform policymakers in terms of long-term policy planning and research prioritization.

The findings of this article are presented as follows: section 2.4. presents the context of farmers' perceptions of the trends and causes of salinity development; farmers' relevance of the salinity problems in their rice cultivation, and adaptation strategies to cope with salinity problem in rice cultivation; section 2.5 discusses farmers' perceptions of salinity problems in relation to Boro season rice cultivation with special attention to the relevance of the salinity problem; explores farmers' adaptation practices to addressing the salinity problem; and reports the consistency of farmers' perceptions of salinity and adaptation strategies with scientific information; and in section 2.6 we present Policy implications of farmers' perceptions for salinity management, and there is conclusion in section 2.7.

2.3 Materials and methods

2.3.1 Selection and description of the study area

Historical salinity data indicate that the extent of salinity-affected cultivable land in the coastal areas of Bangladesh has risen sharply over the last few decades, with a peak observed in 2009 (SRDI, 2010). However, the intensity of salinity-affected areas in the coastal districts of the country is quite variable (Fig. 1, SI). The study areas for this research were located in four coastal villages. We selected two unions² (Budhhata and Khajra) from the Assasuni sub-district of Satkhira and (Gandamara and Chhanua) from the Banskhalī sub-district of Chittagong district of Bangladesh. Subsequently, one village from each union was selected as a study location (Fig. 2.1).

Assasuni sub-district is around 40 km south-east of the Satkhira district headquarter. This sub-district is surrounded by four small rivers, namely Morirchap, Kholpetua, Beta and Kaptaksha. Shrimp aquaculture and agriculture are the main livelihoods of most of the families living in Assasuni. On the other hand, Banskhalī sub-district is around 45 km south of the Chittagong district headquarters. This sub-district is surrounded by the Sangu river and Anwara sub-district to the north, the Satkania and Lohagara sub-districts to the west, the Pekua and Chakaria sub-districts to the south and the Bay of Bengal to the west. This sub-district is dominated by salt cultivation, agriculture and shrimp aquaculture (BBS, 2015).

² A Union is the lowest administrative unit of Bangladesh. (There are 4554 unions in Bangladesh <https://www.bangladesh.gov.bd/site/view/union-list/>)

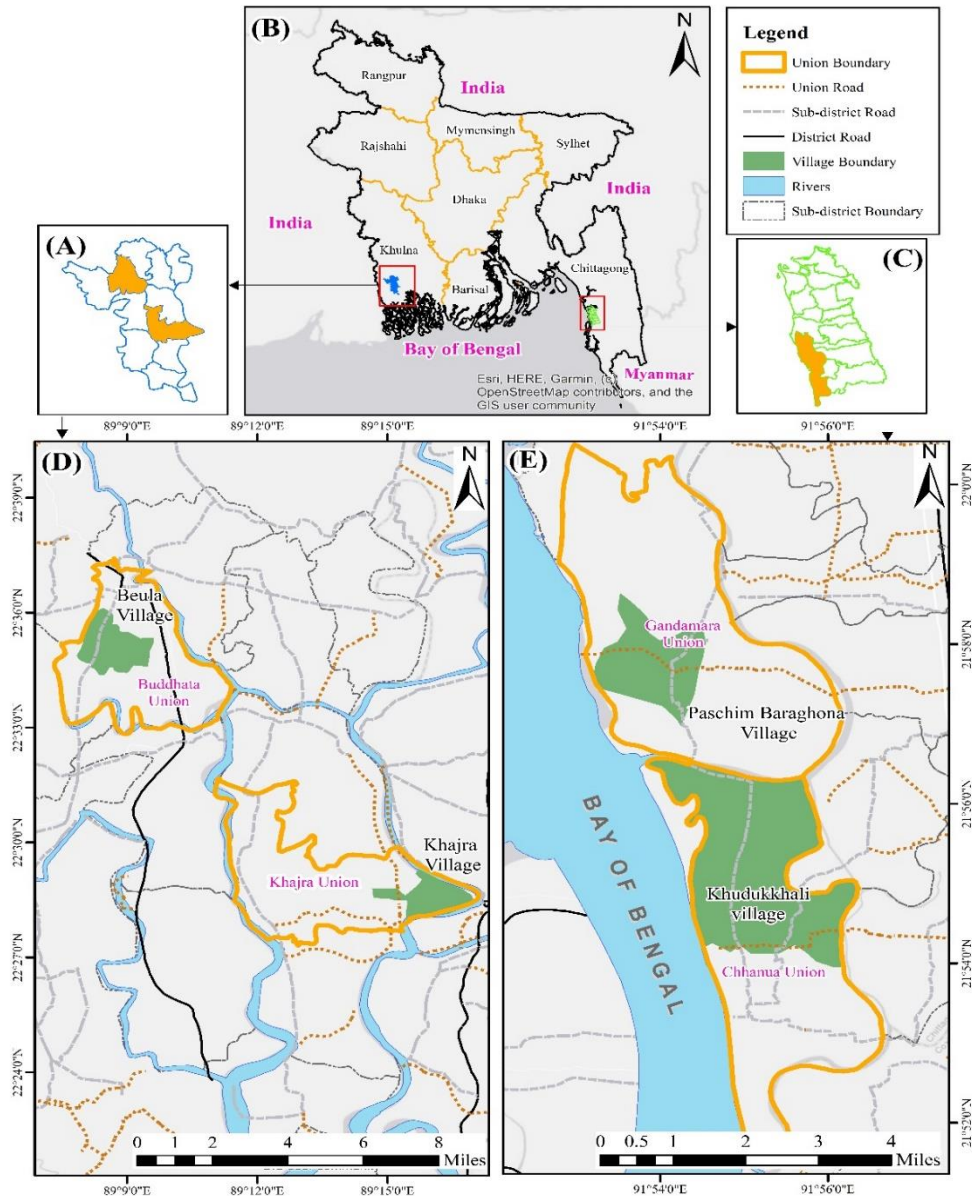


Fig. 2.1. Study area: Assasuni sub-district of Satkhira district in the southwest (A) and Banskhalī sub-district of Chittagong district in the south-east (C) coastal region of Bangladesh. Selected villages (green area) in the Buddhata and Khajra union of Assasuni sub-district (D) and Chhanua and Gandamara union of Banskhalī sub-district (E)

Two separate locations from the south-east and south-west coastal regions of Bangladesh were selected based on their distinct features. For example, the two locations varied in their extent of salinity-affected areas (Appendix 2.1, land topography and type of river system (BWDB, 2013; Hossain and Roy, 2010), and agro-ecological and socio-economic conditions (Appendix 2.2). Selected unions within the sub-districts also varied in salinity-affected areas (Appendix 2.3).

Thus, the differences in these study locations allowed us to compare farmers' perceptions of salinity and adaptation strategies in new dimensions (e.g. the need to utilize farmers' perceptions of salinity in policy initiatives), which was uncommon in the previous studies that covered farmers' perceptions of salinity and land degradation issues in the south-western coastal part of Bangladesh (Abedin et al., 2014; Habiba et al., 2013; Rahman et al., 2017) , and rare in the south-eastern coastal region of Bangladesh.

2.3.2 Data sources and data collection methods

The primary data for this research was collected through semi-structured survey interview from January to April 2018. A follow-up in-field salinity measurement and a second survey were undertaken from February to April 2019. Human Research Ethics Approval (HREA) was sought and gained from the University of New England, Australia; Approval No. HE17-272.

A multistage sampling procedure was used to select the survey participants. The respective administrative units of Bangladesh from national to local level are: division, district, sub-district, union, and village (BBS, 2015). Sixty one farmers from two villages in Assasuni sub-district, and 48 farmers from two villages in Banskhali sub-district, were randomly selected for the face-to-face interviews using a semi-structured survey (Appendix 2.4). The relevant sub-district agriculture officer advised us to consider those villages where rice farmers were most affected by salinity in Boro season. Household heads were selected from the list of Boro season rice grower households provided. A similar type of sampling procedure was also followed by Hasan and Kumar (2020) who studied farmers' perceptions of climate change in coastal Bangladesh.

The survey questions were pre-tested and used to collect data from the selected farmers. The questions focused on several areas relating to farmers' perceptions of salinity trends in their field over the last 20 years. A series of open-ended questions were asked of each rice farmer, exploring:

- the perceived problems they encountered during Boro season rice cultivation;
- the most challenging problems during Boro rice cultivation;
- farmers' perception of the most salinity-sensitive growth stages of rice crops and their observations of plant responses at the salinity-sensitive stages; and

- farmers' adaptation strategies to address salinity problems in rice cultivation.

Following the semi-structured survey, farmers' perceptions of salinity levels, the effects of salinity on rice crops, and salinity adaptation strategies were examined by comparing in-field salinity measurements (i.e. measurements from nine spots in each crop field using a portable salinity meter) and the corresponding farmers' perceptions of the actual salinity (high or low) with the scientific interpretations of these salinity levels. Agronomic practices in these rice fields were also recorded in order to examine the suitability of farmers' adaptation strategies for overcoming the salinity problem. Similar methods were reported by Teshome et al. (2016), who also examined farmers' perceptions of land degradation issues through on-site field observation and informal discussions with the farmers. A total of 36 rice fields (22 from Assasuni sub-district and 14 from Banskali sub-district) were selected from earlier survey lists based on seedling transplanting time (early, late, mid-season). For this study, the transplanting times were categorized as follows: early transplanting from the third week of December to first week of January, mid-season transplanting from mid-January to the end of January, and late transplanting from the first week of February to mid-February. Similar transplanting periods for Boro season rice cultivation have been used by other researchers in the coastal areas of Bangladesh (Hamid et al., 2015). In-field salinity data and the corresponding farmers' perceptions of the salinity level (i.e. perceived to be high or low) were collected during two separate visits to the same rice fields to examine the variations in perceptions of actual salinity measurement. These salinity measured data from the farmers' fields were then classified according to the interpretation of salinity classes (i.e. ECe values), where $ECe < 8.0$ dS/m, were classified as low and $ECe \geq 8.0$ were classified as a high salinity level (SRDI, 2010). The salinity measurement procedures used were in accordance with the guidelines of the Soil Resources Development Institute (SRDI, 2010). Growth stages of rice crops were also recorded during in-field salinity measurement, as defined in the literature (Yoshida and Nagato, 2011). We recorded the growth phases as vegetative stage if the plants were between the seedling and tillering stages, and as reproductive if the plants were in

the booting, heading or flowering stages in the field. The schematic representation of the data collection methods used in this research is presented in Fig. 2.2.

2.3.4 Data analysis

All data collected was transcribed verbatim from Bengali into English by the lead author who is fluent in Bengali. The transcribed responses from the open-ended questions were

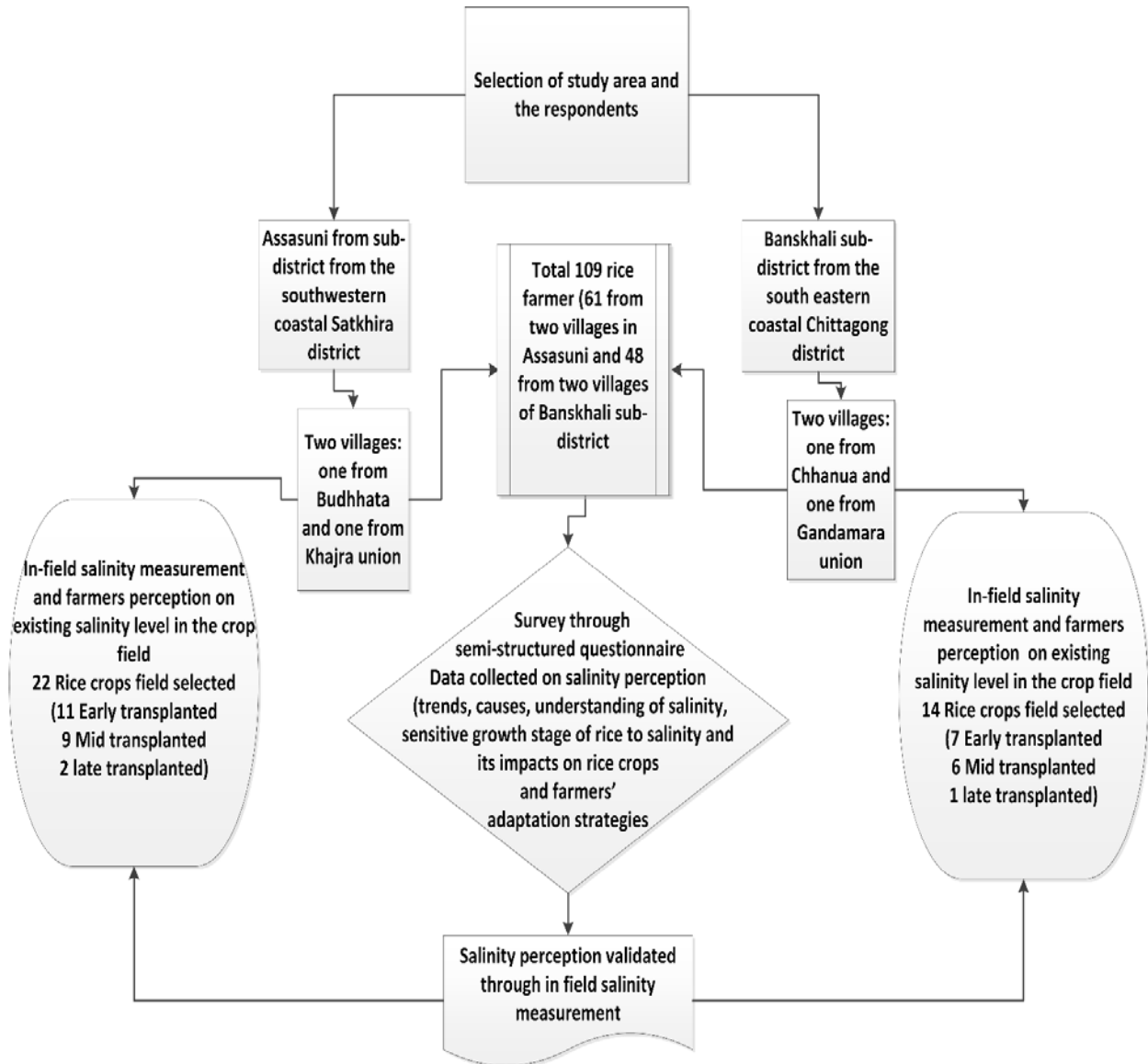


Fig. 2.2. Schematic representation of the data collection methods

categorized into common thematic responses by the lead author, hence avoiding the variation in interpretation that can occur with multiple coders. Each theme was coded with a number in order

to analyze the data using SPSS statistical software (Version 25) and R-studio (Version 1.1.383). Non-parametric chi-square tests were conducted for each of the demographic variables in order to test the mean differences of these variables in two study locations. The variables examined between locations were: age, educational qualifications, total farm size (owned land plus rented land), land ownership (owned land only), farming experience, monthly income, total rice area, and Boro season rice area. Farmers' perceptions of the context of salinization (e.g. trend of salinity over the year, causes of salinity development, sensitive stages of rice to salinity, effects of salinity at the sensitive stages and salinity adaptation strategies) were analyzed using cross-tab analysis, which allowed comparison of the farmers' perceptions (frequencies against each perceived category) in two separate locations. The definitions and code used for responses of farmers against each variable used in the cross-tab analysis are presented in (Appendix 2.5 and Appendix 2.6). Chi-square tests were conducted in order to examine whether the farmers' perceptions in the two study locations varied significantly in relation to each of the variables. Al-Amin et al. (2019) also used a similar test (chi-square) to examine the variations in farmers' perceptions of climate change.

We tested the normality of farmers' perceptions of the in-field salinity measurement data using the Shapiro-Wilk test. A Wilcoxon rank test was performed to examine the association between the farmer's perception and the literature in salinity level categorization (e.g. low or high) of the same salinity measured values. One-way ANOVA was conducted to examine the differences among the three transplanting times for Boro season rice crops in the farmers' fields. Post hoc analysis determined the differences between these three transplanting times in farmers' fields. Linear regression examined the effects of transplanting time, farmers' perceived salinity level at different growth stages of rice and the number of irrigation applications on the yield of rice in farmers' fields.

2.4 Results

2.4.1 Demographic characteristics of the participants

Table 2.1 depicts the demographic characteristics of the farmers interviewed in the study area. Educational qualifications were significantly different between the farmers in the two study locations. Farmers in Assasuni had at least two years more schooling than the farmers in

Banskhali. Total farm size was also significantly larger in Assasuni (1.2 ha) than in Banskhali (0.85 ha). Overall, twice as much land area per farm was under rice cultivation in Assasuni compared with Banskhali, particularly in Boro season. In terms of land ownership, the farmers in Assasuni owned significantly more land (0.74 ha) than those in Banskhali, who owned on average 0.45 ha. Monthly income was also significantly higher in Assasuni (BDT 11983) than in Banskhali (BDT 10730). The farmers in Banskhali were significantly older and more experienced than Assasuni farmers, with farming experience of 25 years and 24 years, respectively (Table 2.1).

Table 2.1. Demographic and socioeconomic characteristics of the rice farmers interviewed in Assasuni (SW) and Banskhali (SE) coastal areas of Bangladesh

Characteristics (unit of measurement)	Assasuni (n= 61)		Banskhali (n=48)		Chi-square test
	Mean	S.E.	Mean	S.E.	
Age	46.3	1.23	48.9	1.08	51.68***
Education (schooling yrs)	7.77	0.65	5.31	0.80	67.51***
Total farm size (ha)	1.2	0.82	0.85	0.54	66.59**
Land ownership (ha)	0.74	0.62	0.45	0.53	134.16***
Farming experience (yrs)	24.33	1.23	25.46	1.22	99.23***
Monthly income (BDT.)	11983	514.04	10730	514.19	104.67***
Total rice area (whole year) (ha)	1.2	0.68	0.6	0.35	102.62***
Boro season rice area (ha)	0.51	0.34	0.27	0.24	75.22***

** Significant at 5% and *** significant at 1% level of significance

Variations in educational qualifications according to different age categories over both study locations are presented in Table 2.2. Overall, the younger cohort of rice farmers (30-40 years of age) were better educated than the older farmers, who had a higher level of illiteracy, especially those in the oldest age categories (Table 2.2). The average rice farmer also had limited education and 37% could only sign (i.e. were unable to read or write).

Table 2.2. Variations in educational qualification according to age categories in coastal areas of Bangladesh (n=109)

Age group	Educational qualifications (% of the participants)								
	Illiterate	Can sign only	Primary school	High school	SSC*	HSC*	Diploma	Graduate	Post graduate
30-40	0.0	6.5	9.7	25.8	12.9	12.9	3.2	25.8	3.2
41-50	0.0	36.6	17.1	19.5	17.1	9.8	0.0	0.0	0.0
51-60	13.8	34.5	13.8	20.7	10.3	0.0	0.0	6.9	0.0
61-70	25.0	25.0	12.5	25.0	0.0	0.0	12.5	0.0	0.0

*SSC (Secondary school certificate; Year-10); HSC (Higher secondary certificate; Year-12)

2.4.2 Farmers' perceptions of the context of salinization in the coastal areas

Farmers' perceptions of salinity trends, past and current salinity levels in their field, and the causes of increased salinity in their field are presented in Table 2.3. There was a significant difference between the farmers from the two study locations in their perception of the causes of salinity ($\chi^2 = 86.44$, $P < 0.05$). However, no significant difference was detected in the rice farmers' perception of salinity trends between the two locations. Regardless of their locality, 87.2% of the surveyed farmers reported that salinity had increased in their field, while 9.2% said salinity had decreased, and only 3.7% said there had been no change in salinity in their fields over the last 20 years. Similarly, irrespective of location, most of the farmers perceived the current salinity level as high (88.9%) and a small percentage of farmers thought it was currently low (10.1%). This is in stark contrast to farmers' perceptions of salinity levels in their fields 20 years ago, when asked at that point, only 15.6% perceived salinity was high and 84.4% perceived it was low. In Banskhal, 53.7% of participants were of the opinion that increases in salt farming were the main cause of salinity development, 29.3% stated that it was due to cyclones, along with increased salt farming, and 17.1% reported erosion of embankments as the cause of salinization. In contrast, the majority of rice farmers (70.4%) in Assasuni reported increased shrimp farming as the cause of the rise in salinity, while 16.7% identified siltation of the river and increased shrimp farming as the cause of salinity development. Only a small proportion of rice farmers surveyed identified cyclones and erosion of embankments as the causes of increased salinity.

Table 2.3. Trends and causes of salinity according to farmers' perception in the Assasuni (SW) and Banskhali (SE) coastal areas of Bangladesh

Farmers' perception of salinity	(% of the participants)		
	Assasuni (N=61)	Banskhali (N=48)	Overall (N=109)
Trend of salinity in their crop field over the last 20 years			
Salinity increased	88.8	85.4	87.2
Salinity decreased	6.6	12.5	9.2
No changes in salinity	4.9	2.1	3.7
Chi-square test	1.65 (p=0.43)		
Current salinity level in their field			
High	91.8	87.8	88.9
Low	8.2	12.5	10.1
Chi-square test	0.54 (p=0.45)		
Salinity level in their field 20 years ago			
High	14.8	16.7	15.6
Low	85.2	83.3	84.4
Chi-square test	0.07 (P=0.78)		
Causes of increased salinity			
Cyclones and increased salt farm	0.0	29.3	12.6
Erosion of embankment	5.6	17.1	10.5
Cyclones and increased shrimp farm	3.7	0.0	2.1
Cyclones and siltation of river	1.9	0.0	1.1
Siltation of river	1.9	0.0	1.1
Siltation of river and increased shrimp farm	16.7	0.0	9.5
Increased shrimp farm	70.4	0.0	40.0
Increased salt farming	0.0	53.7	23.2
Chi-square-test	6.44 (P=0.001)		

P<0.001 denotes significant at 1% level of significance.

2.4.3 Farmers' perceptions of salinity problems in relation to Boro season rice cultivation

Farmers identified a variety of problems during the Boro season rice cultivation, including, from most important to least important: salinity, scarcity of irrigation water, insects and diseases, waterlogging, erratic rainfall, iron in water, access to electricity to operate irrigation pumps, high input cost, and lack of manual labor. A significant difference was also detected in the ranking of these problems between the farmers in the two study locations (Appendix 2.7). However, in both study locations, a high proportion of farmers (67.9%), perceived salinity, as the most challenging

problem during Boro rice cultivation, followed by scarcity of irrigation water (13.8%), and the two issues combined (18.3%) (Fig. 2.3).

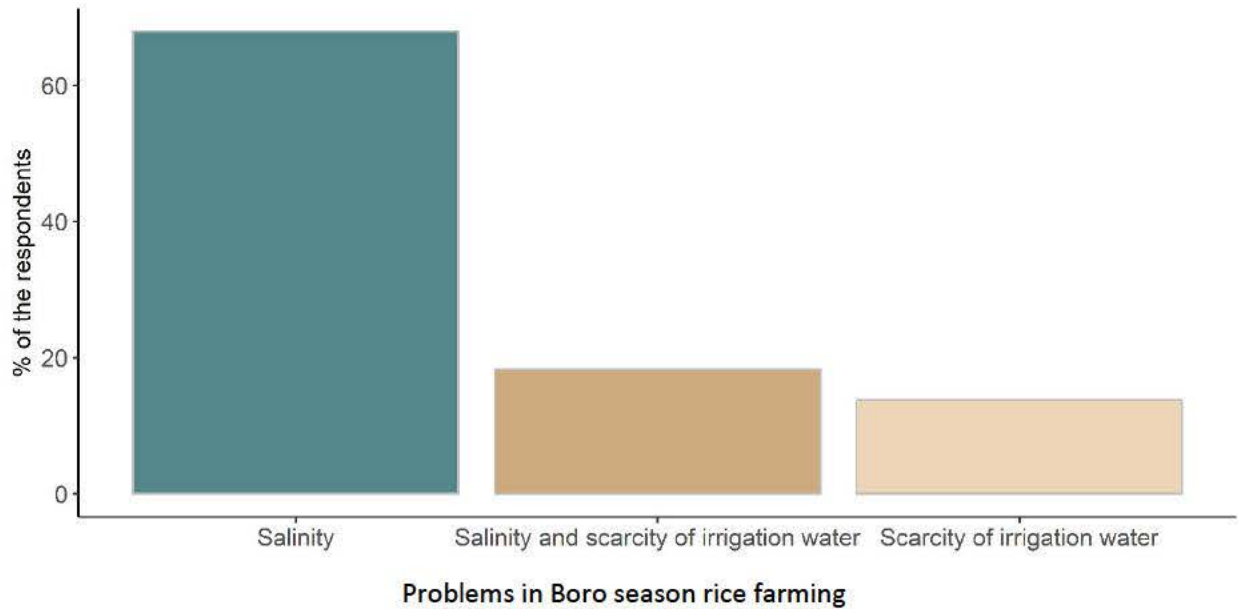


Fig. 2.3. Farmers’ perceptions of the most challenging problems during Boro season rice cultivation in the coastal areas of Bangladesh

The most salinity-sensitive growth stages of the rice plant, as identified by the farmers, included both vegetative (seedling, tillering) and reproductive (booting, heading, flowering) stages. In Assasuni, 50.8% of rice farmers considered the booting stage as the most sensitive to the salinity problem, with fewer farmers mentioning the flowering, seedling and heading stages (10%, 11% and 28% respectively), as vulnerable to the salinity problem (Fig. 2.4). In Banskhali, similar results were recorded as farmers mentioned booting stage of the rice plant as sensitive to salinity (46%) (Fig. 2.4). Across both study locations, 89% of respondents in Banskhali and 90% of respondents in Assasuni identified the reproductive stages of rice as the most sensitive to the salinity problem (Fig. 2.4). Farmers’ understanding and identification of different growth phases of rice plant is presented in (Appendix 2.8).

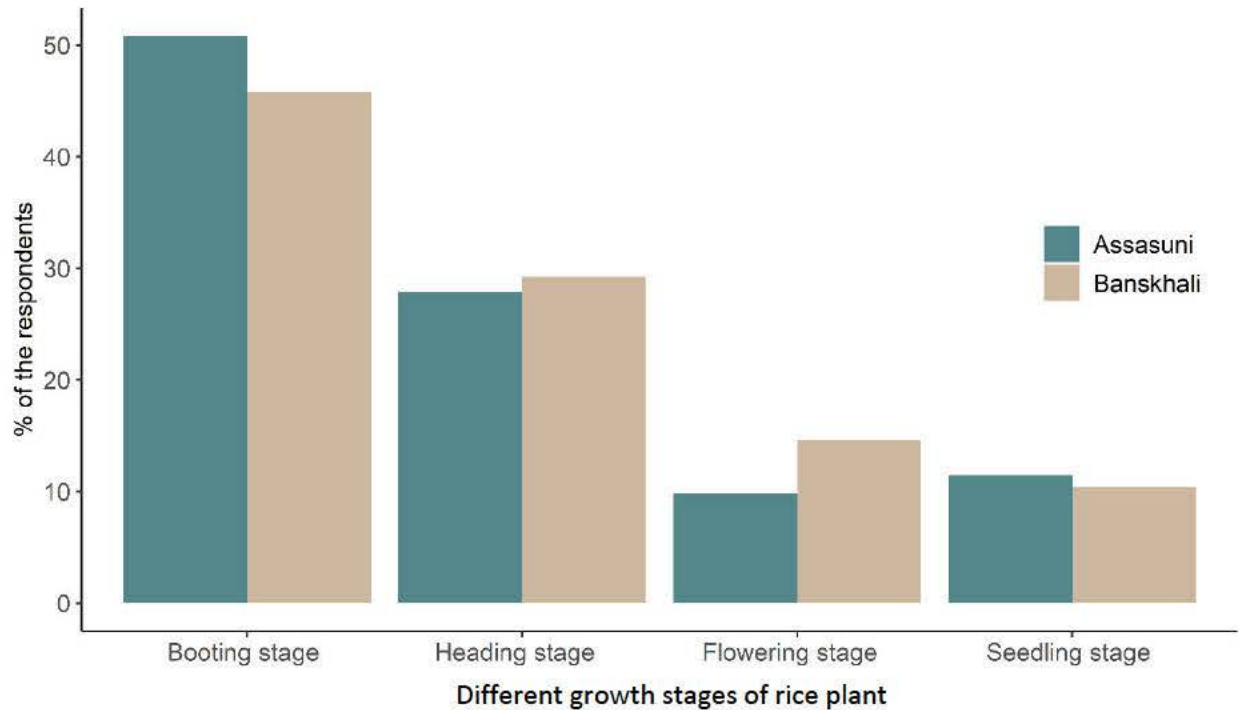


Fig. 2.4. Farmers' perception of the most salinity-sensitive growth stages of the rice plant from household survey in Assasuni (SW) and Banskhalı (SE) coastal areas of Bangladesh

The majority of the farmers surveyed in the two locations (72.5%) mentioned that they observed reduced heading (less panicle extrusion), panicles turning white from the top, and unfilled grain as a consequence of salinity during the reproductive stages. In contrast, 11.9% of rice farmers reported root spoilage and unfilled grain, and 15.6% of them mentioned plants drying from the top as a major effect of salinity during the reproductive stages (Table 2.4). Farmers' understanding of salinity effects (symptoms) on rice plants during the reproductive stages is presented in (Appendix 2.9).

Table 2.4. Farmers’ perception of salinity effects at vulnerable growth stage of the rice plant in Assasuni (SW) and Banskhali (SE) coastal areas of Bangladesh

Locations	% of the participants		
	Less heading (less panicle extrusion), panicle turns into white from the top, unfilled grain	Root spoilage, unfilled grain	Plants dry up from the top and looks like straw
Assasuni (n= 61)	68.9	21.3	9.8
Banskhali (n=48)	77.1	0.0	22.9
All locations (n=109)	72.5	11.9	15.6
Chi-square test	13.42, P=0.001		

P<0.001 denotes significant at 1% level of significance.

2.4.4 Farmers’ adaptation strategies to address salinity problems in the Boro rice growing season

Farmers in the study area of coastal Bangladesh were already applying different adaptation strategies to address the salinity problem during Boro season rice cultivation. In Assasuni, majority of the rice farmers (57.4%) were transplanting seedlings early and using irrigation, while about a third (34.4%) were using a salt-tolerant rice variety and applying irrigation. The proportion of farmers who were applying irrigation water alone to address salinity was 8.2% (Table 2.5). In contrast, in Banskhali, a higher proportion of the rice farmers surveyed (79.2%) were transplanting seedlings early and applying irrigation to overcome the salinity problem. A smaller proportion of these rice farmers (16.7%) were using a salt-tolerant rice variety and applying irrigation, while 4.2% were only applying irrigation to address salinity. Averaging across both locations, 67% of the rice farmers transplanted seedlings early and applied irrigation, 26.6% used a salt tolerant rice variety and irrigation, and 6.4% only applied irrigation to address salinity (Table 2.5). However, the choice of salt-tolerant rice varieties significantly varied across the coastal study locations ($\chi^2 = 36.87$; P=0.001). Across both locations, approximately 41% of the farmers surveyed used BRRI³ and BINA⁴ released rice varieties (BRRI Dhan47, BRRI Dhan67,

³ Bangladesh Rice Research Institute

⁴ Bangladesh Institute of Nuclear Agriculture

Bina Dhan8, Bina Dhan10), 47% mentioned hybrid rice varieties (Hira, Mitali, IT, SL8, Shokti, Tej), and 12% of rice farmers stated that they used a local variety (Gordaan) (Appendix 2.10).

Table 2.5. Farmers’ adaptation strategies for salinity problems in Boro season rice cultivation in Assasuni (SW) and Banskhali (SE) coastal areas of Bangladesh

Farmers’ adaptation strategies	Assasuni (n=61)		Banskhali (n=48)		Overall (n=109)	
	No.	%	No.	%	No.	%
Early transplanting and apply irrigation water	35	57.4	38	79.2	73	67.0
Use of salt tolerant rice varieties and apply irrigation	21	34.4	8	16.7	29	26.6
Apply irrigation	5	8.2	2	4.2	7	6.4
Chi-square test	5.76, p = 0.05					

P=0.05 denotes significant at 10% level of significance.

2.4.5 Consistency of farmers’ perception of salinity and adaptation strategies with scientific information

Of the salinity measurements at the farmers’ field, where farmers perceived salinity to be high (35% of observations) only 22% of those same measures were categorized as high salinity according to scientific interpretation (Fig. 2.5). The Wilcoxon rank test of farmers’ perception and literature-based salinity categorizations of the same salinity measured values found a non-significant association. However, there was a significant difference in defining salinity classification (at high levels) between the farmers’ perception and literature (Fig. 2.5). Out of 36 farmers’ rice fields, measured for salinity, 42% and 59% were planted with salt-tolerant varieties and non-saline tolerant varieties respectively. Under high and low salinity perceptions, farmers’ preferences for using salt tolerant varieties showed a significant association ($\chi^2 = 3.23$; P=0.07).

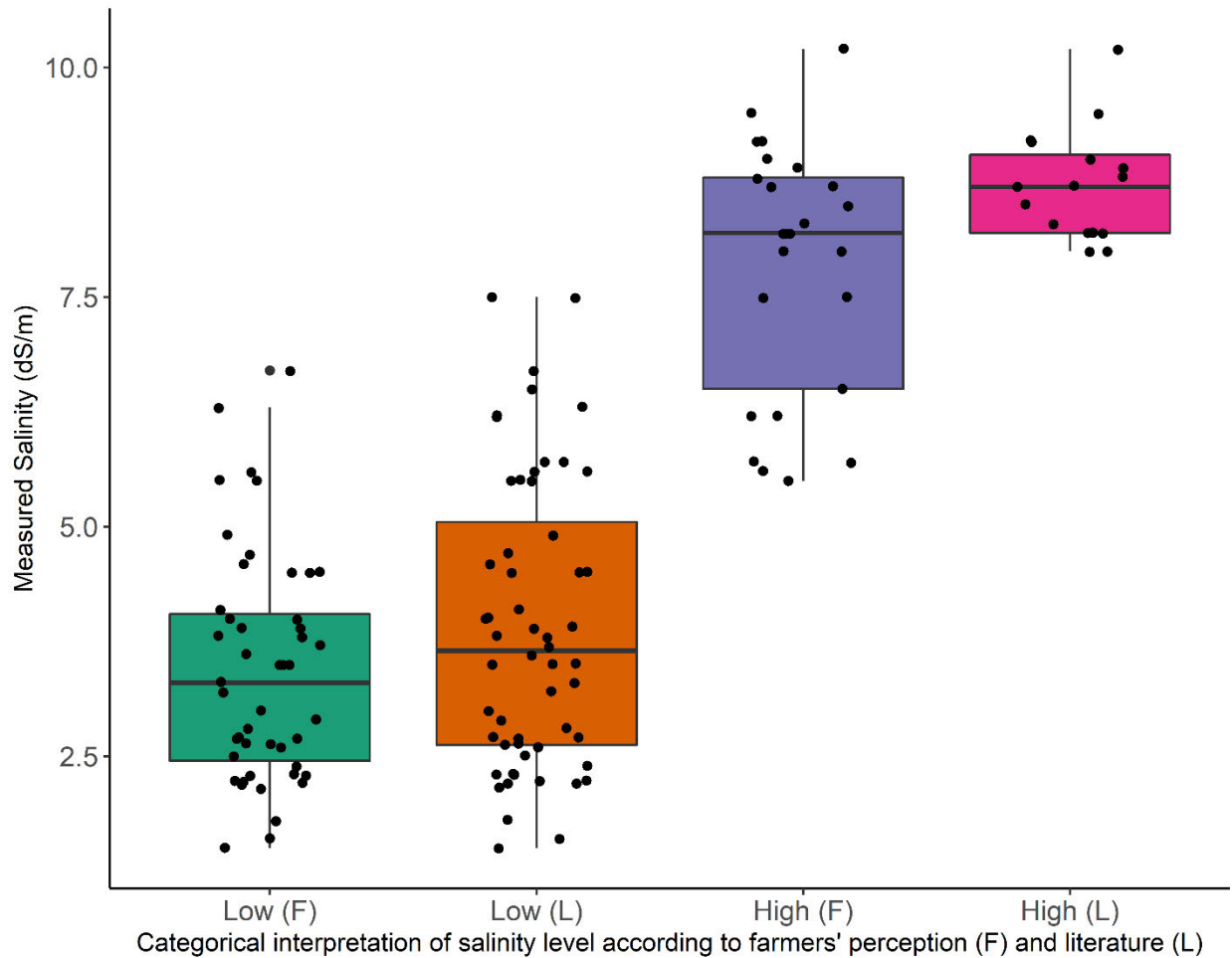


Fig. 2.5. In-field measurement of salinity (EC, dS/m) in farmers' field during Boro rice-growing season (February to April, 2019). In-field measures of salinity were categorized according to farmers' perception and scientific interpretation of the High or Low salinity category. Individual dots represent an average of nine observations (e.g. salinity measurement (EC) taken in each field). Each dot also represent farmers' perception (high or low) and literature interpretation (high or low) of a measured salinity

Where fields were perceived by farmers to have a low salinity level, 34% grew salt-tolerant and 66% grew non-salt tolerant varieties. In contrast, where fields were perceived by farmers to be of high salinity, 56% grew salt-tolerant variety and 44% grew non-salt tolerant varieties (Appendix 2.11). In fields where salinity levels were measured, 50%, 42% and 8% of measures were from early, mid and late transplanted fields respectively. One-way ANOVA showed a significant difference between the transplanting time of Boro season rice in farmers' fields ($P < 0.001$) and recorded salinity levels, with higher salinity levels in mid-transplanted rice fields compared to early or late transplanted rice fields (Fig. 2.6). In the early-transplanted fields,

most of the recorded salinity during the vegetative and the reproductive growth stages of rice were low. However, in mid-transplanted fields, higher salinity was recorded in both the vegetative and reproductive growth stages of the rice crop (Fig. 2.6). Linear regression results also indicated that the yield in the farmers' field was significantly affected by the transplanting time, salinity level, and number of irrigation applications ($R^2=0.671$; $P<0.001$). However, no significant yield differences were observed in the farmers' fields between salt-tolerant and non-salt tolerant rice varieties.

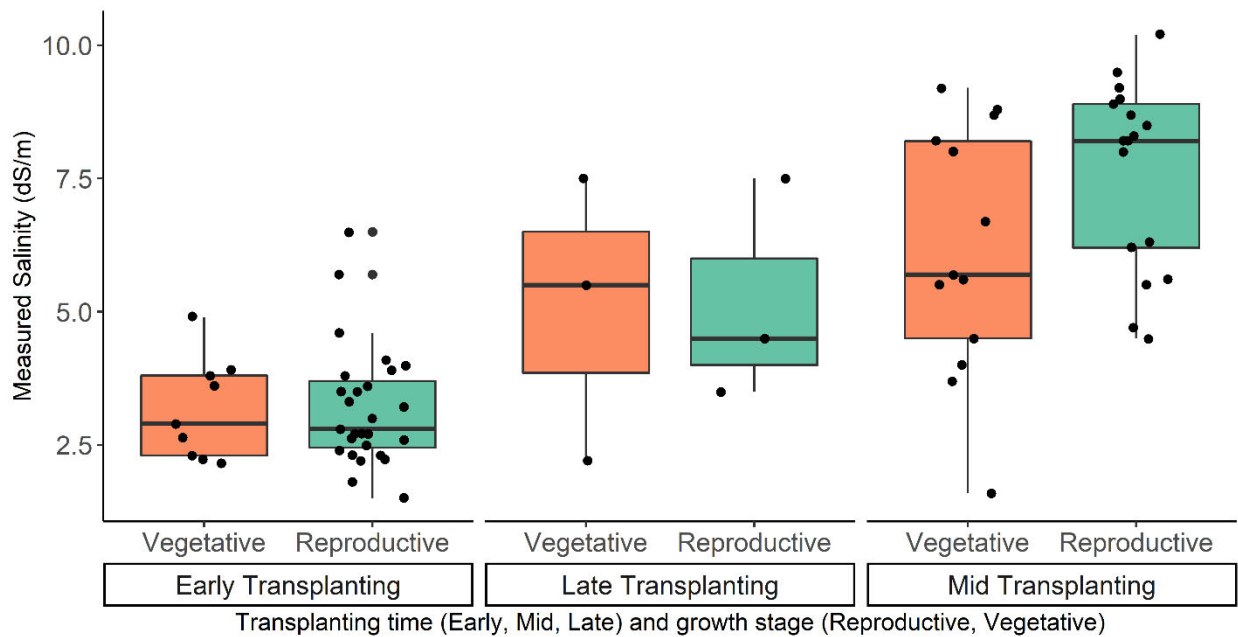


Fig. 2.6. Recorded salinity levels (dS/m) at different growth stages of rice plant in farmers' field transplanted at different time (Early, late and mid transplanting). Individual dots represent an average of nine observations (e.g. salinity measurement (EC) taken in each field) in y-axis

2.5 Discussion

This study examined farmers' perceptions of salinity and adaptation strategies for Boro season rice cultivation in two distal coastal areas of Bangladesh. Firstly, we discuss farmers' perceptions of the trends and causes of salinity. Farmer's perceptions of salinity level were compared to in-field salinity measurements, with the same measurement also categorized according to scientific interpretation. The purpose was to ascertain at what measured salinity farmers perceived it to be high or low and how it compared to scientific categorization.

Furthermore, under fields with high or low salinity levels, we discuss the suitability of farmers' adaptation strategies, the implications of farmers' perceptions of salinity and their responses to the salinity problem in relation to policy initiatives.

2.5.1 Farmers' perceptions of salinity and its causes

Previous studies have suggested that a higher level of education, and greater age have a positive, significant influence on farmers' perceptions and awareness of land degradation in relation to crop production systems (Alam et al., 2016; Uddin et al., 2017). Our study showed that the majority of rice farmers (87%), despite differences in socio-economic status and age, reported increasing salinity over time and perceived current salinity in their fields as being higher than it was 20 years ago. Farmers' perceptions of salinity trends and current salinity levels in their fields did not vary significantly between locations, with all farmers saying that current salinity levels were high (Table 2.3). This outcome of a perceived increasing salinity trend is consistent with other studies (Hossain et al., 2018) where a similar perception of salinity was reported. However, these studies only examined farmers' perceptions of salinity in the south-western coastal region; our study examined farmers' perceptions of salinity in both the south-eastern and south-western coastal regions of Bangladesh. Natural disasters (e.g. frequent storm surges, tidal flooding and prolonged drought), and human interventions (e.g. shrimp farming and salt cultivation, unplanned embankments, siltation of river) were perceived as causes of salinization in both regions. Studies conducted by Hossain et al. (2018) in the south-western coastal areas of Bangladesh have also indicated similar findings. Our results showed that the perceived causes of salinity in the two study locations were emphasized differently. In the south-west, farmers perceived shrimp farming as a major cause of increased salinity whereas in south-eastern locations farmers attributed increased salinity to both salt and shrimp farming. The differences in the perceived causes of salinity in the study area might be due to the fact that local people's perceptions of disasters were subjective and constructed socially (Wachinger et al., 2013). In addition, it can also be argued that people's perceptions of any disaster, are also influenced by surrounding land uses that may impact on their livelihood (Below et al., 2015). The literature also suggests that shrimp farming in the south-western and salt cultivation in the south-eastern coastal region have increased sharply since the 1980s which has exacerbated the salinity problem

in nearby rice fields (Al Mamun et al., 2014; Hossain et al., 2016). This land use change has created social conflicts among different resource user groups, as conversion of land to saline water shrimp and salt farming is detrimental to rice cultivation (Islam, 2006; Parvin et al., 2017). Hence, limited rice farming options impacted by shrimp and salt farming, which might be a reason for the difference in the perceived causes of increased salinity between farmers in the two study locations. Moreover, our study shows that farmers in both study locations perceived erosion of embankments from cyclones as a cause of salinity intrusion. However, it was farmers in the south-eastern region who were more concerned with these causes of increased salinity (Table 2.3). Our findings are consistent with other research (Bempah and Øyhus, 2017) showing that people's degree of exposure to disaster affects their levels of concern about the disaster. Historical data also suggests that cyclonic storms and coastal flooding are more prevalent in the south-eastern coastal regions of Bangladesh (BMD, 2019). However, it is also reported that greater salinity intrusion, and low productivity of rice crops has motivated farmers to convert their land to shrimp farming (Amin et al., 2011). This intricate balance between rice farming and other land uses requires further study of salinity perception and land use change involving all stakeholders (i.e. rice, shrimp, and salt farmers). To accommodate diverse land use options in coastal areas, a suitability-based land zoning has also been proposed by several studies (Islam, 2006), as well as by the Bangladesh government to determine the best use of land through zoning (LandAC, 2019). For relevant stakeholder input, their involvement in identifying potential land use and sustainable use of resources is also required.

2.5.2 Farmers' understanding of the salinity problem and effects of salinity on Boro season rice

In Boro season rice cultivation, our study revealed that farmers perceived increased salinity and scarcity of irrigation water as the most challenging problems (Fig. 2.3). Other studies have also discussed the similar difficulty nature of rice cultivation under saline conditions in the coastal areas of Bangladesh (Haque, 2006; Shelley et al., 2016). However, the literature suggests that decreased fresh water availability and lower precipitation could worsen salinity problems (Hossain et al., 2016), which can ultimately affect rice cultivation in the coastal areas of Bangladesh.

This study has shown that the perceived effects of higher salinity during the reproductive stages of the rice plant (i.e. perceived as the most sensitive stages) (Fig.4) resulted in less heading (panicle extrusion) in rice and subsequently caused 'severe' yield reductions (Table 4). Farmers' perceptions in this study were confirmed to be consistent with agronomic research into salinity-sensitive stages of rice, which reached similar conclusions (Abbas et al., 2015; Hasanuzzaman et al., 2009). Moreover, our study found that farmers were more concerned about the effects of high salinity on early reproductive growth stages (Fig. 2.4, Table 2.4). Despite the fact that rice plants are also sensitive to salinity during the vegetative (germination to seedling) stages (Grattan et al., 2002; Islam and Karim, 2010), this study has shown that farmers are less concerned about salinity effects at the seedling stage. Indeed, farmers' perceptions aligned with the recorded temporal changes in salinity that increased in March and peaked in April to May (Clarke et al., 2015), parallel with the reproductive growth period (March to April) of Boro season rice (Shelley et al., 2016) in the coastal areas of Bangladesh. Thus, this study shows that farmers' perception of salinity problems in relation to rice cultivation was based on their practical observation of plant growth over the Boro rice growing season in salt-affected fields. This finding is also consistent with previous reporting that peoples' perceptions of disasters are shaped by their experiences of being affected by such disasters (Adger et al., 2009; Mertz et al., 2009). This evidence of farmers' perceptions of salinity in relation to its effects on different stages of rice crops, along with the scientific observations, indicates a nuanced recognition of farmers' perceptions of salinity problems in rice cultivation. However, farmers' perceived vulnerability to salinity in rice might vary depending on the temporal and spatial trend of the salinity problem and its impact on rice crop development in other coastal rice growing areas in the world.

2.5.3 Potential of farmers' perceptions of salinity and current adaptation strategies for the salinity management initiatives

This study showed a significant difference in terms of high salinity level classification between the farmers' perception and scientific interpretation of the same measured salinity (Fig. 2.5), which indicates that the farmers' perceived a field affected by high salinity at a lower EC reading than the scientific interpretation of salinity level. This difference in understanding of perceived salinity risk level is also consistent with the study of Ho et al. (2008), who suggested a

gap in understanding of the disaster risks between the local people and experts. The adaptation strategies (e.g. early transplanting, use of salt-tolerant varieties, irrigation application) by farmers to address the salinity problem in Boro season rice cultivation (Table 2.5) revealed by this study are also consistent with reported adaptations to salinity-affected coastal areas in other countries (Can, 2016; Kotb et al., 2000; Maeght et al., 2005).

In relation to adaptation responses to the salinity problem, the results showed that a high proportion of farmers transplanted seedlings early and combined this with irrigation measures (Table 2.5). Moreover, our results from in-field salinity measurement and corresponding farmers' perceptions showed that rice fields, which were transplanted early, potentially avoided high salinity during sensitive growth stages of rice in contrast to mid-transplanted fields (Fig. 2.6). Thus, this adaptation responses of the farmers were pre-emptive of when salinity was most likely to have adverse impacts on rice plant growth (i.e. the reproductive growth stage). Adjustment of transplanting time was also reported as effective in managing salinity problems in rice cultivation in Vietnam (Can, 2016). Our study has demonstrated that farmers' salinity perceptions and adaptation strategies are supported by scientific observations. Indeed, the reproductive phase of the rice plant generally starts 90-95 days after germination and continues for the next 30-35 days (Yoshida and Nagato, 2011). Thus, early transplanting by farmers' might potentially avoid salinity effects at sensitive reproductive stages during the month of April when salinity in the study area generally reaches its highest level (Clarke et al., 2015). This finding reflects the potential of farmers' salinity perceptions to be used as an effective local knowledge-based adaptation strategy, which might be low cost and more locally acceptable, as it has evolved from local practices.

2.6 Policy implications of farmers' perceptions for salinity management

Most of the recent appraisals under policy initiatives in Bangladesh (e.g. NAPA, 2005; BCCSAP, 2009; PPB, 2012; NSDS, 2013; and NAP, 2018) have been specifically designed to address sustainable agricultural production to achieve the SDGs. The formulation of these policy documents has involved stakeholder participation at national (e.g. NSDS, PPB, NAP), local, regional and national level (e.g. NAPA, BCCSAP) with the aim of identifying the key vulnerabilities of the agricultural sector with special attention to the coastal areas of the country. In all these

policy documents, salinity in coastal areas has been recognized as one of the most significant risks to achieving sustainable rice production and meeting the country's SDGs.

Despite local-level stakeholders' participation during the problem-identification phase in formulating these policies, the relevant adaptation measures have largely been constructed at the national level. Therefore, farmers' perceptions of salinity and local-level salinity adaptation measures have been largely ignored in the policy formulation process. For example, BCCSAP and NAPA have prioritized a number of projects, and PPB, NSDS, and NAP have devoted specific chapter emphasizing breeding and extension of salt-tolerant crop varieties, crop diversification, and strengthening of polders and embankments to combat salinization in coastal regions of Bangladesh (BCCSAP, 2009; NAP, 2018; NAPA, 2009; NSDS, 2013). Consequently, a number of salt-tolerant rice varieties have been developed and promoted by governmental organizations. However, while these varieties can tolerate high salinity (e.g. up to 12.0 dS/m) during the vegetative stage (i.e. seedling to tillering) (BINA, 2019; BRRI, 2019), they can only tolerate a salinity level of up to 8.0 dS/m during the reproductive stage, when salinity levels can be in excess of this level in the study area. Given that farmers perceived the reproductive stage of the rice crop as the most sensitive to salinity problem, which also is when high salinity levels are expected in the coastal areas then future breeding initiatives of salt-tolerant rice varieties need to focus on higher salt tolerance at the reproductive stages.

Furthermore, farmers perceived both natural disasters (e.g. cyclones, coastal flooding) and human interventions (shrimp and salt cultivation) as the leading causes of salinity development. Thus, reliance on engineering solutions (e.g. construction of polders, strengthening embankments) (BCCSAP, 2009; GED, 2012; NAPA, 2009) as promoted by the government might prevent salt water inundation from storm surges. However, such measures would largely be ineffective in situations where land use change is an emerging issue (e.g. from rice to shrimp and salt farming) and saline water is required (Al Mamun et al., 2014; Barai et al., 2019). Thus, our study also signifies the importance of integrated policy and research involving all farmer groups (i.e. rice, shrimp, and salt farmers) to address the needs of all farmers at the local level as well as meeting the SDGs at the national level.

A significant difference was shown between farmers' perception and scientific interpretation in defining high salinity, which implies that farmers' might observe salinity damage in rice crops at lower salinity level than the literature suggests. To align with farmers' perceived concerns about the salinity problem, salt-tolerant variety development trials should be conducted in their fields, and especially in those fields affected by high salinity. This partnership would be more likely to produce rice varieties that are well-adapted to local conditions, and more adoptable by local farmers.

Our results also revealed that farmers' adaptation practices (e.g. early transplanting) potentially avoided periods of high salinity prevalence during the reproductive growth stages of rice. Thus, in terms of extension policy, farmers' strategies that have potential merit in adapting to salinity could be replicated in other coastal areas of Bangladesh to demonstrate their effectiveness. Extensive training programs with visual aids demonstrating the salinity sensitive stages of rice crops and the effects of salinity at these growth stages could also improve awareness of the salinity problem among the rice growers.

2.7 Conclusions

Our study revealed that farmers in the coastal areas of Bangladesh were aware of salinization and the leading causes of salinity. This study has shown there was a significant difference of defining high salinity between the farmers' perceptions and scientific literature. Farmers' understanding of the salinity problem in relation to rice cultivation influenced their actions to adapt to this problem. Most of the rice farmers in the study area undertook early transplanting and applied irrigation to overcome salinity problems in Boro season rice cultivation. These adaptation strategies might not prevent salinity from worsening, but can potentially secure rice production by avoiding more saline periods. Farmers' perceptions and their actions in response to a slow growing disaster (i.e. salinity) also makes a distinct contribution to the disaster management literature, which often concentrates on high profile and acute disasters (e.g. floods, earthquakes and cyclones). This study could be replicated to address similar disaster risk (e.g. drought, flash flood) management issues in the agricultural sector around the world.

The lessons learned from our study could be useful in understanding the complex and difficult process of salinity adaptation in coastal Bangladesh. Incorporating farmers' perceptions

and concerns into policy would guide and shape future research, extension activities and long-term adaptation planning which ultimately contribute in achieving the Sustainable Development Goals (SDGs): eradication of poverty (SDG-1), ensuring food and nutrition security (SDG-2) and maintaining good health for all people (SDG-3).

The availability of irrigation water was also perceived as a problem by farmers and needs further investigation involving all stakeholders in order to understand their local preferences to combat salinity problems in the coastal areas. This study only considered Boro season rice cultivation as a case for salinity perceptions and adaptation, which is one of the components of food security. Future study needs to consider overall livelihood context (e.g. social-ecological) of salinity perceptions and adaptation for better understanding of food security in coastal areas of Bangladesh.

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Chapter 3

Context of salinization and adaptation preferences in the coastal areas of Bangladesh: Bringing together farmers' salinity perspectives into policy to achieve SDGs

This paper has been submitted to the Journal of Land Degradation & Development in a Special Issue "Climate Change and Land Degradation" and it is under review

It is presented here with the original contents.

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3.1 Abstract

The increasing salinization of coastal areas of Bangladesh reduces options for rice intensification but offers a suitable environment for shrimp and salt farming. Under these contested land use settings, adaptation decisions to address salinity require an understanding of the salinity perspectives of all farmer types. Primary data was collected from randomly selected rice, shrimp and salt farmers in two coastal sub-districts through semi-structured interviews at household level. Key informant interviews (KIIs) with personnel from research and extension organisations from different levels (e.g. national and local), and focus group discussions (FGDs) with farmers were also conducted to complement the survey results. SPSS and NVivo software used to analyse the survey and KIIs, FGDs data respectively. Results revealed that the salinity perceptions among the various types of farmer differed. While the majority of rice farmers (87%) perceived increased salinity, just over half of the salt and shrimp farmers perceived that salinity has decreased over the past 20 years. Most rice farmers (62%) perceived anthropogenic factors as the main cause of increased salinity, while the majority of shrimp and salt farmers focused more on natural factors. Rice farmers perceived under saline conditions a yield loss (42%), followed by less income (30%). In contrast, shrimp farmers (70%) and salt farmers (55%) perceived production gains when high salinity prevailed. Rice farmers' adaptation preferences to cope with salinity is development of salinity-tolerant rice varieties that have greater tolerance at the reproductive stages, while shrimp and salt farmers' preferences are engineering-based solutions. Thus, research and extension services on integrated coastal resources management need to consider all livelihood perspectives, as this approach could accelerate the pace of achieving the SDGs (i.e.. SDG-1, SDG-2 and SDG-3).

Key words: Coastal areas, livelihoods, salinity perceptions, adaptation preferences

3.2 Introduction

Coastal saline areas generate substantial ecosystem services that provide livelihood options for thousands of millions of people, particularly in the developing regions of the world (Visbeck et al., 2014). These regions are undergoing ever-changing biophysical conditions and impulsive socioeconomic development (Betcherman and Marschke, 2016). Moreover, the increasing population and competing demands for coastal resources present urgent challenges to those policymakers responsible for adaptation planning to address the sustainable development agenda (Neumann et al., 2017). In addition, climate change-induced natural disasters pose significant threats that make these coastal areas vulnerable to environmental stresses (Dessai et al., 2009; Lempert and Groves, 2010). The coastal areas of Bangladesh, which are some of the most vulnerable regions of the world (Yohe et al., 2006), are also exposed to repeated natural disasters (Khan et al., 2015; Talukder and Saifuzzaman, 2016). Among the disasters, salinization is the most opaque in its origins and continuing risk factors, with varying input from both natural and anthropogenic drivers (Hossain et al., 2018a). Salinization also exhibits highly variable temporal and spatial stochastic variations (Clarke et al., 2015), and affects coastal livelihoods in diverse ways (Lázár et al., 2015). Hence, salinity is considered as one of the greatest challenges for sustaining agricultural productivity in the coastal areas (Kabir et al., 2016; Wassmann et al., 2009), and is placing increasing pressure on the sustainability of agricultural productivity, further threatening the function of ecosystem services (Flörke et al., 2019). Despite these negative consequences on agriculture and biodiversity, coastal saline environments offer opportunities for other livelihoods such as shrimp aquaculture and salt farming, as they are not adversely affected by salinity (Lázár et al., 2015). Thus, it is imperative to have comprehensive adaptation planning that presents various alternatives that reflect the diverse preferences of all farming groups affected by the salinization process (Haasnoot et al., 2013; Herman et al., 2015; Kwakkel et al., 2016). Efficient adaptation planning to combat the salinization problem will explicitly trigger the potential of the coastal areas to achieve the sustainable development goals (SDGs) of no poverty (SDG-1), zero hunger (SDG-2) through proper and integrated utilisation of these resources (Hussain et al., 2018; Islam and Shamsuddoha, 2018).

To achieve the SDG targets, the coastal areas of Bangladesh offer significant potential as these areas occupy around 30% of the total land area of the country (SRDI, 2010), and are characterised by diversified land use opportunities (MoA, 2013). Sustainability in coastal resource utilisation would be achieved by recognising all the livelihood options that the coastal environment offers to the people living there, as well as understanding the diverse perspectives of all types of farmers.

Three major livelihood options exist in the coastal areas of Bangladesh: cropping, shrimp aquaculture and salt farming. Until the 1970s, rice cropping in coastal environments was dominated by monsoon season (Aman season) rice cultivation; however, in the 1970s, with the adoption of irrigation technologies and the development of modern, high-yielding rice varieties, a new cropping opportunity emerged in the dry season (Boro season) that significantly increased rice production (Ahmed and Diana, 2015). Unfortunately, widespread adoption of dry season rice cultivation in the coastal areas did not occur as expected due to increasing salinization (Rahman et al., 2011; Szabo et al., 2016). The biggest breakthrough came in 2006 with the development of salt-tolerant rice varieties that were seen as having the potential to increase the area sown to dry season rice in the coastal areas (Islam and Gregorio, 2013), and influenced policymakers to adopt saline tolerant rice varieties development as an adaptation planning to adapt salinity problem. However, these varieties have a certain limitations to cope with salinity stress during the reproductive stages, which also coincide with the period of high salinity in the coastal areas (Clarke et al., 2015). In addition, the scarcity of fresh water for irrigation is an issue that has emerged along with the salinity problem, and which might create further challenges in sustaining dry season rice cultivation (Islam et al., 2020; Rahman et al., 2017). Thus, a number of challenges have emerged for sustaining rice productivity, including increasing salinity threats and fresh water scarcity issues, which could further limit the expansion of dry season rice cultivation.

In contrast, shrimp and salt farming, which have been practised for hundreds of years in the coastal environment and were well established before the inception of dry season rice cultivation in the coastal areas, do not require fresh water, and indeed use brackish water (Al Mamun et al., 2014; Datta et al., 2010; Pokrant, 2014). These farming enterprises thus have encroached into previous rice cropping areas in the coastal regions of Bangladesh due to the

suitable sub-tropical climate and easy access to tidal saline water (Ahmed, 2013; Ahmed et al., 2010; Ahmed and Diana, 2015; Bagchi and Jha, 2011; Pokrant, 2014). Furthermore, these fast-growing farming enterprises contribute to the socioeconomic status of the local people and society in general through employment and enhancement of household incomes (Al Mamun et al., 2014; BSCIC, 2020; FRSS, 2018). However, once land has been developed for shrimp or salt farming, it no longer offers a viable option for rice farming.

Thus, adaptation decisions that can address the salinization problem in the coastal areas of Bangladesh are increasingly become complicated, as this problem results in various farming systems being affected in diverse ways, as well as policymakers face contested solutions (Herman et al., 2015; Kwakkel et al., 2010). For example, salinization squeezes the options for rice intensification while offering a suitable environment for shrimp and salt farming (Lázár et al., 2015). Similarly, different levels of government (e.g. the Ministry of Agriculture, Ministry of Fisheries and Livestock) favour certain solutions to the salinity issue: promoting the use of salinity-tolerant rice varieties and promoting shrimp and salt farming. Under these contested land use options, adaptation decisions that can address the salinization problem, require investigation of both the perspectives of salinization of the local farmers being affected by the increasingly saline environment and their adaptation preferences to cope with salinity (Ramm et al., 2018). In addition, adaptation options generated from the farmers' perspective would enable decision makers to choose from a range of alternative solutions that are interconnected with socioeconomic and natural systems, which would make them more adoptable and less contested (Eakin and Patt, 2011; Wise et al., 2014).

Research that explores farmers' perspectives of salinization and how incorporating this perspective can help policymakers to plan adaptation decisions has attracted limited attention in the existing literature. Furthermore, most studies in the coastal areas of Bangladesh and other regions of the world have investigated farmers' perceptions of salinity based on a single livelihood option such as cropping or shrimp farming (Betcherman and Marschke, 2016; Hossain et al., 2018b; Islam and Tabeta, 2019; Joffre et al., 2018; Kabir et al., 2017; Rahman et al., 2017; Haider and Hossain, 2013). Most of these studies have confined their analysis to the farmers' perceptions of salinity in terms of farm risk, and overlooked their preferred options to cope with

salinization problem. Understanding these preferences could direct decision makers to undertake holistic salinity adaptation planning. In addition, divergent perspectives of salinization that involve all farming groups from the distal coastal areas are absent in the existing literature. Furthermore, how salinity affects the livelihood options of the different farming groups in the coastal areas of Bangladesh has not been adequately addressed in previous studies. A recent study has shown the importance of salinization perceptions and adaptation strategies in the coastal areas of Bangladesh (Islam et al., 2020); however, this study only considered the perceptions of the single livelihood of rice farmers, and therefore the perspectives of salinization of other farming groups such as shrimp and salt farmers were not included.

Our scientific understanding of the salinization problem in the coastal areas will be improved by examining farmers' perceptions of salinization and the preferred adaptation options of all coastal resource user groups, including rice, shrimp and salt farmers. At the same time, such knowledge will also inform policymakers about local-level resource users' preferences with regard to adaptation planning to address the opaque salinity problems, which will assist policymakers to implement sustainable policy, and in turn, trigger the achievement of the SDGs. This study therefore has the following aims:

- to examine how the salinization problem is framed by the different types of farmers in the coastal areas,
- to investigate how salinity affects the livelihood options of the various coastal farming communities, and
- to investigate farmers' preferred adaptation strategies to combat salinization at a community level.

3.3 Research Methodology

3.3.1 Selection and description of the study area

The coastal areas of Bangladesh are divided into three main regions, western, central and eastern, based on distinct biophysical and geographical characteristics (Karim and Mimura, 2008). In the south-eastern coastal area, most of the land falls under the shallow piedmont zone along with the Chittagong hill tracts, and is more stable in nature. The major rivers of this region are the Karnafuli and its tributaries (BWDB, 2013). The south-western coastal zone is an active

delta characterised by the Ganges tidal flood plain and the convergence of a large numbers of creeks and channels. The major rivers of this region are the Gorai and its tributaries (BWDB, 2013; Rahman and Rahman, 2015). Due to a wide range of variations in land topography, river systems and livelihood activities, the salinity dynamics vary significantly in these regions (SRDI, 2010).

Satkhira, one of worst salinity-affected districts of the south-western region, and Chittagong, one of the least-affected districts of the south-eastern coastal region were selected for this study (Table 3.1). The Assasuni sub-district from the Satkhira district and the Banskhalī sub-district from the Chittagong district were then selected, as these two sub-districts represent the most salinity-affected areas within these two districts, and also have diversified land use practices (i.e. rice farming, shrimp farming and salt farming) (SRDI, 2010). Finally, two villages from two unions of the Assasuni sub-district and two villages from two unions of the Banskhalī sub-district were selected for administration of the household survey (Fig. 3.1).

Table 3.1. Comparison of salinity-affected areas in the major coastal districts of Bangladesh

Coastal region	District	Total area (ha)	Salinity-affected area (ha)	% of salinity -affected area
South-western	Satkhira	229,607	153,110	66.68
	Khulna	213,820	147,960	69.20
	Bagerhat	201,331	131,120	65.13
Central	Barishal	195,708	12,360	6.32
	Barguna	167,887	95,620	56.95
	Patuakhali	307,875	155,180	50.40
South-eastern	Noakhali	222,575	52,520	23.60
	Chittagong	262,317	51,480	19.63
	Cox's Bazar	240,867	55,350	22.98

Source: (SRDI, 2010)

3.3.2 Data sources and data collection methods

The major sources of data for this study consist of primary and secondary data. The primary data were collected through formal household surveys, focus group discussions (FGDs), and key informant interviews (KIIs). The household surveys were conducted from February to April 2018 and in 2019 during the dry season (from December to May) in Bangladesh. Prior to conducting household surveys and key informant interviews, and focus group discussions human

research ethics approval (HREA) was sought and received at the University of New England, Australia (Approval No. HE17-272). A pre-tested and semi-structured interview schedule was used to collect primary data from 109 rice farmers, 107 shrimp farmers and 64 salt farmers. Secondary data were gathered from books, journal articles and reports. The respective sub-district Agriculture Officer and Fisheries Officer provided advice on the villages where rice farming was affected by salinity as well as where shrimp and salt farming have emerged as a potential land use. The lists of farmers were obtained from the records of the Agriculture and Fisheries offices in each of the sub-districts. A multi-stage stratified random sampling procedure was followed to select the respondents for the face-to-face interview (Table 3.2). A similar sampling procedure was followed by other studies that have investigated farmers' perceptions of salinity and climate change in the coastal areas of Bangladesh (Hasan and Kumar, 2020; Islam et al., 2020). The male farmer from each household was selected as the interview respondent, as men are traditionally the household head in Bangladesh.

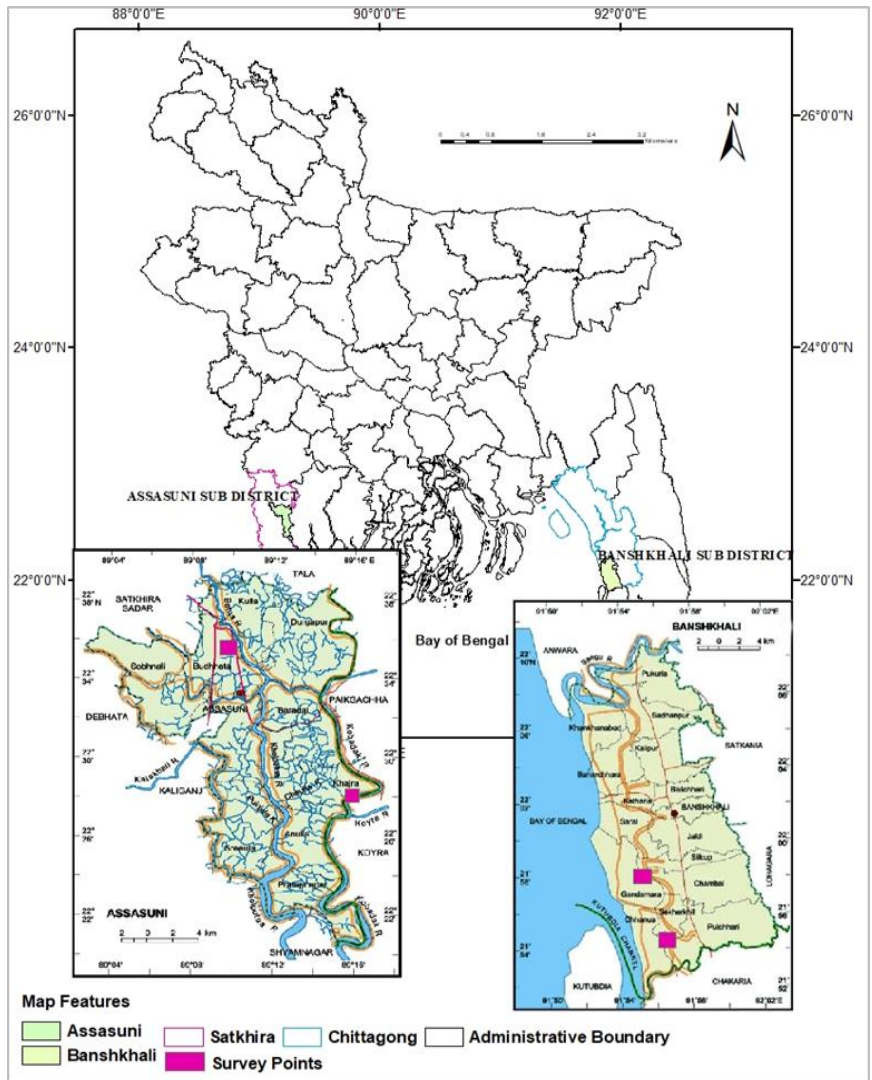


Fig. 3.1. Study locations in the coastal areas of Bangladesh. Assasuni sub-district in Satkhira district (bottom left) and Banskhal sub-district in Chittagong district (bottom right). Location of data collection villages are indicated by pink squares

Table 3.2. Selection of survey respondents from villages in Assasuni sub-district of Satkhira district and Banskhali sub-district of Chittagong district

Stage-1 Selected districts (total no. of districts)	Stage-2 Selected Sub-district (total no. of sub-districts)	Stage-3 Selected union (total no. of unions)	Stage-4 Selected village	Stage-5 Total No. of farmers			Stage-6 Number of interviewed households (percentage)		
				Rice	Shrimp	Salt	Rice	Shrimp	Salt
Satkhira from the south-west (3)	Assasuni (9)	Budhata (11)	Beula	390	340	-	38 (9.7)	24 (7.05)	-
		Khajra (11)	Khajra	195	450	-	23 (11.8)	35 (7.7)	-
Chittagong from the south-east (4)	Banskhali (14)	Chanua (14)	Khudukk hali	415	210	480	32 (7.7)	29 (13.8)	44 (9.1)
		Gondam ara (14)	Paschim Baraghona	180	110	150	16 (8.8)	19 (9.3)	20 (13.3)

Farmers were interviewed about their perceptions of salinity trends in their locality over the last 20 years and whether salinity has been increasing, decreasing or there has been no change. Their perceptions of the current salinity level as well as conditions for 20 years in the past of their locality were also covered. The farmers' perceived causes/drivers of increased salinity, the impacts of salinity on their farming enterprises and their adaptation preferences to cope with the expected extreme salinization were explored by a series of open-ended questions on those topics.

To complement the farmer household interviews, 22 key informant interviews (KIIs) and two focus group discussions (FGDs) were also conducted. KIIs were conducted amongst a wide range of professionals: agricultural extension department personnel, fisheries officers, rice breeders, soil scientists and NGO personnel from the national, district and sub-district levels. These KIIs interviews were conducted at the respective offices of the participants, and FGDs were conducted at the sub-district agriculture offices. Voluntary participation of the KIIs and FGDs respondents were confirmed before the interview and FGDs. A series of open-ended questions

were covered to explore their opinions on the causes of salinization and the adaptation options needed to combat the expected increasing salinity in the future.

3.3.3 Data analysis

Data collected from the interviews of the household head were transferred to usable format by coding the responses. Responses were transcribed from Bengali to English by the lead author who is fluent in Bengali. For open-ended questions, a thematic response matrix was developed and similar responses were placed into these common thematic responses. These were then coded with a number and analysed using IBM SPSS statistical software (Bryman and Cramer, 2012; Seale and Kelly, 2004). ANOVAs were conducted to examine the differences in the independent variables among the different types of farmers. The independent variables examined were age, educational qualifications, total farm size, land ownership, farming experience and monthly average income. The farmers' perspectives of salinity, with particular focus on the trends and causes of salinity and its impacts on their farming enterprises, and their preferred adaptation options were analysed using cross-tab analysis. Chi-square tests were carried out for these categorical variables to test whether farmers' salinity perspectives varied among the different types of farmers (i.e. frequencies against each category). Al-Amin et al. (2019) conducted similar Chi-square tests to examine categorical variables in their investigation of the significance of intra-household differences in farmers' perceptions of climate change.

The data gathered from the KIIs and FGDs were transcribed verbatim from Bengali to English and analysed using NVivo 12 plus software. To complement the survey results, KIIs and FGDs data were coded against themes of causes of salinization, and adaption options to cope with future salinization. Several nodes were created under these themes and responses under each theme were coded into the respective nodes. Word frequency search queries were conducted to recall the most important words or phrases as mentioned by the key informants, and FGDs participants to address specific issues of causes of salinization and adaptation options. Matrix coding queries were also carried out to observe the variations in salinity perspectives (e.g. the causes of salinity) of the different key informants working in different organisations.

3.4 Results

3.4.1 Socioeconomic characteristics of the different types of farmers

Most of the socioeconomic and demographic characteristics differed significantly among the rice, shrimp and salt farmers in the areas studied. Educational qualifications differed significantly among the different types of farmers. Among the three groups of farmers, the shrimp farmers had the greatest number of years at school (8.43) when compared to the rice and salt farmers, who had 6.7 and 3.03 years of schooling, respectively. Total farm size of the shrimp farmers was also significantly higher than that of the rice and salt farmers. Land ownership also differed significantly among the three types of farmers. The shrimp farmers owned the greatest area of land, which was on average 13.00 bigha, while rice and salt farmers possessed 4.6 and 2.02 bigha of land, respectively. Salt farmers had the longest farming experience of 25.58 yrs, while shrimp farmers had 22.23 years of experience. Significant differences were found in monthly average income among the different types of farmers. The shrimp farmers had a monthly income that was almost 1.5 times higher, BDT 19000, than the rice and salt farmers (Table 3.3). The average age of farmers in all groups was between 46 and 48 years old.

Table 3.3. Socioeconomic characteristics of the rice, shrimp and salt farmers in the two coastal study areas

Characteristics (unit of measurement)	Rice farmer (N=109)		Shrimp farmer (N=107)		Salt farmer (N=64)		F-value
	Mean	SD	Mean	SD	Mean	SD	
Age (yrs)	47.44	8.82	46.70	8.56	47.73	8.40	0.35NS
Education (schooling yrs)	6.70	5.42	8.43	4.51	3.03	3.04	27.44**
Total farm size (bigha ⁵)	7.97	5.41	28.86	27.68	7.63	5.54	46.76**
Land ownership (bigha)	4.61	4.51	13.00	18.85	2.02	2.26	20.82**
Farming experience (yrs)	23.02	8.31	22.23	7.90	25.58	7.14	3.73*
Monthly income (BDT ⁶)	11432	3856	19072	3224.56	12192	3695.63	139.95**

** = significant at 5% level of significance, NS = not significant

3.4.2 Context of salinity as perceived by the different types of farmers

Only a small proportion of farmers, regardless of land use, reported no change in salinity in the last 20 years. However, the perspectives of the trend in salinity varied between the

⁵ 1 ha= 7.4 bigha

⁶ 1 BDT = 0.012 USD

different types of farmers in the two coastal study areas (Table 3.4). While 87.2% of rice farmers reported that salinity has increased over the past 20 years, only 35.5% of shrimp farmers indicated this. Shrimp farmers were more likely to indicate that salinity had decreased in the past 20 years (52.3%). A higher proportion of salt farmers (43.8%) than shrimp farmers (35.5%) indicated that salinity had increased, but the majority of salt farmers (51.6%) reported that salinity had declined in the last 20 years. Among the rice farmers, around 90% reported that the current salinity level in their locality was high, with only a small proportion indicating that the current salinity level was low. In contrast, the proportions of both shrimp farmers (46.7%) and salt farmers (60.9%) who reported the current salinity level as being high were both lower when compared with rice farmers, and therefore a much higher proportion of shrimp farmers (53.3%) and salt farmers (39.1%) considered the current salinity level to be low. This result aligns with the farmers' perceived salinity level 20 years ago, which most rice farmers (84.4%) said was low, while 64.5% of shrimp farmers and 46.9% of salt farmers reported it as being high 20 years ago when compared to the present salinity level.

In terms of the main drivers of increased salinity, 62.1% of rice farmers considered that the human interventions of shrimp farming, salt farming and faulty sluice gates are the main effectors, with less emphasis (27.4%) placed on the natural causes such as cyclones, coastal flood, siltation of rivers and less rainfall. Only a small proportion (10.5%) mentioned both anthropogenic and natural causes. In contrast to rice farmers, more emphasis was placed on natural causes as the main drivers of increased salinity by shrimp farmers (39%). A higher proportion (34.2%) mentioned both human interventions and natural causes as the drivers compared with human interventions on their own (26.8%). Among the salt farmers, the main drivers of increased salinity were human interventions (46.9%), while almost equal emphasis was placed on natural causes and human interventions together (26.9%) or natural causes alone (26.2%) (Table 3.4).

Table 3.4. Context of salinity among the different types of farmers in the two coastal study areas

Issues of the salinity problem	% of the respondents			
	Rice farmer (N=109)	Shrimp farmer (N=107)	Salt farmer (N=64)	Overall (N=280)
Trend of salinity over the last 20 years				
Salinity increased	87.2	35.5	43.8	57.5
Salinity decreased	9.2	52.3	51.6	35.4
No changes in salinity	3.7	12.1	4.7	7.1
Chi-square = 68.51**				
Current salinity level				
High	89.9	46.7	60.9	66.8
Low	10.1	53.3	39.1	33.2
Chi-square = 46.66**				
Salinity level 20 years ago				
High	15.6	64.5	46.9	41.1
Low	84.4	35.5	53.1	58.6
Chi-square = 54.20**				
Drivers of increased salinity				
Human interventions (e.g. shrimp farming, salt farming, faulty sluice gate)	62.1	26.8	30.8	46.9
Natural events (e.g. cyclones, coastal flood, siltation of river, less rainfall)	27.4	39.0	10.2	26.2
Human interventions and natural events	10.5	34.2	59.0	26.9
Chi-square = 41.98**				

** indicates significant at 5% level of significance

The findings from the household interviews followed similar trends to the key informant interviews, and focus group discussions with respect to the perspective that anthropogenic drivers have had a major role in increasing salinity. However, there was a clear polarisation between the representatives of Fisheries and Agriculture departments in their views on the role of natural causes in the increasing salinity. The majority of the coded references (92.3%) from the Fisheries Department officers' KIIs were about the natural drivers of salinity, while only 7.7%

of the coded references from the Agriculture Department KIIs mentioned that the natural drivers contributed to increased salinity (Fig. 3.2).

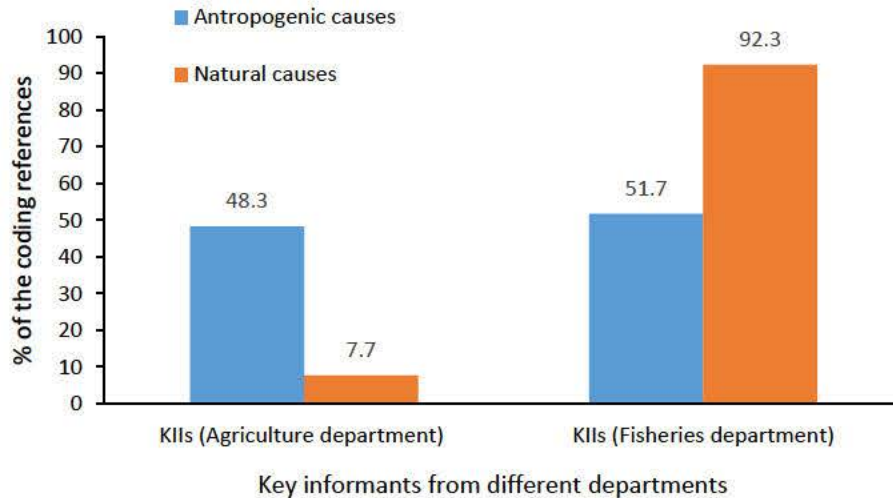


Fig. 3.2. Coding references from the key informant interviews of representatives of the Agriculture and Fisheries departments on the drivers of increased salinity

The KIIs and FGDs also identified the same anthropogenic drivers of increased salinity cases as reported by farmers such as increases in shrimp and salt farming and faulty management of embankments. However, the majority of the KIIs spoke more often about how the unplanned expansion of shrimp and salt farming has been the greatest anthropogenic driver of increased salinity (Fig. 3.3).



Fig. 3.3. Anthropogenic drivers of the increased salinity as reported in KIIs (n=22) and FGDs (n=2)

Table 3.5. Farmers' perceived reasons of decline in salinity

Farmer type (n)	% of the respondents	
	Rainfall increased as compared to the previous decades	Less risk of inundation of saline water due to siltation of rivers and canals
Rice farmers (10)	70.0	30.0
Shrimp farmers (56)	30.4	69.6
Salt farmers (28)	67.9	32.1

Chi-square = 13.22**

** indicates significant at 5% level of significance

3.4.5 Sources of information/farming advice

Farmers in the coastal study areas use different sources for advice and information for their farming enterprises, and there is very little crossover between government departments and enterprises. Rice farmers (50.5%) have a substantial reliance on information and farming advice obtained from the sub-district Agriculture office and the local sub-assistant agriculture officer, and to a lesser extent from neighbouring farmers and local input dealers (26.6%) and neighbouring farmers only (22.9%). Among the shrimp farmers, 51.4% obtain farming advice from neighbouring farmers and 44.9% obtain information from neighbouring farmers and the sub-district Fisheries office. In contrast, salt farmers get farming advice almost exclusively from neighbouring farmers (92.2%), while the remainder also mentioned neighbouring farmers and government personnel (Table 3.6).

Table 3.6. Sources of information and farming advice of the different types of farmers

Farmer type (n)	% of the respondents				
	Agriculture office and local sub-assistant agriculture officer	Neighbouring farmers	Neighbouring farmers and local input dealers	Neighbouring farmers and local fisheries office	Neighbouring farmers and government personnel
Rice farmers (109)	50.5	22.9	26.6	0	0
Shrimp farmers (107)	0	51.4	3.7	44.9	0
Salt farmers (64)	0	92.2	0	0	7.8
Chi-square = 253.56***					

*** indicates significant at 1% level of significance

3.4.6 Impacts of high salinity on the farming enterprise of the different types of farmers

The perceived impacts of high salinity of the different types of farmers in the coastal areas of Bangladesh were very much focused on their main enterprise, with most concerned about impacts on yield. For rice farmers, high salinity had negative consequences on yield, with 42.2% reporting that “rice plants dry up, unfilled grain, lower yield, income reduce”, 30.3% also mentioned that “crop cultivation becomes difficult, lower yield, income reduced” and 27.5% stated that they observe “damage to soil fertility, lower yield, less income”. In contrast, increased salinity for shrimp farmers has positive impacts on yield and income potential, with 69.2% mentioning “movement of fish in the pond is noticeable, higher yield, more income”, while 30.8% reported that “growth of fish is good, higher yield, more income”. Similarly, salt farmers reported positive impacts of increased salinity on yield with 54.7% stating “density of water increase, higher yield”, and the remainder reported that they receive a “higher yield of salt” (Table 3.7).

Table 3.7. Impacts of high salinity on farming enterprises

Farmer types (n)	(% of farmer interviewees)						
	Rice plants dry up, unfilled grain, lower yield, income reduced	Damaged soil fertility, lower yield, less income	Crop cultivation becomes difficult, less yield, income reduced	Growth of fish is good, higher yield, more income	Movement of fish in the pond is noticeable, higher yield, more income	Density of water increases, higher yield	Higher salt yield
Rice farmers (109)	42.2	27.5	30.3	0.0	0.0	0.0	0.0
Shrimp farmers (107)	0.0	0.0	0.0	30.8	69.2	0.0	0.0
Salt farmers (64)	0.0	0.0	0.0	0.0	0.0	54.7	45.3

Chi-square = 560.0***

*** indicates significant at 1% level of significance

3.4.7 Adaptation preferences to cope with expected high salinity

The household interviews found significant differences in the adaptation preferences under expected high salinity among the different types of farmers in the two coastal areas of Bangladesh. Rice farmers placed the greatest emphasis on agronomic solutions to high salinity, with approximately 60% referring to “salt tolerant rice varieties with greater tolerance during the reproductive stages, and early transplanting”, while a smaller proportion (around 20%) mentioned “develop facilities to harvest rain water during monsoon and use it during the dry season” and around 16% suggested, “improved irrigation facilities”. There was little emphasis (4%) on engineering solutions such as “strengthening of the embankments facilities”. This result contrasts with the adaptation preferences to higher salinity for most shrimp farmers (57%), who suggested engineering solutions such as “strengthening embankment facilities” be used to increasing salinity, while 35% prefer to have “canal excavation”. Salt farmers placed even greater emphasis than shrimp farmers on engineering solutions to increase salinity, with around 74% suggesting “strengthening embankment facilities”, and only around 22% suggesting “canal excavation” as their preferred adaptation options (Fig. 3.5).

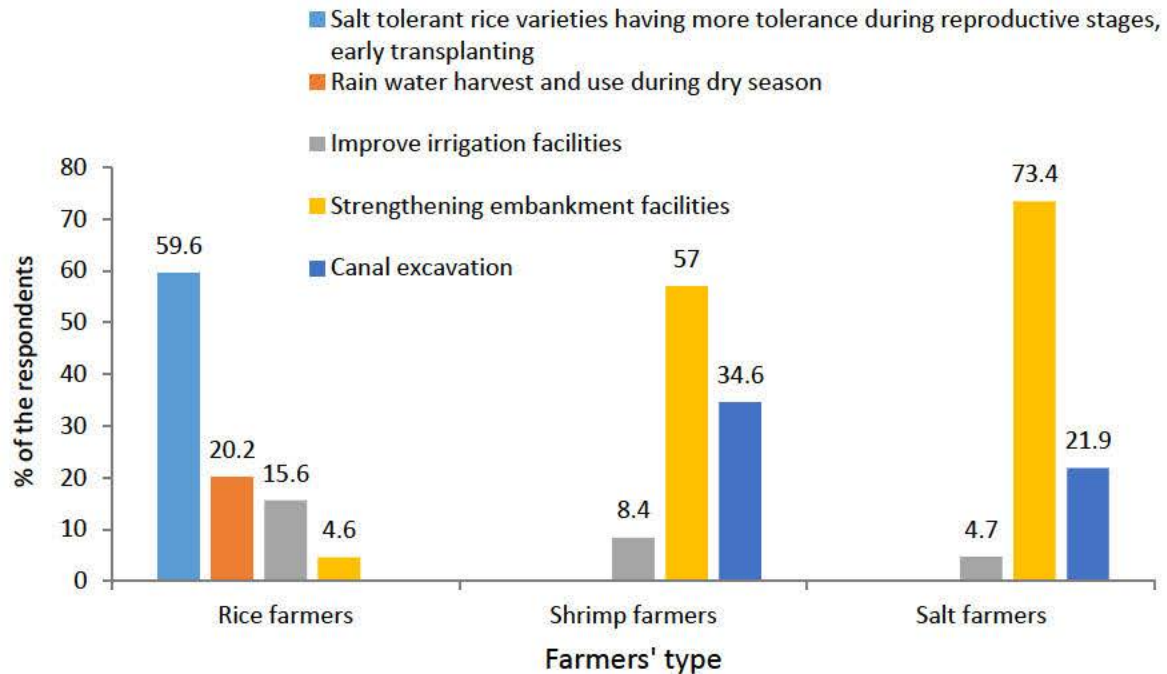


Fig. 3.5. Adaptation preferences to cope with expected high salinity among the different types of farmers

Adaptation preferences mentioned by the different types of farmers to cope with expected high salinity were also found to align with the responses from the KIIs, and FGDs to the main enterprises of rice, shrimp and salt farming. Among the coded references related to the adaptation options, 43% were from the Agriculture Extension Department personnel, 39% of coded references were from research organisations and around 10% were from the Fisheries Department. Word frequency query search results showed that use of salt-tolerant rice varieties and irrigation techniques were mentioned as the most preferred options to cope with expected high salinity, but these organisations were also highly represented in the sampling (Fig. 3.6). The specific options mentioned by the agriculture extension staff were mostly agronomic technical options such as the use of salt-tolerant rice varieties, application of irrigation regularly and early transplanting. In contrast, officers from the Fisheries Department talked mostly of engineering solutions such as canal excavation and strengthening of embankment facilities, although they had a minor representation in the KIIs.

farmers perceived that the difficulties they have been experiencing during the Boro rice growing season are due to the trends in increasing salinity. Rice farmers in the coastal areas have reported that salinity has been the most significant barrier to dry season rice farming (Islam et al., 2020).

The findings of this study also showed differential perceptions among the different types of farmers on the causes of salinity in the coastal areas. The majority of the rice farmers perceived that a particular human intervention cause of salinity might limit land that is available for rice farming following the extension of shrimp farms into the adjacent cropping fields. These shrimp farms are typically twice the size of rice farms. A large body of literature also indicates that shrimp farmers are socioeconomically more powerful, and they have not only converted their own rice fields into shrimp farming but also actively bought up neighbouring farmers' land for shrimp farming, which is a process that has ultimately increased salinity in the coastal areas (Ahmed et al., 2010; Deb, 1998).

In contrast, rather than admit that their own farming enterprises are a contributing factor to the worsening salinity in the area, the shrimp and salt farmers' attribute the causes of increased salinity to the natural drivers. In addition, natural causes like cyclones and frequent inundation may have negatively affected their previous rice yields, and their economic insolvency could have triggered a conversion of their land to shrimp and salt farming. Thus, the shrimp and salt farmers' perceptions of the causes of salinity in the coastal areas emphasise the natural drivers. The literature demonstrates that salinity has caused lowered rice yields, and that these lower yields have influenced those farmers in the coastal areas to convert their cropping land into shrimp and salt farms (Ahmed, 2013; Amin et al., 2011). Those farmers who said salinity has decreased also mentioned that the reasons behind their thinking were related to the level of dependency of their livelihood options on the availability of saline water. As those farmers might encounter difficulty in getting saline water due to siltation of rivers and canals from lower water flows, thus their perceptions of the salinity trends are shaped by these experiences (Mertz et al., 2009).

Different types of farmers perceived that high salinity has impacted on their farming livelihood options in diverse ways. Rice farmers perceived that the negative impact on their farming enterprise of the high salinity is reduction in rice yields. As yields have been drastically

reduced due to the impact of high salinity, their overall income from this livelihood option has reduced, which could influence rice farmers' perceived impacts in negative ways. Yield reduction due to high salinity has been reported in the literature (Hasanuzzaman et al., 2009; Joseph and Mohanan, 2013; Zeng et al., 2003), which supports the farmers' perceptions of the impacts of high salinity on sustainable rice farming. On the other hand, the shrimp and salt farmers' perceived positive impacts of high salinity on their livelihood options are most likely due to the requirement for saline water for these farming enterprises, which ultimately increases their farm income.

This study has demonstrated that there are significant differences in the opinion on the adaptation preferences to cope with expected high salinity in the coastal areas. The rice farmers' preferred options to deal with the increasing salinity are to have salt-tolerant rice varieties and improved irrigation facilities, as these appear to be plausible and practical solutions to those farmers who own small areas of land and have a low monthly income. They may also have fewer options to move to other cost-intensive livelihoods and prefer to use salt-tolerant rice varieties to extend the time they can continue cultivation of their current landholding, even though they expect conditions to worsen.

Given the rice farmers are concerned about the anthropogenic drivers as the causes of salinization, they did not suggest cessation of shrimp and salt cultivation in their localities as a solution. However, some of the rice farmers mentioned the need to create facilities for rainwater storage in the wet season that could be used for irrigation in the dry season. As conversion of cropland to brackish water for shrimp and salt farms is almost irreversible, their preferred options are concentrated on their own farming opportunities rather than complete shifts of enterprise.

In contrast, the shrimp and salt farmers' preferred adaptation options are predominantly associated with the engineering solutions of strengthening embankment facilities and canal excavation. As shrimp and salt farmers are more concerned with the natural drivers of the increased salinity, these perceived causes have probably influenced their preferred adaptation options to cope with expected high salinity.

3.5.2 Potential of differential salinity perspectives of farmers to achieve the SDGs, and future research directives

For policymakers in Bangladesh whose aim is to achieve the sustainable development goals, particularly SDG-1, SDG-2 and SDG-3, the coastal areas are the key focus of research and extension initiatives for agricultural development. However, these areas are also considered to be hotspots for several environmental stresses, and salinity is one of these stresses, which has been triggered by both natural and human interventions. Salinity affects the coastal farmers in contrasting ways: it negatively affects rice farming, but has positive impacts on shrimp and salt farming. Therefore, policy initiatives that are undertaken to address this polarised problem should consider the preferred adaptation options of all types of farmers.

Achieving the SDGs requires that all types of farmers are able to use their land sustainably to maintain and increase their farm productivity and thus contribute to food security in coastal Bangladesh. Thus, research and extension policy initiatives for rice farmers need to be more localised and targeted to the rice farmers' needs. One initiative should be developing salt-tolerant rice varieties that are tolerant during the reproductive stages when salinity levels are highest and not just during the germination and seedling emergence stages (Islam et al., 2020). Another initiative should be improvement of irrigation facilities to provide fresh water for as long as possible during crop growth. Facilities should also be developed to store monsoon rainwater which can be used for irrigation in dry season rice farming (i.e. Boro season). Another possible intervention could be cultivation of saline tolerant rice in wet season alternating with salt-shrimp/prawn farming in the dry season which have shown great potential to improve livelihood as well as climate change resilient farming system in the Mekong delta (Dang, 2020; Brennan et al., 2002). Although, shrimp and salt farmers' preferred adaptation is strengthening of the embankments, which could protect the land from frequent inundation, canal excavation planning could be more useful for bringing saline water from the sea. Thus, efficient sluice gate management and equitable land zoning and its' strict implementation could help ensure proper utilisation of coastal resources for all types of farmers.

These actions could allow the different types of farmers to use their resources sustainably for their own livelihood improvement, and also to contribute to achievement of the SDGs. However, the contesting of land use by the different types of farmers could create uncertainty

for the policymakers in planning these adaptation decisions. Thus, further research is required to explore the threshold yield loss of dry season rice as perceived by the local farmers, as this information could signal a tipping point for the cessation of rice farming in the coastal saline areas.

3.6 Conclusions

Salinization that has been caused by both natural and anthropogenic drivers is one of the crucial risk factors for coastal livelihoods in Bangladesh. The impacts of this salinization have resulted in highly spatial-temporal variations and contested land uses. Thus, the adaptation decisions being made by policymakers require knowledge of the perspectives of all types of farmers who are affected by increasing salinity, either positively or negatively, in the coastal saline areas of Bangladesh. The findings of this study demonstrated a differential perception of salinity among the various types of farmers. While the majority of the rice farmers perceived an increasing trend in salinity, half of the shrimp and salt farmers perceived it to have declined. Strongly contrasting emphases on the perceived causes of increased salinity in the coastal areas were also found, with rice farmers being more focused on human interventions than natural causes, and shrimp and salt farmers placing less emphasis on human intervention. This study suggests that the way farmers' livelihood options are affected by the salinity has driven their perceptions about the problem. It has also demonstrated that rice farmers' preferred adaptation options are predominantly linked to agronomic technical solutions like the development of salt-tolerant rice varieties and irrigation improvements, while shrimp and salt farmers' preferences linked to engineering solutions such as strengthening embankment facilities.

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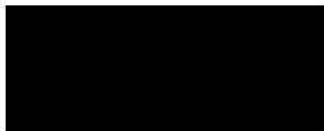
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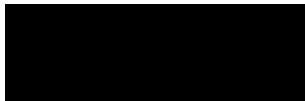
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Chapter 4

Salinity-affected threshold yield loss: A signal of adaptation tipping points for salinity management of dry season rice cultivation in the coastal areas of Bangladesh

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4.1 Abstract

The potential existence of threshold yield loss in dry season rice growing systems under coastal saline environment remains unexplored, a scenario that could have policy relevance in government planning of rice intensification in the coastal areas of Bangladesh. This study applied the adaptation tipping points (ATPs) approach to investigate threshold yield loss from multiple perspectives of farmers affected by salinity. Data were generated from 280 randomly-selected farmers (rice farmers, n = 109; shrimp farmers, n = 107; salt farmers, n = 64) from two coastal sub-districts using a semi-structured survey. Key informant interviews and focus group discussions were conducted to complement the survey results. Our study revealed that despite government actions to promote dry season rice cultivation, farmers have been growing less rice in this season, with salinity-affected yield loss being the prime reason. Most of the rice farmers have considered that they would discontinue rice cultivation in this season due to yield loss, while shrimp and salt farmers have already reduced rice cultivation for the same reason, and shifted to shrimp and salt farming as they perceived these enterprises as highly profitable and require less labour than rice farming. Rice farmers would tolerate a greater rice yield loss (23%) under saline conditions compared with the shrimp (16%) and salt farmers (14%). The yield loss thresholds indicate the need for government actions to support and encourage integrated land management for rice, shrimp and salt farming, rather than research and extension efforts for dry season rice expansion alone. These actions could strengthen sustainable livelihood options to ensure food security, and contribute to the achievement of sustainable development goals, for instance no poverty (SDG-1), zero hunger (SDG-2), and good health and well-being (SDG-3).

Key words: Salinity, Dry season rice, Uncertainty, Tipping points, Threshold yield loss, Coastal areas

4.2 Introduction

Achieving the sustainable development goals (SDGs) is the key component of the national policy agenda of Bangladesh. To meet these objectives, the government has contextualised the SDGs by mainstreaming these goals in most of the guiding policy frameworks, for instance the five-year plans (FYP), national food policy (NFP) and national agricultural policy (NAP) (GED, 2018). Among the SDGs, no poverty (SDG-1), zero hunger (SDG-2) and good health and well-being (SDG-3) are explicitly linked to agricultural development to ensure food security in the country (Hussain et al., 2018; Islam and Shamsuddoha, 2018). To maintain the pace required to sustain food security, government agencies such as research and extension services have placed a strong emphasis on the intensification of rice-dominated cropping systems, as rice alone occupies 77% of cropping land (BBS, 2020). Two potential pathways for cropping intensification have emerged in the literature: increasing production by growing more crops over the year and expanding cropping to new areas (Godfray et al., 2010). In Bangladesh, expansion of cropping to new land has limited potential as most of the arable land is already developed for cropping (FAO, 2014; Krupnik et al., 2015). The coastal areas, which account for 2.8 million hectares, have been a focal point for policymakers to intensify rice-dominated cropping systems (Hossain et al., 2020; Krupnik et al., 2015). However, salinization is the major constraint to cropping intensification in these areas, as more than 67% of land in this region is affected by moderate to high levels of salinity (i.e. >8.0 dS/m) and remains fallow, as only high salt-tolerant crops can grow in this saline environment (MoA, 2013; SRDI, 2010). In addition, about 2000 km² of the coastal areas of Bangladesh are likely to be inundated by the end of this century due to climate change-induced sea level rise, which will further increase the area affected by salinity (Hasan et al., 2020).

Despite these threats of salinization, intensification of rice cultivation in the coastal areas remains the top priority for policymakers, as food security and agricultural development in Bangladesh is synonymous with boosting rice cultivation, which contributes around 94% of total national grain production (BBS, 2020). Of the three rice growing seasons⁷, Boro (referred to as dry season, henceforth) is the most productive season due to being less affected by natural

⁷ In Bangladesh there are three rice growing seasons viz. Aus, Aman and Boro, which are semi-rain-fed, rain-fed and irrigated, respectively.

calamities (e.g. flood), and it contributes 54% of total rice production (BBS, 2020). The promotion of salt-tolerant rice varieties at the farm level is seen as a means of addressing the constraints to rice intensification in the coastal saline areas (Islam and Gregorio, 2013; MoA, 2013). However, it has been reported that most of these varieties cannot withstand the high salinity experienced after heavy inundation from cyclones (Rabbani et al., 2013). These rice varieties also have limitations in adapting to salinity stress, especially during the reproductive stages of the growing season, which coincide with the prevalence of the highest salinity levels in the salt-affected coastal regions (Islam et al., 2020b). These findings have raised uncertainty about whether rice intensification can be sustainable in the coastal areas, and how long these 'tolerant' varieties would be sustainable to achieve local farmers' objectives; that is, how long these varieties would continue to adapt to increasing salinity and still produce a higher yield per unit area (Clarke et al., 2015; Dasgupta et al., 2015).

In addition to crop-based agriculture, which is the primary livelihood option for poverty alleviation and ensuring food security (Lázár et al., 2015; Talukder and Saifuzzaman, 2016), other farming enterprises such as shrimp and salt farming have emerged. These enterprises have shown significant potential for being able to contribute to food security through socioeconomic development (Ahmed et al., 2012). Shrimp is the second largest export-earning sector of Bangladesh, that supplies around 2% of the global demand and adds US\$400 million to the national economy (Akber et al., 2017; BFFEA, 2017; FRSS, 2018). About 1.5 million people are directly employed in this sector, and the livelihoods of about 5 million households are associated with shrimp-farming industries (DoF, 2012). The salt industry is also an emerging sector that is concentrated in the south-eastern coastal region, and has the potential to enhance the livelihoods of millions of people who are directly or indirectly associated with it (Al Mamun et al., 2014). This rapidly growing farming enterprise produces 1.8 million tonnes of crude salt annually, and generates around US\$20 million for the national economy (BSCIC, 2020). However, negative environmental and social consequences (e.g. loss of biodiversity, salinity intrusion, social conflict) associated with these emerging industries have been reported in the literature (Abdullah et al., 2017; Paul and Vogl, 2011).

Thus, the government planning of dry season rice expansion in the coastal areas with the aim of coping with salinization through saline tolerant varieties while maintaining agricultural sustainability is becoming increasingly complicated due to the involvement of multi-dimensional issues interconnected with food security (Neumann et al., 2015; Nilsson et al., 2016). For example, while the government has promoted the cultivation of rice in the dry season to ensure food security, its future is uncertain due to threats of an increasingly saline environment. On the other hand, even though there are some negative consequences associated with shrimp and salt farming, these enterprises contribute to food security by enhancing household income. Thus, policymakers are likely to encounter a high level of planning uncertainty in the expansion of dry season rice production due to salinity threats and emerging land uses resulting from local farmers' preferences.

To address decision-making under both the profound uncertainty and the competing social objectives, a few approaches to adaptation decision-making have emerged (Haasnoot et al., 2013; Kwakkel et al., 2015). Among these approaches, adaptation tipping points (ATPs) are considered to be more robust in addressing uncertainty in diverse agricultural systems that intersect with socioeconomic phenomena because they are stakeholder-derived (Werners et al., 2013). The ATPs signify the situation at which the current management strategies can no longer achieve the policy objectives targeted to meet local demand under climate change or transformed societal preferences (Kwadijk et al., 2010).

Thus, the sustainability of dry season rice cultivation in the coastal areas of Bangladesh under increasingly saline environments and the competing land uses require a signal of plausible thresholds that can potentially be achieved through the ATP approach (Werners et al., 2016). Thresholds are commonly used in climate or environmental systems, and are often considered as points of no return (Russill and Nyssa, 2009). In socio-ecological systems, a threshold indicates a situation that the society perceives as inadequate to meet their demands, and forces them to migrate to other economic options (Bardsley and Hugo, 2010). Understanding the various social dimensions of thresholds is undoubtedly important in prioritising policy issues regarding decision-making in adaptation planning under complex societal and land use preferences (Bölscher et al., 2013; Lenton, 2013; Walker et al., 2003).

However, the determination of thresholds of a system connected with multifaceted drivers (e.g. environmental and social) has attracted little attention in the current literature on the use of the ATP approach. Numerous studies have been conducted in different parts of the world that have focused on the application of ATPs to determine thresholds, with most concentrating on climate change, particularly in relation to water management issues dominated by complex engineering and model-based simulation studies (Kwadijk et al., 2010; Lavery and Donovan, 2005). A few studies have been conducted in agricultural systems, such as determining the threshold temperature for grapevine cultivation under climate change (Moriondo et al., 2013) and threshold identification for wetlands management (Nanda et al., 2018). However, the potential existence of thresholds in rice-dominated agricultural systems under increasingly saline coastal areas remains unexplored (van Ginkel et al., 2020).

A few studies have been carried out in Bangladesh that have applied the ATP approach to investigate tipping points in flood management systems (Ahmed et al., 2018), adaptation pathways of coastal water management under salinity (Hossain et al., 2018) and comprehending farmers' perceptions of the salinity tolerance of rice (Islam et al., 2020a). However, local farmer-driven thresholds in coastal rice growing systems that are connected with other land use perspectives have not been considered in the existing studies. In addition, the farming perspectives of local people in coastal saline environments and the underlying reasons for these perspectives have received less attention in the existing literature. The present study fills this gap by examining local farmers' (i.e. rice, shrimp and salt farmers) perspectives of their dominant livelihood options and their perceived threshold yield loss in rice, which could signal the tipping points of salinity adaptation of dry season rice cultivation.

The determination of salinity-affected threshold yield loss of dry season rice that has been based on local farmers' perceptions will provide a realistic mechanism for policymakers to prioritise research and extension planning to support farmers. To the best of our knowledge, this study is the first attempt to apply the ATP approach from the farmers' perspective in coastal rice growing systems under salinity-affected environments. It will consider the dominant livelihood options, and demonstrate the potential for the application of ATPs to determining salinity-affected threshold yield loss, which can provide input into adaptation decisions that aim to cope

with salinity in coastal areas. The main aim of the research was to determine the threshold yield loss (%) of dry season rice cultivation in the coastal areas of Bangladesh based on farmers' perception. In order to achieve this aim the following objectives were addressed: the perspectives of different types of farmer towards growing rice in dry season; the perspectives of different types of farmer on discontinuation of dry season rice farming enterprises; and finally how different types of farmer perceive yield of rice under non-saline and highly saline environments, and their least acceptable yield during dry season rice cultivation.

The rest of this chapter is organized as follows: Section 4.3 introduces the conceptual research framework with key definitions of different concepts (e.g. adaptation, thresholds, tipping points), and how these has been defined in this study, also presented in this section. This section also presents research methodology applied in this study to achieve the objectives. Section 4.4 describes the key findings of this study with special attention to salinity affected threshold yield loss from the different types of farmer. Section 4.5 provides discussions of our findings and key policy implications of these findings, and there are concluding remarks in section 4.6.

4.3 Conceptual framework and research methodology

The conceptual framework and the research methodology used in this study are discussed in this section, as well as how the threshold yield loss of dry season rice was determined in the coastal rice growing areas of Bangladesh. The literature suggests that there is a significant temporal and spatial variation in salinity in the coastal areas of Bangladesh (Clarke et al., 2015), and this salinity affects coastal people in diverse ways (Lázár et al., 2015). Therefore, this study considers the impact of salinity on all farmer types in the study region. Earlier work found that rice yield could serve as a potential threshold value because it has significance for local people (Islam et al., 2020). The literature also shows that up to 50% yield loss of rice can occur at salinity levels of 6.0 dS/m or higher (Hasanuzzaman et al., 2009; Radanielson et al., 2018). Thus, the farmers' perspectives of the salinity-affected threshold yield loss of rice cultivation in dry season can provide a signal to policymakers as to whether dry season rice intensification in the coastal areas will be sustainable or not.

4.3.1 Adaptation in agricultural system

Adaptation to climate change in agricultural systems refers to modifications through agronomic and or other management practices to minimise or avoid risks in response to climate change and/or any other external stresses (Smit and Pilifosova, 2003). The most commonly practised adaptation strategies include the use of new crop varieties, irrigation practices and conservation agriculture (Smit and Skinner, 2002). However, adaptation practices in agriculture are location-specific, and also depend on various socio-ecological factors and the livelihood of the farming community (Deressa et al., 2011). This study considered that the innovation and promotion of salt-tolerant rice varieties in the coastal areas is an adaptation strategy that has influenced how policymakers address the constraints of dry season rice expansion under coastal saline environments. The policy objectives were to have a degree of certainty (e.g. can withstand salinity) regarding the use of these salt-tolerant rice varieties under coastal saline environment (MoA, 2013).

4.3.2 Adaptation tipping points (ATPs)

Adaptation tipping points (ATPs) are defined as the points where the magnitude of change due to climate change or any other social change is such that the current management strategy will no longer be able to meet the objectives for which the strategies are undertaken (Werners et al., 2015). The ATP informs policymakers as to when a management strategy may fail and when other strategies are needed (Kwadijk et al., 2010), and thus provides direction and guidance to policymakers on when thresholds of a management system are reached due to changes in the environment or societal preferences (Kwakkel et al., 2016).

4.3.4 Threshold and salinity-affected threshold yield loss

The first step in determining tipping points is to identify the threshold level of a system as understood by the different stakeholders associated with that system. In the biophysical system, the threshold is often considered to be irreversible (Russill and Nyssa, 2009). In agricultural systems, thresholds are considered to be the points where the perceived cost of applying inputs exceeds the perceived benefits (Gomez et al., 1997). In the socio-ecological system, thresholds signify the maximum acceptable limits that are perceived as being inadequate to meet demand, and where adaptation involves alternate options as a means of dealing with

the changes in the system (Bardsley and Hugo, 2010). For this study, we defined the salinity-affected threshold yield loss as the level of yield loss (%) under saline environments that different types of farmers perceive as being unacceptable for continuation of rice cultivation during the dry season.

4.3.5 Selection and description of the study area

This study was undertaken in four coastal villages in the salinity-affected coastal region of Bangladesh. Satkhira district from the south-western and Chittagong district from the south-eastern coastal regions were selected based on the severity of their salinity-affected areas, with Satkhira being one of the worst affected districts and Chittagong being one of the less salinity-affected districts (Appendix 4.1). In addition, these districts represent a distinct coastal saline environment where crop agriculture, shrimp aquaculture and salt farming represent the dominant land use practices (Fig. 4.1). Assasuni and Banskhali sub-districts were then selected from the Satkhira and Chittagong districts, respectively, and two villages from two unions⁸ of Assasuni sub-district and two villages from two unions of Banskhali sub-district were selected to conduct the household survey (Fig. 4.2).

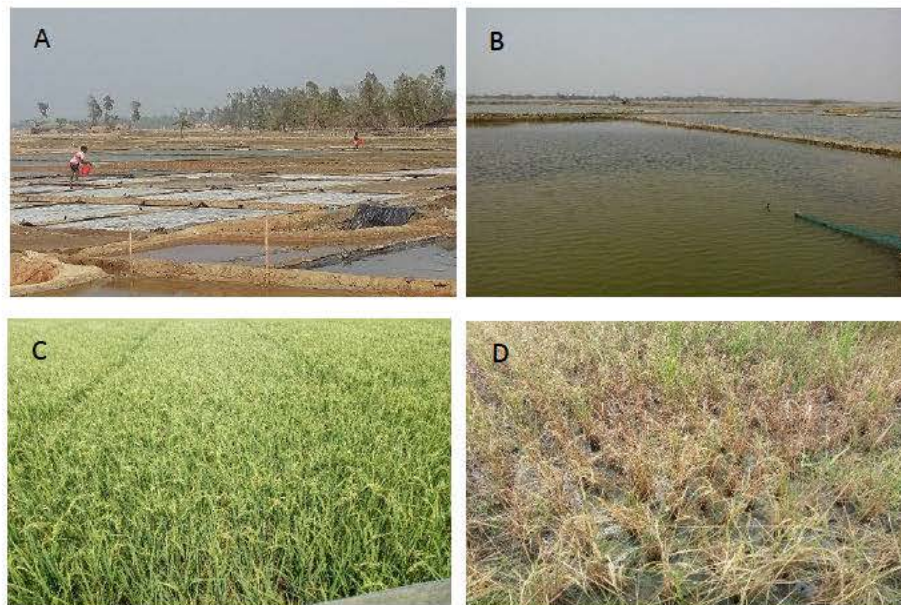


Fig. 4.1. Different farming practices in the study area. Salt farming (A), Shrimp farming (B), Rice farming (C) and Salinity-affected rice field (D). Pictures taken by the lead author during the field trips

⁸ Union is the lowest tier of local government in Bangladesh. There are 4554 unions in Bangladesh.

<https://oldweb.lged.gov.bd/DistrictArea2.aspx?Area=UnionParishad&DistrictID=39>

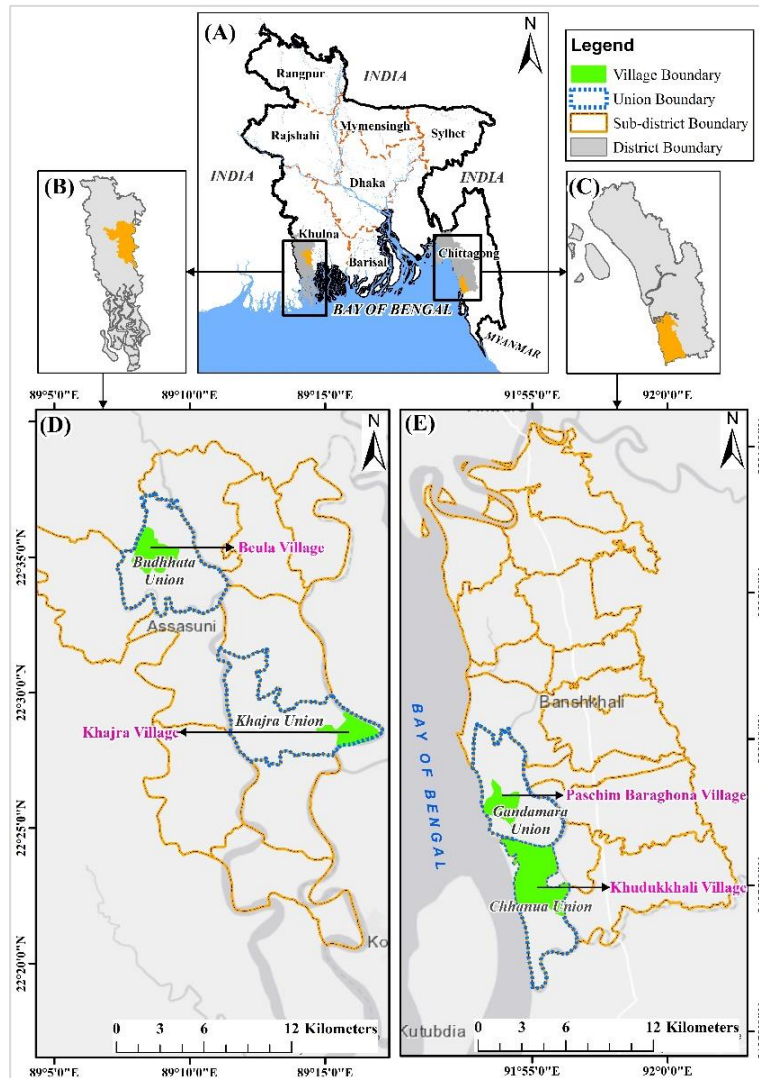


Fig. 4.2. Study locations in the coastal areas of A) Bangladesh. B) Assasuni sub-district - Satkhira district, and C) Banskhalia sub-district - Chittagong district. The studied villages: D) Beula village in Buddhata union, Khajra village in Khajra union, and E) Paschim Baraghona village in Gandamara union, and Khadukkhali village in Chhanua union

4.3.6 Data sources, data collection and threshold yield loss determination methods

This research used both primary and secondary data. Primary data were collected through formal household surveys conducted in 2018 (January to April) and 2019 (February to April). Before conducting household surveys, Human Research Ethics Approval (HREA) was received from the University of New England, Australia (Approval No. HE17-272). A multi-stage stratified random sampling procedure was followed to select the survey respondents. For the survey, 61

dry season rice farmers and 59 shrimp farmers from the two villages in Assasuni sud-district and 48 dry season rice farmers, 48 shrimp farmers and 64 salt farmers from the two villages in Banskhali sub-district were randomly selected (Appendix 4.2). A similar multi-stage random sampling procedure has been used in other studies in the coastal areas of Bangladesh; for instance, Hasan and Kumar (2020) and Islam et al. (2020) studied farmers' perceptions of climate change and salinity. Sub-district agriculture and fisheries officers provided advice on the villages where salinity is a major problem for rice cultivation, which has resulted in reduced rice farming and/or changes to shrimp and salt farming. Farmers were categorised as rice, shrimp and salt farmers based on the main occupations and the principal income source. Although respondents were categorised into three farmer types, all types of farmers cultivate rice to some extent, even if for subsistence use only (Barai et al., 2019). Salt farmers from Banskhali sub-district were also included, as salt farming in this area is one of the major livelihoods in addition to shrimp farming, and also influences salinity dynamics as well as rice farming during dry season (Al Mamun et al., 2014). Male respondents from each household of the three categories of farmer were selected for face-to-face interviews.

Pre-tested and semi-structured questionnaires were used to collect primary data from the selected farmers. Respondents from each farming category were asked about their primary income sources and land use patterns, specifically the land under different crops. They were asked about their perspectives of rice cultivation under saline environments, the season when less land was used for rice cultivation and why they commit less land for rice during this season. To examine the perceived impact of high salinity on rice yield, all farmers were asked about rice yield under high salinity. Farmers were also asked about the rice yield they obtained during dry season rice cultivation in fields unaffected by salinity, as well as their perceived yield if salinity affected the crop during the salinity-sensitive stages, such as the reproductive stages. Rice farmers were also asked about the least acceptable yield below which they would discontinue dry season rice cultivation. Similar questions were posed to shrimp and salt farmers, but their question was the minimum yield from their previous experience at which point they decided to reduce cultivation of dry season rice and shift to shrimp and salt farming. Farmers provided their perceived yield of rice in local units, which were number of mounds/bigha. These yield values

were then converted to t/ha for data analysis, based on 1 ha being equal to 7.41 bigha, and 1 tonne being equal to 27 mounds, and the converted values were used to calculate the salinity-affected threshold yield loss (%). Salinity-affected threshold yield loss (%) was calculated using the following equation:

$$\frac{\text{Perceived yield from field unaffected by salinity} - \text{Perceived least acceptable yield}}{\text{Perceived yield from field unaffected by salinity}} \times 100$$

The reason for not directly asking farmers for a threshold yield loss was to derive the percentage based on their reported and expected yield, as farmers were able to report and estimate rice yield as it was based on their local measure of yield. Thus, calculated threshold yield loss represented more accurately farmers' perceived threshold rather than asking them what percentage of yield loss they would tolerate. To calculate whether reported yield of a district in the coastal regions is below or above the farmers' perceived threshold, farmers' perceived least acceptable yield was used as common metric, and it was then compared with the reported yield of that respective district (BBS, 2020). Based on these threshold yield loss values, a rice yield map was developed for the coastal areas of Bangladesh to demonstrate which areas of the coastal regions are more sensitive to farmers' derived threshold.

Focus group discussions and key informant interviews were conducted to complement the survey findings on farmers' perceptions, particularly yield loss of rice under salinity, unacceptable yield loss (i.e. threshold yield loss) and reasons for shifting to other farming options. In total, two focus group discussions and 22 key informant interviews were conducted. The participants of the focus group discussions were selected from the earlier survey list and included experienced rice, salt and shrimp farmers. Key informant participants included personnel from the Agriculture and Fisheries departments, rice breeders, soil scientists and NGOs from both local and national levels. Key informant interviews were carried out at the office of each participant. Participants confirmed their voluntary participation in the interviews. A similar procedure of validating survey data through key informant interviews and focus group discussions was reported when investigating farmers' perceptions of salinity and climate change vulnerability in the coastal areas (Hasan and Kumar, 2019).

4.3.7 Data analysis

The data collected from the household survey of farmers were coded and analysed using IBM SPSS statistical software (Rovai et al., 2013). All questionnaire data were transcribed from Bengali to English by the lead author (M. A. Islam), who is fluent in Bengali. The responses to the open-ended questions were categorised into common themes and coded with a number to conduct the analysis. An ANOVA was conducted to compare the means of the different independent variables in the two locations as well as among the three farmer types. The independent variables examined were age, educational qualifications, total farm size (owned land and rented land combined), land ownership (owned land only), farming experience (years) and monthly income. Farmers' perspectives of their farming were analysed using cross-tab analysis. These perspectives were related to primary income source, major land-use patterns, least rice growing seasons and why, reasons for reduction in dry season rice, and shifting to shrimp or salt farming. Chi-square tests were conducted for these categorical variables to examine whether the farmers' perspectives on farming enterprises in the two study locations varied significantly in relation to each of the categorical variables (i.e. frequencies against each category). Similar Chi-square tests have been used to examine categorical variables in several studies that have investigated the significance of farmers' perceptions of salinization and climate change (Al-Amin et al., 2019; Islam et al., 2020). Land use patterns were calculated using MS Excel from the farmers' total cultivable land and land under different crops, and expressed as a percentage. An ANOVA was carried out to examine the difference in perceived yield in fields unaffected by salinity, affected by high salinity, least acceptable yield and maximum acceptable yield loss. Post hoc analysis was carried out to identify the significant differences in these variables among the different farmer types and location. The schematic representation of the research framework presented in the figure 4.3.

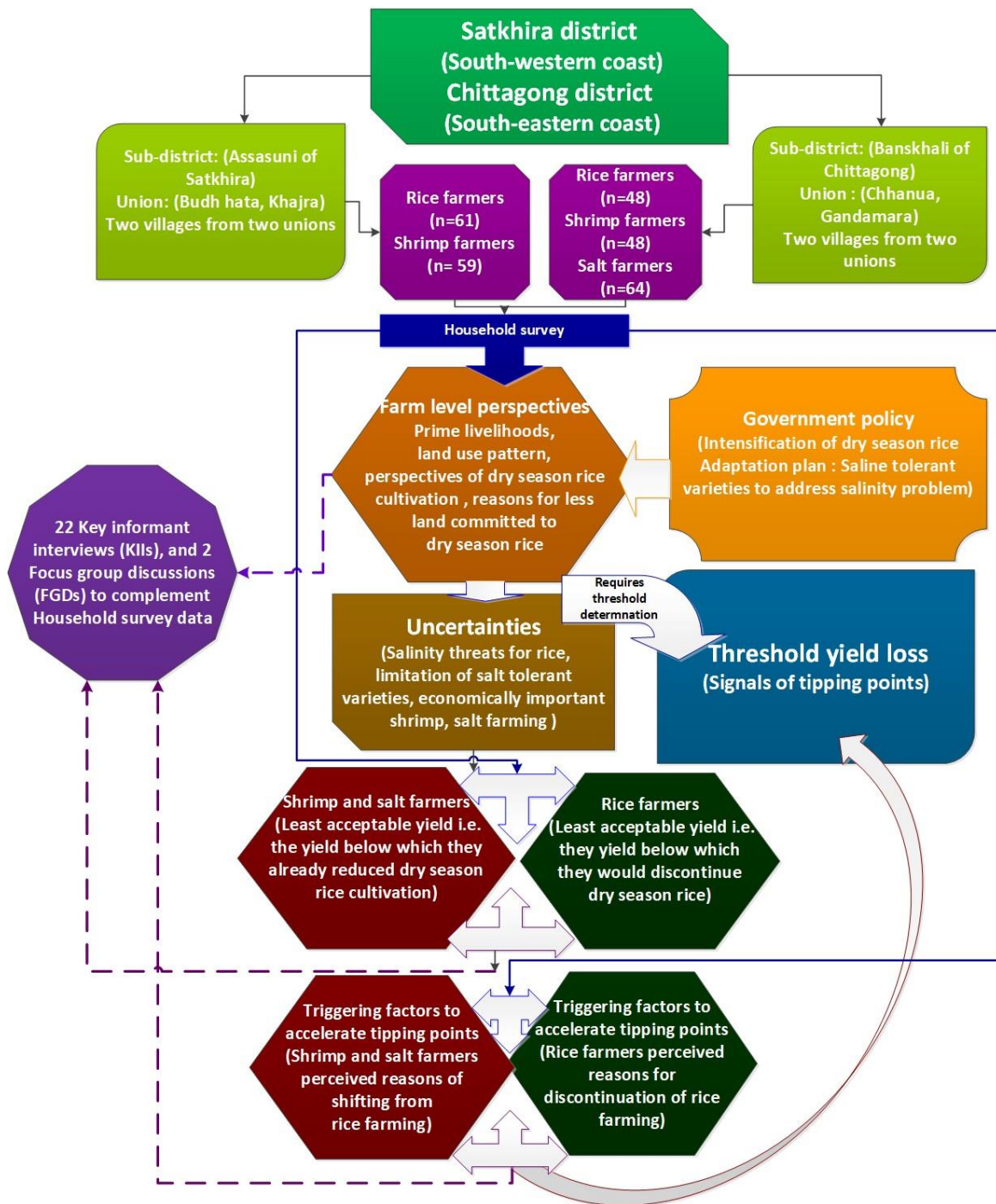


Fig. 4.3 Schematic representation of the research framework to determine the threshold yield loss through ATP approach

4.4 Results

4.4.1 Socio-demographic features of the farmer types and location

The salient features of the three groups of farmers in the two study locations are presented in Table 4.1. Education was the key demographic feature that varied significantly between the farmer types in the two study locations, as the education qualifications differed significantly between farmer types and between the two study locations. In both study locations, shrimp farmers had an average between one to three years more schooling compared with rice farmers. Of all the farmer types, salt farmers had the least educational qualifications (only three years of schooling). However, in relation to age and farming experience, most farmers were approaching 50 years of age and farming experience was around a quarter of a century (Table 4.1). In Banskhali, salt farmers had the longest farming experience (25 years), while rice and shrimp farmers had 21 and 24 years of farming experience, respectively, in the same locality. In Assasuni, rice farmers had 23 years of farming experience and the shrimp farmers had only 20 years of farming experience. Total farm size was also significantly different between the farmer types in the two study locations. Shrimp farmers in both locations had larger farms when compared to the rice and salt farmers. In Banskhali, the average farm size of shrimp farms was 42 bigha, which was more than double that of the shrimp farmers in Assasuni. In contrast, rice and salt farmers in Banskhali had 6.60 and 7.63 bigha of land, respectively, while rice farmers in Assasuni had 9.07 bigha. The mean monthly income was significantly different between the farmer types, but average monthly income in the study locations was not. Average monthly income of the shrimp farmers in both study locations was almost double that of rice and salt farmers (Table 4.1).

Table 4.1. Socioeconomic characteristics of the different groups of farmers in the two coastal sub-districts in Bangladesh

Characteristics (unit of measurement)	Banskhali (south-east)						Assasuni (south-west)				F-values of ANOVA	
	Rice (n=48)		Shrimp (n=48)		Salt (n=64)		Rice (n=61)		Shrimp (n=59)		Farmer locations	Farmer types
	Mean	Std. D	Mean	Std. D	Mean	Std. D	Mean	Std. D	Mean	Std. D		
Age (yr)	48.87	7.52	47.77	7.93	47.73	7.80	46.31	9.62	45.83	9.01	3.78*	0.31 ^{NS}
Education (schooling yr)	5.31	5.54	8.08	4.15	3.03	3.04	7.77	5.10	8.71	4.80	6.11**	16.27**
Total farm size (Bigha ⁹)	6.60	3.85	42.52	29.40	7.63	5.54	9.07	6.19	17.74	20.50	22.52**	59.31**
Land ownership (Bigha)	3.33	3.70	16.56	25.21	2.02	2.26	5.62	4.85	10.10	1073	1.55 ^{NS}	21.38**
Farming experience (yr)	21.92	5.75	24.38	7.87	25.58	7.14	23.89	9.83	20.50	7.54	0.74 ^{NS}	2.08 ^{NS}
Monthly income (BDT ¹⁰)	10730	3562.4	20645	3369.0	12192	3695.6	11983	4014.8	17794	2468	2.55 ^{NS}	141.16**

** , * represent significance at 5% and 1% level, respectively. NS = Not significant.

⁹ 1 ha=7.41 bigha

¹⁰ 1 BDT = 0.016 USD

4.4.2 Primary income sources of farmers

The primary sources of income varied among farmer types and study location (Table 4.2). Among the rice farmers in Assasuni, rice and other crop cultivation was the main source of income for around 87% of the farmers, while for around 13% of the rice farmers, it was rice and other crops alongside shrimp farming. A similar pattern of main income source distribution was reported by rice farmers in Banskhali. In contrast, among the shrimp farmers in Assasuni, 78% had shrimp farming as the main income source and 22% shrimp along with rice and other crops as their main income source. Among the shrimp farmers in Banskhali, around 80% had shrimp and salt farming as their main income source, while around 20% were involved in shrimp farming only. Among salt farmers in Banskhali, 78.1% reported salt farming as the primary income source, 20.3% reported rice, other crops and salt farming, while 1.6% reported shrimp and salt farming.

Table 4.2. Primary source of income categorised by farmer types in the two coastal sub-districts of Assasuni and Banskhali

Type of farmer	Locations (number)	% of the respondents					
		Rice and other crops cultivation	Rice and other crops cultivation, salt farming	Rice and other crops cultivation, shrimp farming	Shrimp farming	Shrimp and salt farming	Salt farming
Rice	Assasuni (61)	86.9	0.0	13.1	0.0	0.0	0.0
	Banskhali (48)	85.4	14.6	0.0	0.0	0.0	0.0
Shrimp	Assasuni (59)	0.0	0.0	22.0	78.0	0.0	0.0
	Banskhali (48)	0.0	0.0	0.0	20.8	79.2	0.0
Salt	Banskhali (64)	0.0	20.3	0.0	0.0	1.6	78.1

Chi-square test = 495.9**

** represent significant at 5% level of significance

4.4.3 Land use pattern of the different types of farmers in the coastal areas

Land use pattern (i.e. the percentage of land under each farming enterprise), differed significantly between farmer types (Fig. 4.4). Rice farmers in Assasuni and Banskhali were mostly

committed their land to rice (86%), with livestock and other crops using a smaller proportion of land (11.5%), while some land was used for salt and/or shrimp farming (Fig. 4.4A). The land use of the shrimp farmers in Assasuni includes 87% of land under shrimp farming, 11% under rice and 2% of land being used for livestock and other crops. On average, 70% of the land owned by shrimp farmers in Banskhali is used for shrimp farming, 24% for salt, and the remainder for rice, livestock and other crops (Fig. 4.4B). Most of the land belonging to salt farmers in Banskhali was used for salt farming (86%), 11% for rice, 2% is for livestock and other crops, and 1% is used for shrimp farming (Fig. 4.4C).

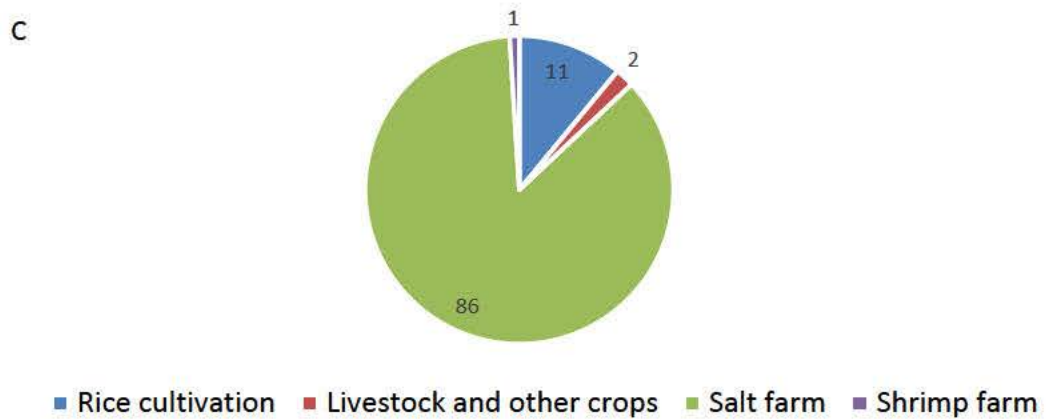
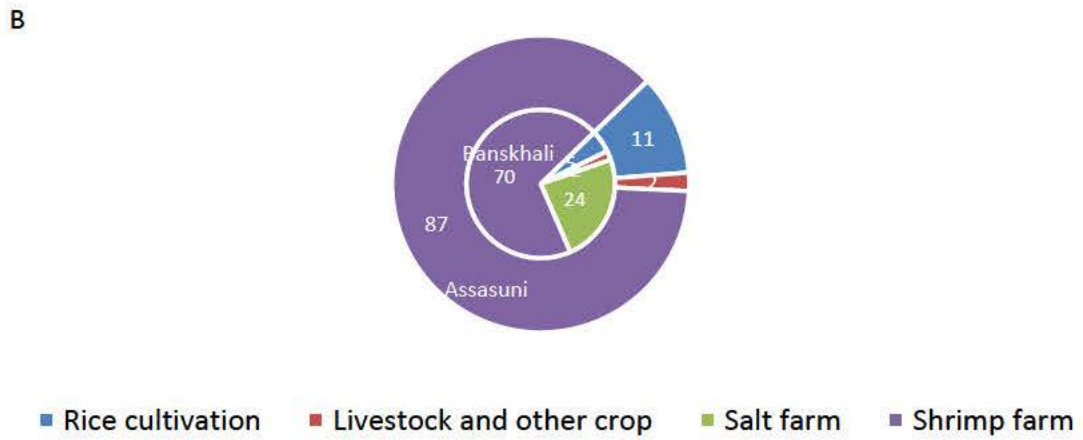
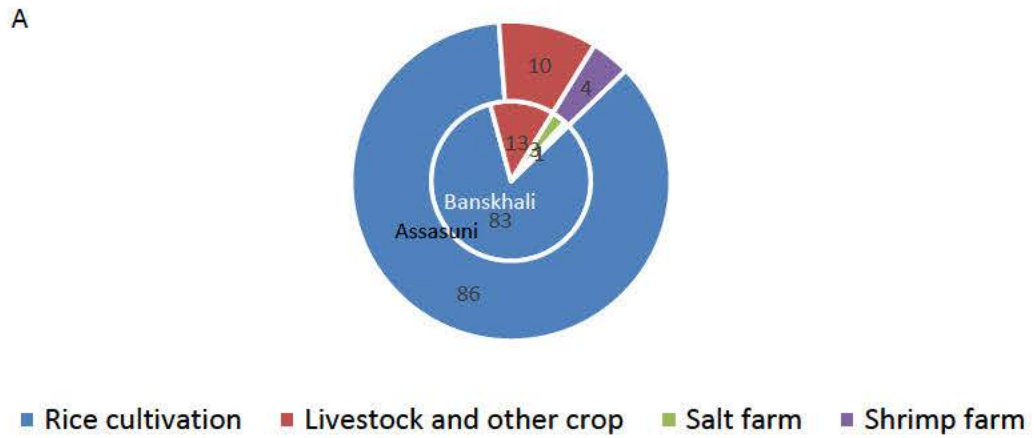


Fig. 4.4. Land use pattern in coastal study areas of Bangladesh of A) rice farmers of Assasuni and Banskhali, B) shrimp farmers of Assasuni and Banskhali, and C) salt farmers of Banskhali

4.4.4 Least rice growing season in the coastal study area

Farmers were asked in which season they usually commit less land to rice. A significant difference was found between the seasons that farmers choose to grow rice. Those farmers not growing rice or with a small land area committed to rice growing overwhelmingly regarded the dry season as being less favourable. Similarly, a high proportion of rice farmers from both study areas viewed the dry season as being the least favourable season for rice growing (Assasuni 85.2% and Banskhali 75% of respondents, respectively). The more favoured rice growing season is Aman, especially for those farmers growing small areas of rice (Table 4.3).

Table 4.3. Least utilised rice growing season for commercial or subsistence reasons according to farmer type in the two coastal areas of Bangladesh

Type of farmers	Locations (Number of respondents)	% of the respondents		
		Response rate	Boro	Aman
Rice farmer	Assasuni (n=61)	100	85.2	14.8
	Banskhali (n=48)	100	75.0	25.0
Shrimp farmer	Assasuni (n=54)	91	97.3	2.7
	Banskhali (n=38)	79	95.8	4.2
Salt farmer	Banskhali (n=42)	67	94.9	5.1

Chi-square = 17.85**

** represent significant at 5% level of significance

4.4.5 Farmers' perceived causes of reduced rice cultivation during dry season

Farmers' perceived causes for reduced rice cultivation during the dry season commonly referred to the lower yield in the two study locations. However, the lower yield was combined with other factors. For instance, in the case of the rice farmers in Assasuni, there is also the issue of the scarcity of irrigation water. Most shrimp farmers in Assasuni and in Banskhali (64% and 70% of respondents, respectively) stated that the higher labour requirement is a reason for growing less rice in the dry season in addition to the problem of reduced yield due to high salinity. The largest proportion of salt farmers in Banskhali (37.4%) cited reduced yield due to high salinity and high production costs as the major causes of reduced rice cultivation during the dry season (Table 4.4).

Table 4.4. Farmers’ perceived causes of reduced rice cultivation for commercial or subsistence purposes in dry season categorised by farmer type, and location

Type of farmers	Locations (Number of respondents)	% of the respondents			
		Lower rice yield due to high salinity and scarcity of irrigation water	Lower rice yield due to high salinity, high production cost	Lower rice yield due to high salinity, higher labour requirement	High production cost and less profitable
Rice farmer	Assasuni (n=61)	65.4	25.0	0.0	9.6
	Banskhali (n=48)	41.7	36.1	0.0	22.2
Shrimp farmer	Assasuni (n=54)	5.4	19.6	64.3	10.7
	Banskhali (n=38)	10.9	15.1	70.0	13.0
Salt farmer	Banskhali (n=42)	25.4	37.4	18.6	18.6

Chi-square = 109.9**

** represent significant at 5% level of significance

4.4.6 Rice farmers’ perceived reasons for discontinuing rice cultivation during dry season

For nearly 50% of rice farmers at both locations, a loss of yield was the major reason for discontinuing rice farming (Table 4.5). The other almost 50% of rice farmers in Assasuni, also suggested that they would get “involved in shrimp farming”, along with yield loss due to severe salinity. The remaining 50% of rice farmers in Banskhali responded that “rice farming will not be profitable, will move to other types of farming” but did not specify the type of enterprise (Table 4.5).

Table 4.5. Rice farmers’ perceived reasons for discontinuing rice cultivation during dry season

Locations (Number of respondents)	% of the respondents		
	Yield loss of rice due to salinity will be severe	Rice farming will not be profitable, will move to other type of farming	Yield loss of rice due to high salinity will be severe, will be involved in shrimp farming
Assasuni (n=61)	44.3	8.2	47.5
Banskhali (n=48)	47.9	50.0	2.1

Chi-square = 37.89**

** represent significant at 5% level of significance

4.4.7 Shrimp and salt farmers' perceived reasons for shifting to shrimp and salt farming

Farmers have been influenced to shift to shrimp and salt farming by a variety of factors. No single factor leads to the shift from dry season rice growing to shrimp or salt farming. The most common reasons farmers reported for taking up shrimp farming were a combination of factors that included profitability, lower labour requirements and the reliability of income, as well as the effects of high salinity on yield in the dry season (Fig. 4.5), as evidenced by 45% of salt farmers in Banskhali citing higher yield loss of rice due to high salinity.

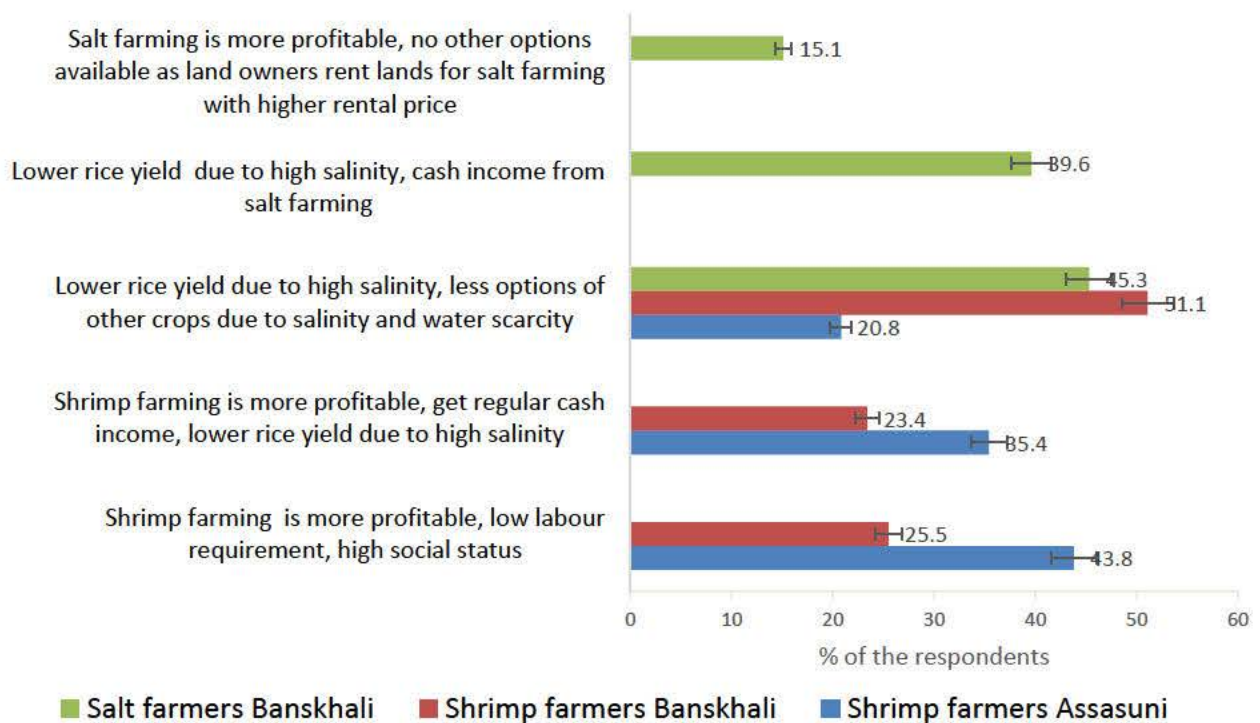


Fig. 4.5. Perceived reasons for reducing rice cultivation and shifting to shrimp and salt farming in the coastal studied locations

4.4.8 Farmers' perceived yield of rice in non-saline and high saline environments, and the least acceptable yield

There were significant differences in rice yield between the fields unaffected by salinity and the fields affected by high salinity, as well as a perceived least acceptable yield among the different types of farmers in the two coastal sub-districts surveyed. Rice farmers perceive rice yields to be higher in non-saline conditions and reduced under high saline conditions, and are

prepared to accept a lower rice yield before they would stop growing rice compared to shrimp and salt farmers (Table 4.6).

Table 4.6. Reported yield from rice fields unaffected by salinity, perceived yield under high salinity, and the perceived least acceptable yield by the different types of farmers in the two study locations

Farmer types and location		Perceived yield in field unaffected by salinity (t/ha)		Perceived yield in high salinity affected field (t/ha)		Perceived least acceptable yield (t/ha)	
		Mean	Std. dev	Mean	Std. dev	Mean	Std. dev
Farmer type	Rice farmer (n=109)	5.32 ^a	0.46	2.94 ^a	0.41	4.06 ^a	0.32
	Shrimp farmer (n=107)	5.22 ^{a,b}	0.35	2.54 ^b	0.37	4.40 ^b	0.27
	Salt farmer (n=64)	5.13 ^b	0.34	2.42 ^{b,c}	0.33	4.39 ^{b,c}	0.29
Location	Assasuni (n=160)	5.1	0.43	2.5	0.46	4.3	0.36
	Banskhali (n=120)	5.3	0.37	2.8	0.40	4.2	0.31
F-value of farmer type		5.06**		45.67***		39.30***	
F-value of location		4.84**		19.77**		3.7**	

***, ** represent significance at 1% and 5% level of significance, respectively.

Mean values in column having common letters did not vary significantly

4.4.9 Salinity-affected threshold yield loss

The threshold yield loss (%) perceived by rice farmers was significantly different from that of the shrimp and salt farmers. However, no significant difference was recorded in the perceived threshold yield loss among the shrimp and salt farmers. Moreover, the perceived threshold yield loss among the farmers in the two study locations showed highly significant differences. The mean threshold yield loss (%) perceived by the rice farmers was 23%, while shrimp and salt farmers perceived the threshold yield loss as 16% and 14%, respectively. The farmers in Banskhali perceived a higher level of threshold yield loss (20%) compared to the farmers in Assasuni, who perceived the threshold yield loss in rice as 17% (Fig. 4.6). Moreover, combining all types of farmers in the two study locations, the salinity-affected threshold yield loss was determined as 18%.

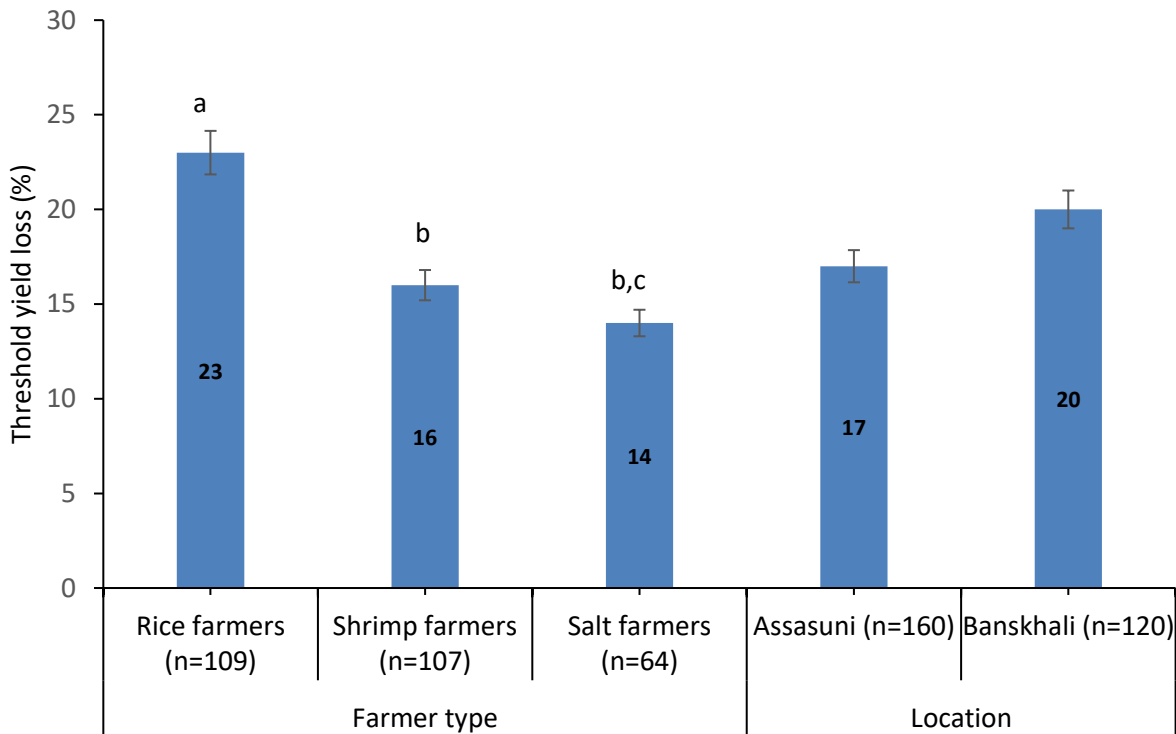


Fig. 4.6. Salinity-affected thresholds yield loss (i.e. maximum acceptable yield loss) as perceived by rice, shrimp and salt farmers in south-west and south-east coastal regions of Bangladesh. F-value of farmer type=74.83***, F-value of location=14.85***, columns having common letters did not vary significantly

4.4.10 Yield map of the dry season rice in the coastal areas of Bangladesh

This study indicated that the least acceptable yield among the sampled farmers varied from 4.06 t/ha to 4.4 t/ha with an average of all sampled farmers being 4.3 t/ha. Using the farmers' perceived least acceptable yield (i.e. 4.3 t/ha) as the common metric, it was then compared with the reported average yield in the respective districts (BBS, 2020). This study then calculated whether the reported yield in the respective districts is below or above the farmers' perceived threshold yield (Table 3 SI). A rice yield map of the whole coastal area of Bangladesh then developed to visually demonstrate the status of actual yield in the respective districts (i.e. whether the rice yield below or above the farmers' perceived threshold). The rice yield map indicates that in most of the areas (districts) in the exposed coastal region, dry season rice yields are already below the farmers' perceived threshold signifying possible tipping points (Fig. 4.4). The results also demonstrate that the Barguna and Patuakhilai districts were the most vulnerable areas in term of reaching the farmers' perceived threshold yield loss.

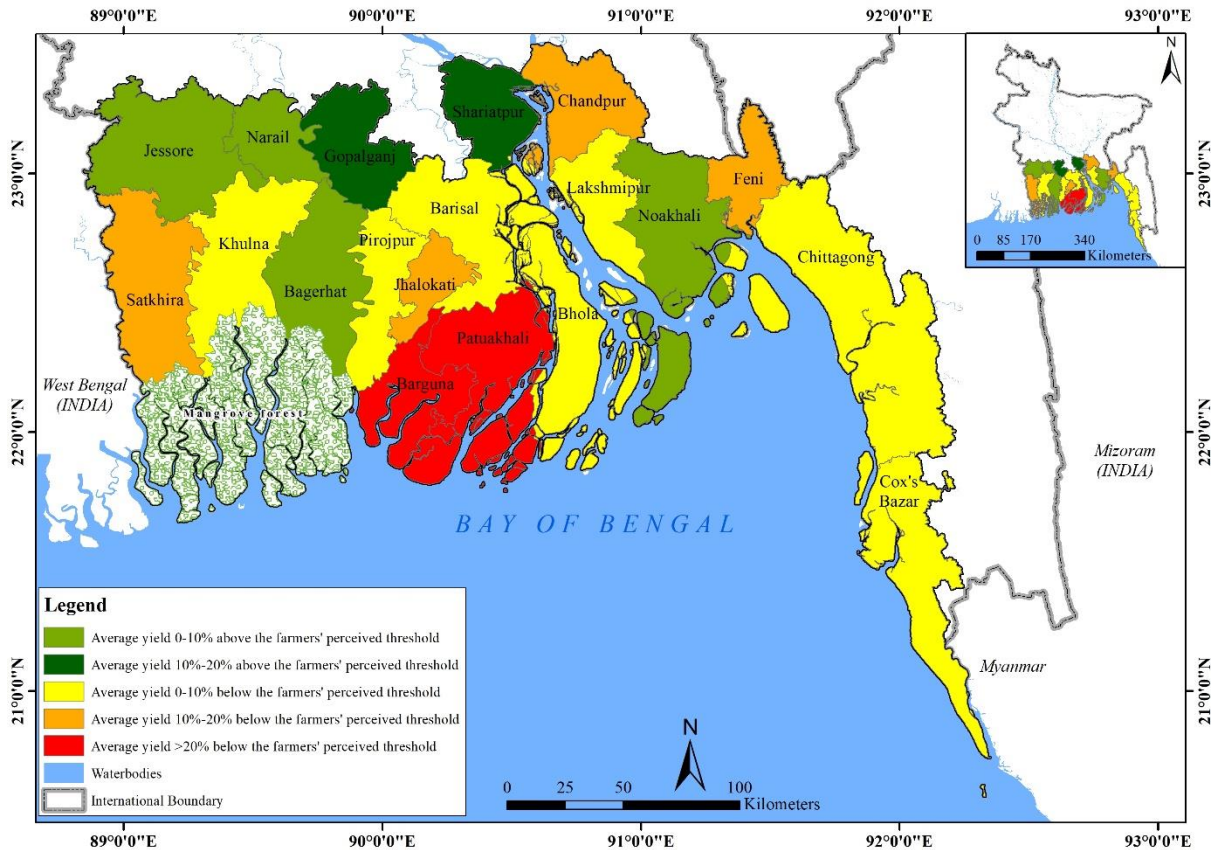


Fig. 4.7. Dry season rice yield map in the coastal regions of Bangladesh. Green-coloured areas indicate average yield is higher than the farmers’ perceived threshold, and yellow to red areas indicate yield in these areas is already below the farmers’ perceived threshold

4.5 Discussion

According to the policymakers in Bangladesh, the coastal areas have the most potential for agricultural intensification, and in this instance the expansion of rice in dry season to achieve the SDGs. In this study, the ATP approach was applied to determine the threshold yield loss (%) under an increasingly coastal saline environment by considering the perspectives of different types of farmers who grow rice to a greater or less extent. Firstly, we will discuss the perspectives of these different farmer types in relation to dry season rice cultivation, and their perceived yield loss thresholds under coastal saline environment. We then discuss the research and extension policy

implications of these thresholds in terms of intensification of rice cropping in the highly variable salinity-affected coastal areas of Bangladesh.

4.5.1 Perspectives of different types of farmers on dry season rice cultivation and their perceived yield loss thresholds in dry season rice farming

This study examined the perspectives of farmers in the coastal areas of Bangladesh who are currently growing rice (i.e. rice farmers), and those farmers who in the past had grown rice but now are predominately engaged in shrimp or salt farming. Results revealed that all types of farmers regardless of their location have allocated less land for dry season rice cultivation due to experiencing lower rice yield due to rising salinity. Indeed, salinity in the coastal areas has increased manyfold over the last three decades (SRDI, 2010) and farmers in the coastal areas of Bangladesh were aware of increased salinity in their crop fields (Hasan and Kumar, 2019; Islam et al., 2020b). This heightened awareness of increasing salinity and its impact on rice yield by farmers has been reported in several coastal rice growing areas of the world, even though the reduction in area of rice cultivation has been noted (Be et al., 2008; Hoque and Haque, 2016).

The results of this study indicated that regardless of the locations, farmers in the coastal areas have been focusing on the impact of rising salinity on rice yield, and they have perceived a 50% yield loss under high salinity levels, which may occur sporadically and patchily with not every farmer experiencing these conditions every year (Table 6). A previous study confirmed that farmers perceived a field as being highly saline if the salinity level was greater than 6.0 dS/m (Islam et al., 2020b). Several studies also reported around 50% yield loss of rice at a salinity level of 6.0 dS/m or higher (Hasanuzzaman et al., 2009; Radanielson et al., 2018b; Zeng et al., 2003). Thus, farmers perceived yield loss of rice under a high saline environment is consistent with scientific evidence. This signifies that farmers accurately perceived yield loss if their rice field was experiencing high salinity. Thus, the salinity-affected threshold yield loss determined in this study aligns closely with the rice farming experiences of different types of farmers in a coastal environment threatened by increasing salinity. However, a more holistic threshold yield loss value should also include other factors, other than high salinity that also influence rice yield penalties such as season, other soil degradation issues (e.g. soil acidity, loss of soil carbon and

soil structure decline), agronomic practices (e.g. transplanting time, spacing, weeding, fertilizer, irrigation and rice variety).

This study has shown a significant difference in the perceived threshold yield loss among the different types of farmers in the two studied coastal sub-districts. Although all farmers were sensitive to yield loss, results revealed that rice farmers would tolerate higher yield loss compared with shrimp and salt farmers. As rice farming was not the primary income source of shrimp and salt farmers, a smaller yield loss was considered less acceptable to them. Nevertheless, as shrimp and salt farmers have reduced rice cultivation to subsistence levels it seems yield loss due to salinity is not a high priority consideration. In contrast, it seems rice farmers were prepared to tolerate a higher degree of yield loss because they have fewer options to move out of rice farming to other enterprises due to low income, and small landholdings. Literature shows that shrimp and salt farming requires capital investment that is beyond the current financial capacity of many rice farmers (Gurung et al., 2016; Hossain et al., 2006).

Despite all farmers perceiving a 50% yield loss if salinity conditions were high, the threshold yield loss at which all types of farmers would cease to grow rice in the dry season is far lower (18% across all farming types), indicating a heightened sensitivity of farmers to saline conditions. Thus, it indicates that farmers might not wait until 50% yield loss to discontinue dry season rice cultivation. However, the evidence for actual salinity levels in farmers' fields is difficult to obtain with the most recently published data on actual salinity levels was in 2009. Thus, farmers' actual experience of high salinity levels is difficult to verify but it could be surmised that their experience of high salinity levels is likely to be spatially patchy, and highly variable over time, with the wet season not experiencing high salinity as much as the dry season. Thus, farmers may not encounter high salinity conditions on an annual basis, but they generally perceive that conditions have worsened over time, especially for rice farmers. However, the threshold yield loss would be consistent across land use types as this is the highest level of acceptable yield loss that the various farmer types would tolerate to continue dry season rice farming.

4.5.2 Policy implications of the farmers' perceived threshold yield loss and future research directions

Despite the threats of increasing salinization, expanding rice cultivation in the coastal areas remains a steadfast policy position of the Bangladesh Government to ensure food security and to achieve the SDGs (MoA, 2013; NAP, 2018). However, this study has shown the possible existence of threshold yield loss that could have policy implications as follows. Decision makers should consider farmer types and location specific extension advice for agricultural sustainability as tolerance of yield loss thresholds varied among the types of farmers as well as between the south-west and south-east coastal locations. The results showed that the rice farmers would tolerate a higher percentage of yield loss compared to other types of farmers, which we hypothesise is because they had limited options to move out of rice farming into other enterprises due to small farm size and inability to acquire more land. Shrimp and salt farmers expressed lower level of yield loss tolerance in dry season rice cultivation compared with rice farmers, which signifies the potential for converting their remaining portion of land under rice, albeit a small proportion, to these farming systems, especially as salinity worsens. In addition, these farming enterprises were more attractive to those undertaking them due to high profitability, high social status and less labour requirement. Under this scenario of dry season rice area continuing to reduce in land area, while other enterprises expand it is likely to limit the land available for rice cultivation during dry season. Indeed, shrimp and salt farming in the coastal areas increased substantially over the last three to four decades. The land area under shrimp farming has increased by 13 fold since the 1980s, while salt farming has more than doubled in land area (BSCIC, 2020; FRSS, 2018). Land zoning guidelines for crops, shrimp aquaculture, and salt farming based on the yield loss threshold could also allow sustainable coastal resource usage for all types of farmer. Thus, government research effort should be more focused on integrated land management to develop sustainable and environmentally friendly shrimp aquaculture, and salt farming technologies, which could also potentially reduce salinity intrusion into adjacent crop land by uncontrolled shrimp, and salt farming expansion, and increase overall livelihoods of the coastal communities to ensure food security.

Scenarios of the dry season rice yield in the coastal areas of Bangladesh presented in Figure 7 indicated that reported yield of most of the areas (districts) in the exposed coastal region already below the farmers' perceived threshold. The results also demonstrate that the Barguna and Patuakhali districts were the most vulnerable in term of reaching the farmers' perceived threshold yield loss. Thus, it signifies the necessity of location specific government extension efforts to improve the rice productivity. For example, more efforts to disseminate existing high yielding and saline tolerant varieties could be useful to improve overall yield during dry season. In addition, extension services could invest greater effort in promoting farmers' salinity adaptation measures (e.g. early transplanting), which have shown potential merit in avoiding higher salinity during reproductive stages in dry season rice (Islam et al., 2020b). Furthermore, the development, and promotion efforts of high-yielding and saline-tolerant rice varieties for wet season particularly for coastal areas could potentially increase yield in this season to compensate salinity affected yield loss during dry season. However, flooding problem (flash floods, seasonal flood), waterlogging are also emerging issues which affects wet season rice cultivation. Thus, development and promotion of sub-mergence tolerant varieties should also be useful to compensate yield loss during dry season. However, waterlogging problem also reported as one of the emerging challenges in the coastal wet season rice farming particularly in the south-western region (Alam et al., 2017; Khan et al., 2015; Moniruzzaman, 2012). Thus, future research could be carried out to evaluate the trade-offs between salinity affected dry season rice and flooding affected wet season rice cultivation which would better inform policymakers to intensification decisions of rice farming systems in the coastal areas of Bangladesh.

The threshold yield loss defined in this study is farmer derived, and knowing the threshold yield loss can signal to policymakers at what % of yield loss a farmer would discontinue growing rice and when government needs to provide more support to keep them above that threshold. Determining the threshold yield loss (%) required data collection at a local level, and a governance process to incorporate this farmer derived value. Rather than using a response to a direct question on % yield loss that farmers would tolerate, this study calculated the threshold yield loss (%) from the yield that farmers would get from the unaffected fields and the minimum acceptable yield. This approach is more locally relevant as farmers might not be able to express

their tolerance yield loss in percentage terms but could provide what minimum yield they would accept in their local unit. Determining threshold yield loss from the local farmers' perspectives means that these are more locally relevant as it is legitimate with farmers' derived values. Thus, threshold yield loss determined in this study is locally relevant and a legitimate measure having been constructed from local farmers' perspectives and experience. At the same time, the data indicate to policymakers that the level of acceptable farmer risk is higher than first anticipated, and these signals need to be included in rice intensification planning as well as research priorities for sustainable coastal resource management. However, yield loss of rice is not the only determining factor that governs farmers' decision to stop growing rice. For commercial rice farmers, the market price of rice could have an influence if prices paid dropped markedly in combination with a higher level of expected yield loss, which needs to be addressed by further studies.

Limitations of this study were the inability to identify the actual salinity value against farmers' perceived yield loss thresholds in dry season rice and the time-frame when these salinity thresholds (i.e. tipping points of the dry season) would be reached. However, known threshold yield loss in dry season rice identified in this study can be used to functionalize the ATPs through modelling approaches. Future research could be carried out using appropriate crop models such as DSSAT (Hoogenboom et al., 2019) and APSIM (Radanielson et al., 2018a) to operationalize the realistic ATPs of dry season rice to investigate at what salinity level and length of time-at which farmers' derived threshold yield loss would be reached.

4.6 Conclusions

The decision to cope with salinization in the coastal areas while maintaining sustainability in coastal rice farming during the dry season is becoming more complicated due to multi-dimensional issues interconnected with food security and the SDGs. This study applied the adaptation tipping points (ATPs) approach to determine the salinity-affected threshold yield loss that signals potential tipping points of dry season rice farming in the coastal areas of Bangladesh. Despite government actions to intensify rice farming in the coastal areas, it's cultivation during the dry season is in decline among all farmer types where salinity problems are apparent. Salinity that results in lower rice yield could initiate a plausible discontinuation of dry season rice farming

in the coastal areas, which could be accelerated by expansion of profitable land uses (e.g. shrimp and salt farming) which also require less labour and provide regular cash income to the farmers. Our study showed that there were significant differences in the salinity-affected threshold yield loss among farmer types. Rice farmers would tolerate a greater rice yield loss (23%) under saline conditions compared with the shrimp (16%) and salt farmers (14%). Differential salinity-affected threshold yield loss among the different types of farmers signifies the need of government action to promote sustainable land management research for a more diverse farming system that combines rice, shrimp and salt farming, instead of more effort in research and development into rice intensification, especially in dry season. This action could assist in delivering sustainable livelihood options to ensure food security and accelerate the achievement of the SDGs (e.g. “no poverty (SDG-1), “zero hunger (SDG-2)”, “good health and well-being (SDG-3)”).

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(To appear at the end of each thesis chapter submitted as an article/paper)

We, the PhD candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated in the *Statement of Originality*.

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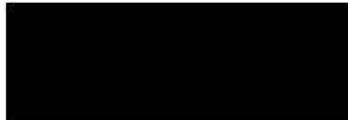
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Chapter 5

Synthesis and General Conclusions

5.1 Overview

The ultimate research aim of this study was to determine a farmer-derived threshold yield loss of dry season rice cultivation in coastal saline environments that could signal the plausible adaptation tipping points of salinity management of coastal dry season rice farming in Bangladesh. To achieve this aim, this study applied the adaptation tipping points (ATPs) approach. This approach has been reported to have great potential for guiding policymakers in making adaptation decisions (Hossain et al., 2018a; Werners et al., 2013). However, the use of the ATP approach in previous studies predominantly focused on engineering-based climate change adaptation decisions such as innovative water management systems (Kwadijk et al., 2010; Kwakkel et al., 2016), and computer-based simulation modelling of ecosystem services (Nanda et al., 2018; van Slobbe et al., 2016). This research provides new insights into how the ATP approach can be applied in the coastal rice growing system to inform policymakers about the potential existence of a threshold yield loss that could guide them in their adaptation decisions on rice-intensification planning in saline environments, and provides alternative options for achieving the sustainable development goals (SDGs).

To achieve this aim, it was first necessary to explore local rice farmers' perceptions of the salinity problem and their related adaptation actions to cope with the salinity, and then compare them with scientific understandings. Previous studies have confirmed that adaptation actions in response to natural disasters are shaped by people's perceptions (Adger et al., 2009; Mertz et al., 2009). In addition, understanding how the different types of farmers who live in close proximity perceive and respond to salinity is also imperative, as the salinity problem exhibits spatial and temporal variation, and could affect them in diverse ways (Clarke et al., 2015; Lázár et al., 2015). Thus, farmers' salinity perceptions provided a solid base for determining the threshold yield loss through the application of the ATP approach, which could signal potential tipping points for salinity management of coastal dry season rice farming. This management could be, for instance, through improvements in salinity-tolerant varieties as one means of salinity adaptation planning. In this chapter, key research findings are presented schematically in Figure 5.1. These key findings are discussed with reflections on the efficacy of the methods used, and the potential of these findings for future policy initiatives is discussed.

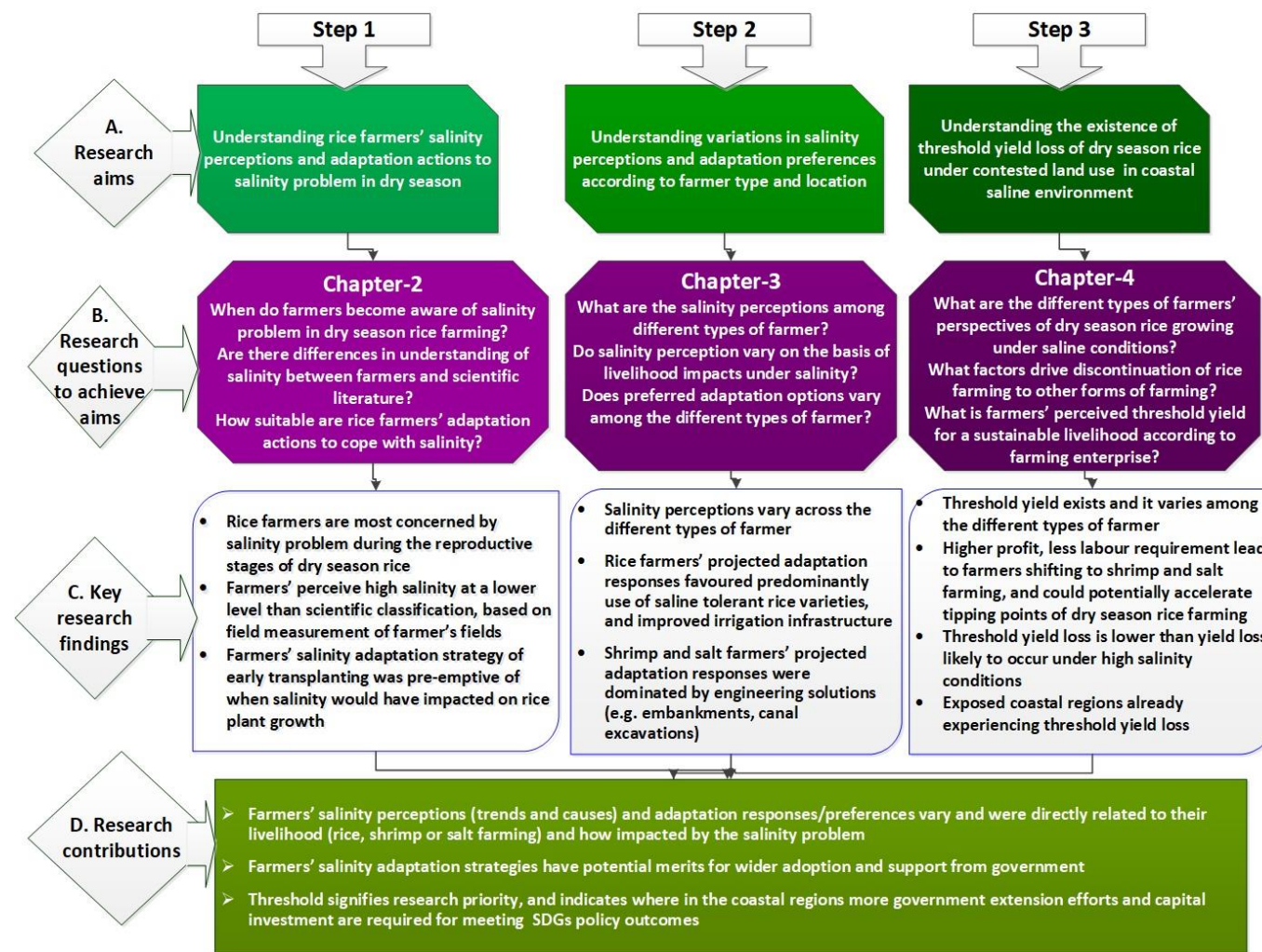


Fig. 5.1 Conceptual diagram of fundamental steps to apply ATP approach and key findings of the research work of “Adaptation tipping points of salinity management for Boro season (dry season) rice cultivation in the coastal areas of Bangladesh”. Key research aims are presented in Panel (A). The key research questions formulated to achieve the research aims are demonstrated in Panel (B). Panel (C) indicates the key research findings from each chapter. Research contributions are presented in Panel (D)

5.2 Understanding rice farmers' perceptions of salinity problem, their relevance and adaptation actions in dry season rice cultivation

This study explored rice farmers' salinity perceptions in order to understand their concerns of salinity problem in dry season rice cultivation. The study sought to investigate whether there were any differences in the understanding of the salinity problem between the farmers and the scientific literature, as well as their responses to cope with the problem. The results of this study have revealed that farmers ranked high salinity as the greatest challenge in dry season rice farming, followed by scarcity of irrigation water. Salinity in the coastal areas has risen over the last few decades (Baten et al., 2015) and has affected rice production. The literature also reported up to 50% yield loss of rice if the rice field is affected by salinity at or above the salinity level of 6.0 dS/m (Hasanuzzaman et al., 2009; Radanielson et al., 2018). Undoubtedly, a decline in yield potential could have influenced farmers' concern over increasing salinity in dry season rice cultivation. Additionally, rice cultivation during this season is highly dependent on irrigation. These two issues combined would exacerbate the salinity problem, hence the effects would be more apparent in the farmers' crop and would have heightened farmers' awareness of the impact (CCC, 2009). Several studies have indicated that salinity intrusion and scarcity of fresh water are the most challenging problems for coastal rice farming in Bangladesh (Haque, 2006; Shelley et al., 2016).

This study has shown that farmers perceived the reproductive stages of rice plants to be the most sensitive to salinity stress. Farmers reported higher yield loss if their rice fields were affected by salinity during these stages. Although most of the growth stages of rice plants were reported to be very sensitive to salinity stress (Grattan et al., 2002; Islam and Karim, 2010), farmers in the coastal study areas were more concerned about the salinity effects during the reproductive growth stages. In fact, temporal salinity trend data in the coastal study region of Bangladesh indicated that salinity levels start to increase from the month of March and peak over April to May (Clarke et al., 2015). In general, the reproductive stages of the rice plant during the dry season appear from March to April (BRRI, 2019; Shelley et al., 2016), and coincide with the higher salinity periods. Thus, farmers' awareness of the salinity problems during the reproductive stages was supported by measured data. Thus, these findings indicate that farmers' perceptions

were based on their experiences and observations of the problem during the rice-growing season.

This study has also shown significant differences in the understanding of high salinity between the farmers and the science-based classification of salinity levels (i.e. high or low salinity level). Along with in-field measuring of the salinity status, this study asked the farmers to report about their perceptions of the salinity levels in their crop field, and their opinion as to whether they perceived the salinity of that rice field as being high or low. Then, this study investigated how the field-measured salinity values (i.e. ECe values) have been categorised in the literature according to the soil salinity categorisation presented in the report of the Soil Resources Development Institute (SRDI, 2010). This study showed that the farmers' perceived a rice field as being affected by high salinity when the salinity is at a lower level than the literature would suggest. This finding demonstrates that farmers could observe damage (e.g. drying of leaves from the top, inflorescence becomes white) to their rice crops even at the lower salinity level. Thus, the findings of this study confirmed that farmers' perceptions of the salinity problem are strongly shaped by their experience of the salinity problem during dry season rice cultivation (Adger et al., 2009; Mertz et al., 2009). Furthermore, this study showed that early transplanting is one of the major adaptation strategies employed by farmers to cope with the salinity problem during dry season rice cultivation. To explore the suitability of the farmers' practised adaptation strategy of early transplanting, this study collected salinity data from the early, mid and late-transplanted farmers' rice fields. At the same time, the salinity measurement, growth stages of the rice plants and yield data from that farmer's crop were recorded. The findings indicated that those rice fields transplanted early recorded low levels of salinity during the sensitive reproductive stages. These observations demonstrate that the farmers' adaptation actions are pre-emptive of when salinity could have severe impacts on crop growth. Thus, findings revealed that farmers are well aware of the salinity problem, and understand when salinity problem could damage their crops, and their according adaptation actions have strong scientific basis to cope with salinity problem.

5.3 Understanding variations in perceptions of salinity and adaptation preferences according to different types of farmers

This study has shown that according to local farmers' perceptions, salinity has increased in the coastal areas of Bangladesh over the last 20 years, which is a situation that is also supported

by the literature (Hasan and Kumar, 2020; Hossain et al., 2018b). Even though salinity perceptions varied significantly among different types of farmers, they did not vary between the two studied locations. While the majority of the rice and salt farmers reported increasing salinity, almost half of the shrimp farmers mentioned that salinity has decreased in their locality over the last 20 years. These contrasting perceptions of salinity trends among the different types of farmers are due to the nature of the salinity impacts on their livelihood options. For example, a slight increase in salinity negatively affects growth and yield of rice and limits the options for rice cultivation. A vast body of literature indicates that rice farming land has been significantly reduced in the coastal areas of Bangladesh due to increasing salinity (SRDI, 2010; Szabo et al., 2016). Hence, rice farmers' perception of increased salinity is supported by empirical evidence. Farmers were most affected by salinity due to a reduction in rice yield, which they attributed to increasing salinity. In contrast, shrimp and salt farmers perceived a trend of decreasing salinity as these farming enterprises require saline water, and its presence does not negatively influence production in their farming enterprises.

In terms of causes of increased salinity in these coastal areas, this study also showed differential perceptions between the different types of farmers. The rice farmers' perceived drivers of increased salinity may be due to the limited options for their rice farming land. Their perceptions might have resulted from the conversion of cropping land to shrimp farming in their locality. In contrast, the shrimp and salt farmers' perceptions of natural causes may be influenced by their previous experience of yield loss of rice due to natural cyclone-induced salinity. In addition, these farmers may not consider that their own farming activities have been a factor in increasing salinity.

The rice, shrimp and salt farmers have differential framing of the salinity problem, which influences their adaptation preferences to cope with expected increases in salinity. The shrimp and salt farmers' preferences for strengthening embankments and canal excavation could be influenced by their perceptions of the causes of salinity. They believe that salinity is caused mainly by natural causes such as cyclone and siltation of rivers, and thus consider engineering solutions such as embankments and canal excavations as appropriate to cope with salinity. In contrast, although rice farmers perceived that salinity has increased in last 20 years, mostly due

to the expansion of shrimp and salt farming, their preferences for coping with salinity are dominated by agronomic solutions. Interestingly, the choice of agronomic solution rather than controlling shrimp and salt farming expansion could be due to the rice farmers having less land and less income compared to the shrimp farmers and salt farmers. Thus, they might not wish to express an opinion that could go against shrimp farmers, who are reported to be rich and powerful (Deb, 1998). The rice farmers suggested that improved salt-tolerant varieties of rice that have a higher degree of tolerance during the reproductive stages and improved irrigation facilities (e.g. electricity facility to operate irrigation pump) would allow them to adapt to increasing salinity. These types of solutions are more suited to their circumstances with their small landholdings and low income, especially when compared to the shrimp and salt farmers.

This study explored the perspectives of all types of farmers who live in the coastal areas to identify the differential framing of the salinity problem and understand the complex societal dynamics of this problem. The findings revealed that different groups of farmers have their own ideological behaviour and perceive the salinity problem in diverse ways. Additionally, different government organisations have their own organisational goals that affect national-level policymakers' adaptation decisions. For example, the mandate of the Ministry of Agriculture is to support rice farming in saline environments. At the same time, shrimp and salt farming is supported by other government organisations such as the Department of Fisheries and the Bangladesh small and cottage industries (BSCIC), which also prioritise shrimp and salt farming in the coastal areas, and consider them an essential part of local farmers' livelihoods. Thus, both the differential framing of the salinity problem and the enterprise-specific supported activities in these coastal areas necessitate research to further investigate the signals of plausible tipping points for dry season rice farming in the coastal saline areas that can incorporate these pluralistic views of the salinity problem.

5.4 Understanding the existence of threshold yield loss in coastal dry season rice farming systems

This study applied the ATP approach to investigate threshold yield loss that could signal possible tipping points of salinity management for dry season rice farming in the coastal saline environment. The perspectives of dry season rice farming of all types of farmer were investigated, and the factors that motivate farmers to shift to other types of farming (i.e. to shrimp or salt

farming) were examined. The threshold point of yield loss was considered as the yield loss (%) at which rice farmers would discontinue dry season rice farming, and where shrimp and salt farmers had already shifted to these alternative options.

Regardless of the locations, all types of farmers mentioned that their yield was reduced due to the impacts of salinity during the dry season. This situation resulted in them growing less rice during this season. It has also been reported that farmers in the coastal areas perceive that increased salinity in their crop fields (Hasan and Kumar, 2019; Islam et al., 2020) could result in commitment of less land to rice farming during the dry season. Over a period of time, there could be a shrinking of land committed to this enterprise, with possible discontinuation altogether. Shrimp and salt farmers have already reduced rice farming to subsistence levels and shifted to shrimp and salt farming because these enterprises are highly profitable, have a high social status and have a low labour requirement, rather than as a result of increasing salinity. Indeed, shrimp farming is reported to be highly profitable in many coastal areas of the world, which supports the opinions of the farmers in this study (Ahmed, 2013; Johnson et al., 2016; Kabir et al., 2016).

Despite all types of farmers indicating that up to 50% yield loss occurs under high salinity, the threshold yield loss at which they would shift from rice cultivation during the dry season was at a lower threshold (i.e. 18% yield loss). Thus, this threshold indicates a heightened sensitivity of farmers in dry season rice farming under the coastal saline conditions. This threshold figure could be the result of not all rice fields being affected by salinity but farmers generally perceiving that the salinity conditions have worsened over time. Indeed, there is considerable spatiotemporal variation in the salinity problem in the coastal areas of Bangladesh (Clarke et al., 2015). However, the yield loss threshold would still be consistent, as it is the highest level of acceptable yield loss they would tolerate to continue dry season rice farming.

The threshold yield loss determined in this study was farmer-derived, as it was based on their minimum acceptable yield to stay in dry season rice farming. This study calculated the threshold yield loss (%) from the yield that farmers would get from the unaffected fields and the minimum acceptable yield, rather than using a response to a direct question on % yield loss that farmers would tolerate. This calculation is more locally relevant as farmers may more easily express the minimum yield they would accept using their local unit rather than to express in

percentages. By expressing the minimum acceptable yield in their local yield unit, this study determined the actual threshold yield loss from the farmers' perceived yield from the unaffected rice field. Based on the farmers' threshold yield, this study revealed that average yield during the dry season in most of the exposed coastal regions, particularly in the central and south-western coastal regions of Bangladesh, is already below the threshold that could provide possible signals for tipping points dry season rice farming.

5.5 Potentials of the research findings to operationalise the ATP-driven research-extension policy initiatives

Previous studies conducted on farmers' perceptions predominantly focused on climate change issues (Biratu and Asmamaw, 2016; Kabir et al., 2019; Kabir et al., 2017). The few studies that have investigated farmers' salinity perceptions had a particular focus on drinking water salinity, health issues and coastal water management (Hasan and Kumar, 2019, 2020; Hossain et al., 2016; Hossain et al., 2018a; Javed et al., 2018; Kabir et al., 2020; Ziaul Haider and Zaber Hossain, 2013) rather than smallholder farming. By addressing the salinity problem in coastal dry season rice farming, this study is providing a new dimension for uncertainties in salinity adaptation planning in the rice-intensification decisions made under increasing saline environments with diverse salinity perspectives of the different types of farmers and livelihoods.

This study developed three fundamental steps (i.e. understanding rice farmers' salinity perception, differential perceptions of the salinity problem and understanding the existence of threshold yield loss, as presented in Fig. 5.1) to apply the ATP approach and achieve the ultimate research goal of determining the threshold level that signals tipping points for dry season rice farming. Salinity-tolerant rice varieties that have been developed and promoted by government agencies as a means of salinity adaptation have influenced policymakers to expand dry season rice in coastal areas as a solution to the salinity problem. Based on these steps, the actions required to operationalise the ATP-driven research-extension policy initiative are presented in Figure 5.2.

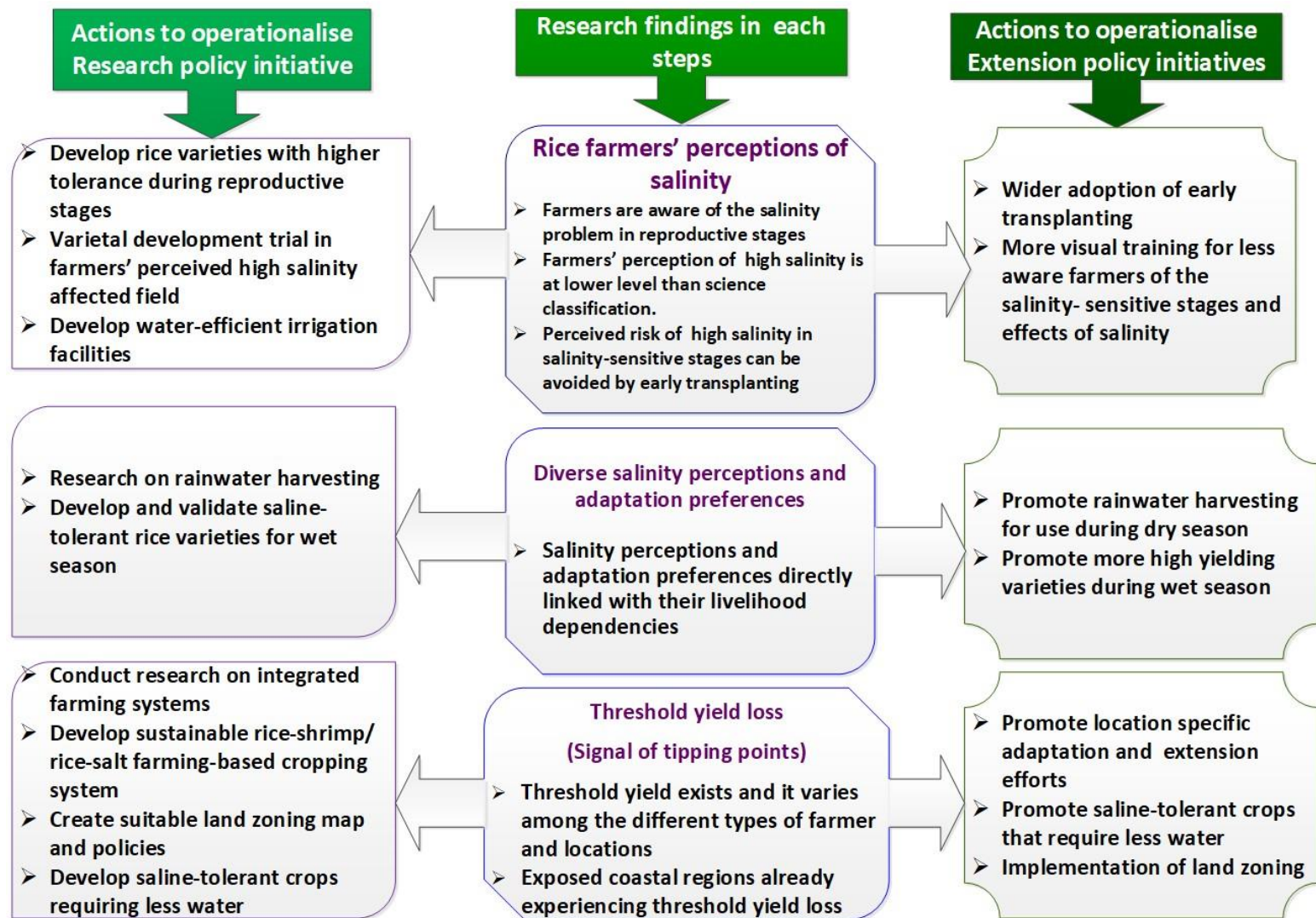


Fig. 5.2. Operationalising the ATP-driven research-extension policy initiative

In the first step (i.e. understanding the rice farmers' perceptions of salinity), this study addresses the rice farmers' perceptions of salinity and shows their potential for incorporation into the policy initiatives. Rice farmers are the central stakeholders of the coastal dry season rice farming system, and they are concerned about the vulnerability of the reproductive stages of rice, which is the stage that is most sensitive to salinity stress. They perceive that high salinity in these stages results in yield loss. Thus, research priority in the development of salinity-tolerant rice varieties should be more focused on developing varieties that have higher salinity tolerance during these stages. For rice farmers, early-transplanting practices potentially avoid the high-salinity periods during the reproductive stages. This practice could be adopted in wider extension planning. To develop a comprehensive understanding of the variation in perceptions of salinity between farmers and the scientific literature, salt-tolerant crop varietal trials should be carried out in fields perceived by farmers to be highly saline.

In the second step (i.e. differential perceptions of salinity problem), this study explored the salinity perspectives of the other groups of farmers who operate in the coastal farming region alongside the rice farmers to understand the diversity of salinity perceptions and adaptation preferences. As salinity affects different coastal farmers in different ways, the findings indicated the presence of diverse adaptation preferences. Thus, policymakers should consider the salinity adaptation preferences of all types of farmers to allow sustainable use of coastal resources to achieve the SDGs. Although shrimp and salt farmers' adaptation preferences are mostly focussed on engineering solutions such as canal excavation and embankments, these solutions could also bring about improvements for rice cultivation during the dry season. For example, canal excavation could potentially create rainwater storage facilities during the wet season that could be used for irrigation during the dry season. However, strict legal arrangements would need to be put in place for proper use of canals as shrimp farmers are richer and more powerful and may influence the canal operation activities.

The literature indicates projected climate change will induce reduced upstream river flows and decrease precipitation (Dasgupta et al., 2014), which could limit the availability of fresh water during the dry season and result in increased salinity in the coastal areas. Thus, focusing on a single measure to actively manage the salinity problem in dry season rice cultivation (such

as through the use of existing saline-tolerant varieties that have less tolerance during the reproductive stages) may not be successful without improved irrigation facilities. To accommodate these pluralistic land use options in coastal areas, researchers and the Bangladesh Government have proposed suitability-based land zoning (Islam, 2006) to determine the optimal use of land through zoning (LandAC, 2019). The involvement of relevant stakeholders in identifying potential land use and sustainable use of resources is also required to formulate well-accepted land use policies, as studies have also shown that there has been little representation of local stakeholders' opinion in the policy formulation phases (Islam et al., 2020).

In the third step (i.e. understanding the existence of threshold yield loss), this study determined the threshold yield loss, which was defined as the maximum acceptable yield loss that different types of farmers perceived as undesirable. The findings in the previous steps confirmed that farmers are clearly concerned about the salinity problem during dry season rice farming, and their actions are found to be consistent with the scientific evidence. The second step also demonstrated that farmers' adaptation preferences vary according to how they perceive the salinity problem, which indicates that farmers' understanding of the salinity problem is based on their lived experiences and the consequences of management or land use decisions. Thus, threshold yield loss from their perspective would be more robust and relevant to policymakers when considering the direction of rice-intensification planning in their salinity adaptation decisions. The higher level of threshold yield loss tolerance of the rice farmers indicates that they may have limited options to move to alternative livelihoods. Thus, to ensure that they have a sustainable rice yield in coastal saline environments, locally preferred practices like early transplanting could be scaled over the wider coastal areas. In addition, development and provision of higher-yielding varieties of rice for wet season cultivation could potentially increase overall farm production to compensate the yield losses during dry season rice cultivation.

This study aimed to provide a comprehensive understanding of the salinity problem from the perspective of multiple types of farmers, and to define a threshold yield loss that can guide policymakers to address the uncertainties in salinity adaptation decisions in coastal dry season rice-intensification planning. The threshold yield loss defined in this study is farmer-derived, and

can signal to policymakers the % yield loss point at which a farmer would discontinue growing rice and when government needs to provide more support to keep them above that threshold. The threshold determined in this study demonstrated as being a more legitimate level of yield loss as it reflects the diverse farmers' perspectives. The Bangladesh Government has adopted several policies to achieve the SDG targets. Achieving these goals potentially depends on successfully operationalising the policy framework at the farm level. This study has brought farmers' salinity perceptions into sharp relief and has developed the farmer-derived threshold yield loss, which could be useful for operationalising research and extension policies and achieving the SDG outcomes particularly SDG-1, SDG-2 and SDG-3.

This research has highlighted a number of well-entrenched issues surrounding land use change and the effects of salinity on dry season rice production. The alternatives to the current land use pattern are considered in the following section along with potential areas for future research and policy directions. This research has shown that farmers perceive scarcity of irrigation water is a major challenge for rice growing in the coastal areas along with the salinity problem. Farmers' adaptation preferences also stressed the need for improvement of irrigation facilities to cope with salinity. Therefore, placing all research efforts into the development of salinity-tolerant rice varieties might not help to address the salinity problem in dry season rice intensification planning.

In addition, precipitation could decrease further because of climate change, and fresh water could become less available in the coastal areas (Dasgupta et al., 2015). Therefore, research and extension efforts also need to examine alternate solutions. Examples include developing and promoting salinity-tolerant pulses and other crops, and fitting these into a coastal cropping system. Such a strategy could be helpful as these crops also require less water than rice farming (Aravindakshan et al., 2020).

In addition, farmers perceive the reproductive stages of rice as being the most vulnerable to salinity stress, and the reproductive stages coincide with the periods of highest salinity in the coastal areas. Salinity-tolerant variety development should therefore be focused on these stages. However, it is also evident that rice has limitations in its ability to cope with salinity stress during the reproductive stages (Grattan et al., 2002), which could compromise the aim of developing a

greater yield potential in saline soils. This horizontal expansion of rice could therefore be more challenging in the coastal areas given that there are additional limiting factors such as the availability of fresh water. The literature shows that specific research and extension efforts that have focused on sustainable coastal land utilisation (Brammer, 2014) have provided a pluralistic perception of salinity and its impact on enterprises, finding that there is no “one-size-fits-all” solution. Wet season rice farming in the coastal areas is becoming more prevalent in parts of Bangladesh, not only in the south-eastern region in particular but also in other coastal regions. Thus, promotion of high-yielding and salinity-tolerant rice crops for the wet season could compensate for the lower yield potential of the dry season crop and increase overall production from the coastal areas. In addition, rainwater harvesting through canal excavation and use of water collected during the dry season rice farming could be utilised to ameliorate the effects of salinity on rice. This study has also shown the existence of threshold yield in coastal dry season rice cultivation, with the major areas of the exposed coastal regions already experiencing lower yields.

This study has also demonstrated that shrimp and salt farmers have already reduced their own rice cultivation and have shifted to these alternative farming enterprises (i.e. shrimp and salt farming), not only because of the salinity effects on rice yields but also because socioeconomic factors have influenced them to move to these productive enterprises that are less vulnerable to salinity.

5.6 Limitations of this study and future research direction

This study was conducted in two sub-districts of the coastal areas and only focused on the dry season. This study did not compare rice with other shrimp and salt farming enterprises at other times of the year. Although the salinity problem in the coastal areas is acute during the dry season, its overall impact could be observed on the livelihood options for the remainder of the year. Thus, future research should be conducted that considers both the socioeconomic analysis of land use practices/options over the entire year and farmers’ perceptions to define tipping points of coastal rice farming systems. Furthermore, it is necessary that future research initiatives focus on understanding the sustainable utilisation of coastal resources to allocate these resources among all types of farmers. The literature also indicates that a rotation of

freshwater prawn production during the wet season and rice production during the dry season on the same area of land is emerging as a feasible land use practice in many coastal areas (Ahmed, 2013; Dang, 2020; Kabir et al., 2016). This system could have greater potential for improving coastal livelihoods. Thus, an integrated research and extension approach, particularly for the sustainable use of coastal resources, is a crucial government priority for addressing the SDGs.

In this study, we applied the ATP approach through three sequenced steps. These steps can be replicated to address any environmental stress in cropping agriculture in similar coastal saline environments in other geographical settings. This study identified the farmer-derived salinity-driven threshold yield loss that could signal possible tipping points for the cessation of dry season rice farming, depending on the type of farming enterprise. However, for a well-defined and comprehensive understanding of the tipping points and the time frame within which these would occur, more research is required. The farmer-derived threshold yield loss identified in this study could be used as an entry point to comprehensive understanding of tipping points through crop modelling studies. This study could not identify the actual salinity value for farmers' yield loss thresholds in the dry season and predict the time frame for reaching these thresholds (i.e. tipping points of the dry season). However, known threshold yield loss in dry season rice identified in this study can be used to functionalise the ATPs through modelling approaches. Future research could be carried out using appropriate crop models such as DSSAT (Hoogenboom et al., 2019) and APSIM (Radanielson et al., 2018) to operationalise the realistic ATPs of dry season rice cultivation to determine the salinity level and the time frame over which the farmer-derived threshold yield loss would occur.

5.7 Conclusions

Achieving the sustainable development goals is a key policy agenda of the Bangladesh Government. Intensifying dry season rice farming in the coastal areas is a top priority in achieving these goals. However, increasing salinity in the coastal areas is a key constraint to this policy agenda. At the same time, shrimp and salt farming have emerged as enterprises that offer improved livelihoods for people who have been historically poor. Nevertheless, such unplanned expansion of shrimp and salt farming has had consequences for coastal dry season rice farming. Thus, constraints on rice farming from increasing salinity as well as contested land use have

created uncertainty for the policymakers when making salinity adaptation decisions. To provide farmers' perspectives and perceptions of these issues, this study examined a threshold yield loss of dry season rice from the perspectives of all types of farmers. To address multi-layered issues, this study applied the adaptation tipping points (ATP) approach by adopting three sequenced steps to determine the salinity perceptions of rice farmers, the perceptions and adaptation preferences of all types of farmers, and threshold yield loss as perceived by these farmers who live in close proximity and use the coastal resources.

The majority of the farmers in the coastal areas of Bangladesh perceived that salinity has increased over the past 20 years, and they mentioned both natural and human interventions as the main drivers of that increase. However, perceptions of salinity and the perceived underlying causes vary across the farmer types. While rice farmers are more concerned about the anthropogenic causes, shrimp and salt farmers perceive that the causes of salinity are dominated by natural processes that could have been exacerbated by climate change.

This study has demonstrated that salinity, followed by scarcity of fresh water for irrigation, are considered the most pressing problems during dry season rice farming. However, the rice farmers are more concerned about the salinity problem during the reproductive stages, when salinity in the coastal areas reaches its peak. Farmers' adaptation actions such as early transplanting potentially avoid the high-salinity period in the coastal areas, which demonstrates its potential for being adopted in the wider coastal areas. There are significant differences between farmers and the scientific literature in the understanding of high salinity. The findings of this study indicated that farmers' perceptions of salinity and adaptation preferences are directly related to the ways in which their livelihood is affected by this problem. While rice farmers' adaptation preferences are mostly confined to agronomic solutions, shrimp and salt farmers' preferred options are dominated by engineering solutions.

The findings of this study demonstrated the potential existence of threshold yield loss in dry season rice farming. However, in this study, it varied among the different types of farmer and between the two coastal locations. The results indicated that in addition to salinity threats, socioeconomic factors associated with shrimp and salt farming (e.g. higher profit, less labour requirement, cash income) could potentially accelerate the tipping points of dry season rice

farming. The findings also indicated that exposed coastal areas are already experiencing this signal for the tipping points of dry season rice cultivation, which also necessitates location-specific extension efforts and research that prioritises an integrated approach to coastal resource management. These actions could assist in delivering sustainable livelihood options to ensure food security and accelerate the achievement of the SDGs (e.g. no poverty (SDG-1), zero hunger (SDG-2), good health and well-being (SDG-3)).

5.8 References

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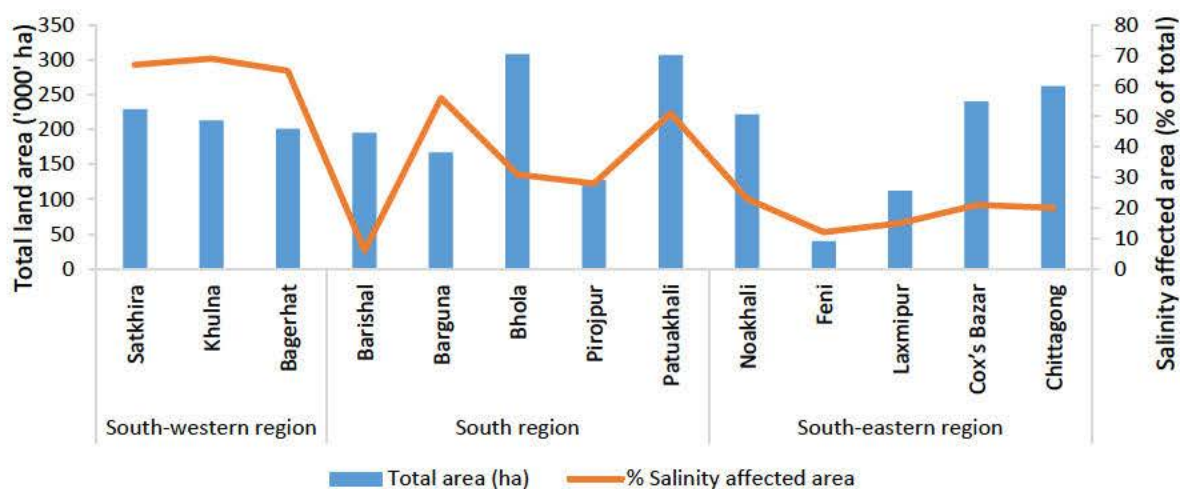
APPENDICES

Appendix 2.1 Agro-ecological and socioeconomic conditions of the study areas in Assasuni sub-district (SW), and Banskhali sub-district (SE)

Study Sub-district	Agro-ecological zone (AEZ)	Soil fertility level	Total land area (% of total land area salinity affected)	Main crops	Average household size	Literacy rate %
Assasuni (SW)	High Ganges River Floodplain, Ganges Tidal Floodplain	Low to medium	40982 ha (81% saline area)	Rice (Aman, Aus, Boro), Wheat, Chilli, Jute, Mustard	4.76	40.3
Banskhali (SE)	Chittagong Coastal Plains	Medium	37690 ha (31% saline area)	Rice (Aman, Aus, Boro), Mustard, Potato, Taro, and other vegetables	5.45	29.5

Source: (BBS, 2016; Rahaman et al., 2018; SRDI, 2010)

Appendix 2.1. Land area affected by salinity in major coastal districts of Bangladesh; Source: (SRDI, 2010)



Appendix 2.3. Salinity affected area of selected unions of Assasuni and Banskhal sub-districts

Name of Sub-district	Name of Union	Total land area (ha)	Total salinity affected land (ha)	% of salinity affected area
Assasuni	Budhhata	3355	320	9.50
	Khajra	3725	1350	36.25
Banskhal	Gandara	2972	450	15.20
	Chhanua	2020	950	47.20

Source: Total land area were collected from (BBS, 2015) and salinity affected area were collected from the Sub-district Agriculture Office, 2019

Appendix 2.4. Multistage random sampling and selection of the participants

Stage-1	Stage-2	Stage-3	Stage-4	Stage-5	Stage-6
Selected districts (total district)	Selected Sub-district (total no. of sub-district)	Selected union (total no. of unions)	Selected village (total no. of villages)	Total Boro rice grower households per village	Number of interviewed households (percentage)
Satkhira from the south-west (3)	Assasuni (9)	Budhata (11)	Beula	390	38 (9.7)
		Khajra (11)	Khajra	195	23 (11.8)
Chittagong from the south-east (4)	Banskhali (14)	Chanua (14)	Khudukkhali	415	32 (7.7)
		Gondamara (14)	Paschim Baraghona	180	16 (8.8)

Source: Total land area data were collected from BBS, 2015 and salinity affected area were collected from the respective Sub-district Agriculture Office

Appendix 2.5. Coding used for different categorical variables

Variables	Definition
salinity increased	=1
salinity decreased	=2
no changes in salinity	=3
Perceptions of salinity level	
High	=1
Low	=2
Perception on the causes of increased salinity	
cyclones, increased salt farm	=1
Cyclones, erosion of embankment	=2
Cyclones, increased shrimp farm	=3
Cyclones, siltation of river	=4
Siltation of river	=5
Increased shrimp farm, siltation of river	=6
Increased shrimp farm	=7
Increased salt farm	=8
perceptions on the most difficult problem to manage during Boro season rice	
Salinity	=1
Scarcity of irrigation water	=2
Salinity and scarcity of irrigation water	=3
perception of the most salt-sensitive growth stage of the rice plant to salinity	
Seedling stage	=1
Booting stage	=2
Heading stage	=3
Flowering stage	=4
Perception on the effects of salinity if it occurs at the most sensitive stages	
Less heading (panicle extrusion), panicle turns white from the top, unfilled grain, yield reduce	=1
Root spoilage, unfilled grain	=2
Plants dry up from the and looks like straw	=3
Salinity adaptation strategies	
Early transplanting and apply irrigation	=1
Use salt tolerant varieties, apply irrigation water	=2
Apply irrigation water	=3
Age	
30-40	=1
41-50	=2
51-60	=3
61-70	=4

Educational qualifications	
Graduate	=1
Illiterate	=2
High School	=3
SSC	=4
Primary	=5
Do sign only	=6
HSC	=7
Diploma	=8
Post graduate	=9

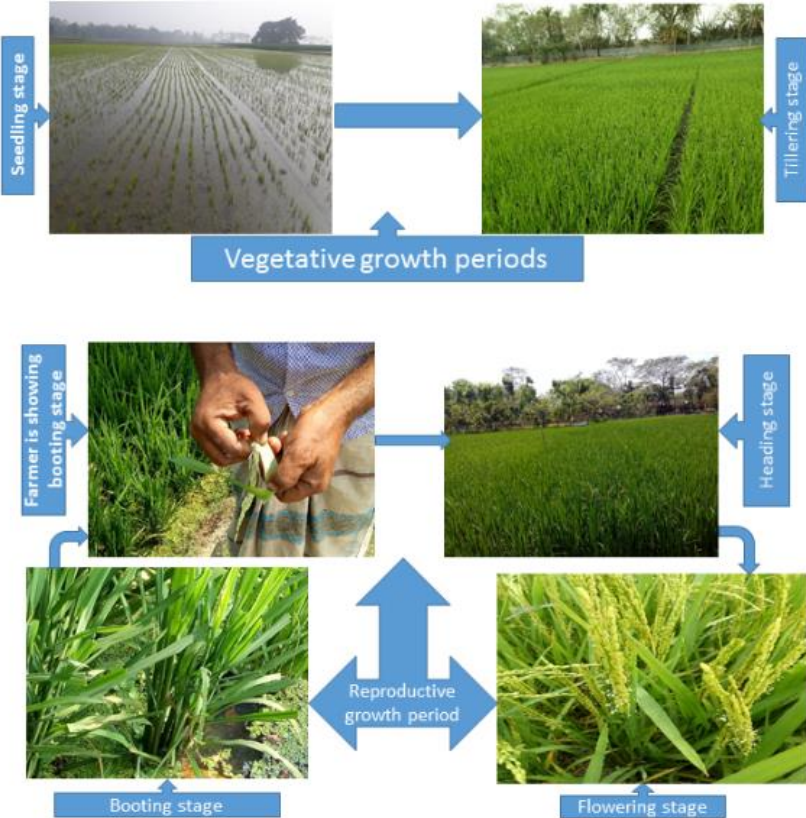
Appendix 2.6 Coding used for different categorical variables

Description of variables	Definition
Type of varieties used by the farmers	
Salt tolerant	=1
Not salt tolerant	=2
Transplanting time of seedling at the farmers' field	
Early transplanted	=1
Late transplanted	=2
Mid transplanted	=3
Growth stages during salinity measurement	
Vegetative stage	=1
Reproductive stage	=2
Farmers' perception of a measured salinity	
if perceived as low	=1
if perceived as high	=2
Salinity level categorization as defined in literature	
if measured salinity <8.0 dS/m	=low,
if the measured salinity >= 8.0 dS/m	=high

Appendix 2.7. Top ranked problem faced by the farmers in the two study locations

Locations	% of the respondents								
	Scarci ty of irrigat ion water	Salinity	High labor cost	High input cost	Insects and diseases	Water logging	Access to electricity to operate irrigation pump	Iron in water	Erratic rainfall
Banskhali (n=48)	35.4	39.6	2.1	2.1	16.7	0.0	4.2	0.0	0.0
Assasuni (n=61)	9.8	75.4	0.0	0.0	1.6	4.9	0.0	3.3	4.9
Both locations (n=109)	21.1	59.6	0.9	0.9	8.3	2.8	1.8	1.8	2.8
χ^2 test	$\chi^2 = 32.83, P=0.000$								

Appendix 2.8. Farmers' understanding and identification of different growth stages of rice plant (Photos: M.A. Islam)



Appendix 2.9. Farmers' understanding of salinity effects (symptoms) on rice plant during the reproductive stages (Photos: M. A. Islam)



Panicle turning white from the



Plants dying and look like burning



Less headings (panicle)

Appendix 2.10. Salt tolerant rice varieties cultivated as mentioned by the farmers during Boro season in the study locations

Locations (N)	% of the respondents		
	BRR I and BINA rice varieties (BRR I Dhan47, BRR I Dhan67, Bina Dhan8, Bina rice 10)	Hybrid rice variety (Hira, Mitali, IT, SL8, Shokti, Tej)	Local variety (Gordaan)
Assasuni (61)	72.0	4.0	24.0
Banskhali (48)	11.5	88.5	0.0
Both locations (109)	41.2	47.1	11.8
Chi square test	$(\chi^2 = 36.87; P=0.000)$		

Appendix 2.11. Farmers' perceived salinity level and use of salt tolerant varieties in the study locations

Farmers' perceptions about the salinity level of the field	Variety used (%)	
	Salt tolerant	Not salt tolerant
Low salinity	34	66
High salinity	56	44
Chi square test	$(\chi^2 = 36.87; P=0.07)$	

Appendix 4.1. Comparison of salinity-affected areas in the major coastal districts of Bangladesh

Coastal region	District	Total area (ha)	Salinity-affected area (ha)	% of salinity -affected area
South-western	Satkhira	229,607	153,110	66.68
	Khulna	213,820	147,960	69.20
	Bagerhat	201,331	131,120	65.13
Central	Barishal	195,708	12,360	6.32
	Barguna	167,887	95,620	56.95
	Patuakhali	307,875	155,180	50.40
South-eastern	Noakhali	222,575	52,520	23.60
	Chittagong	262,317	51,480	19.63
	Cox's Bazar	240,867	55,350	22.98

Source: (SRDI, 2010)

Appendix 4.2. Selection of survey respondents from villages in Assasuni sub-district of Satkhira district and Banskali sub-district of Chittagong district

Stage-1 Selected districts (total district)	Stage-2 Selected Sub-district (total no. of sub-district)	Stage-3 Selected union (total no. of unions)	Stage-4 Selected village	Stage-5			Stage-6		
				Total No. of farmers	Number of interviewed households (percentage)				
				Rice	Shrimp	Salt	Rice	Shrimp	Salt
Satkhira from the south-west (3)	Assasuni (9)	Budhata (11)	Beula	390	340	-	38 (9.7)	24 (7.05)	-
		Khajra (11)	Khajra	195	450	-	23 (11.8)	35 (7.7)	-
Chittagong from the south-east (4)	Banskali (14)	Chanua (14)	Khudukh ali	415	210	480	32 (7.7)	29 (13.8)	44 (9.1)
		Gondam ara (14)	Paschim Baraghona	180	110	150	16 (8.8)	19 (9.3)	20 (13.3)