Bringing farmers' perceptions into science and policy : Understanding salinity tolerance of rice in southwestern Bangladesh under climate change

Land Use Policy

Islam, Md Aminul; Shelia, Vakhtang; Ludwig, Fulco; Bruyn, Lisa Lobry; Habib ur Rahman, M. et al

https://doi.org/10.1016/j.landusepol.2020.105159

Land Use Policy xxx (xxxx) xxx

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Bringing farmers' perceptions into science and policy: Understanding salinity tolerance of rice in southwestern Bangladesh under climate change

Md. Aminul Islam [a,b,c], Vakhtang Shelia [b,d,e,*], Fulco Ludwig [c], Lisa Lobry de Bruyn [a], M. Habib ur Rahman [b,f,g], Gerrit Hoogenboom [b,d,e]

[a] University of New England, Australia
[b] AgWeatherNet Program, Washington State University, Prosser, Washington, USA
[c] Wageningen University, the Netherlands
[d] Department of Agricultural & Biological Engineering, University of Florida, Gainesville, Florida, USA
[e] Institute for Sustainable Food Systems, University of Florida, Gainesville, Florida, USA
[f] Institute of Crop Science and Resource Conservation (INRES), Crop Science Group, University of Bonn, Germany
[g] Department of Agronomy, Muhammad Nawaz Shareef University of Agriculture, Multan, Pakistan

A R T I C L E I N F O

Keywords:
Vulnerable growth stage
Panicle emergence
Salt intrusion
Salinity tolerance threshold

A B S T R A C T

Salinization is a major global issue due to its adverse impact on agricultural productivity and sustainability. A substantial part of the coastal region of Bangladesh is affected by different magnitudes of salinity. Therefore, maintaining sustainable agricultural production is a major emphasis for policymakers. The objective of this study was to assess the salinity tolerance threshold for Boro season rice cultivation in the southwestern coastal areas of Bangladesh based on farmers' perceptions of salinity problem. We applied an adaptation tipping point (ATP) approach that signifies the points, e.g., timeframe, when the threshold of a system is reached and alternate strategies must be considered for management planning. The primary data were collected through household surveys and focus group discussions, and were then interpreted and harmonized with literature reviews and expert opinions. The results revealed that farmers perceived the panicle emergence stage of rice as the most vulnerable to salinity and that a high salt concentration in the soil during this growth stage results in a lower yield. In southwestern Bangladesh, panicle emergence of rice during the Boro season is usually observed from March to April, the same period when salinity reaches its peak level. Based on farmers' perspectives of salinity problems and literature, this study defined the salinity tolerance threshold between 4–5 dS/m for traditional Boro season rice varieties and between 8–10 dS/m for newly released salt-tolerant rice varieties. We conclude that for the traditional Boro season rice varieties the tipping points might already have been reached in some coastal areas of southwestern Bangladesh, while for newly released salt-tolerant rice varieties these tipping points could be reached in the near future.

1. Introduction

Salinization is a major global issue due to its adverse impact on most major crops and the risk of reducing agricultural productivity. Salinity problems can arise under any climatic condition as a result of either natural or human-induced activities. Saline soils are especially widespread along the coast of the arid and semi-arid regions in the world where the amount of rainfall is insufficient to leach the mineral salts out of the root-zone (Shahid et al., 2018). In the coastal areas of Bangladesh, soil salinization has increased at a rate of around 0.75 % per year over the last few decades, and the salt affected area from 0.83 M ha in 1973 has reached to 1.06 Mha in 2009, in accordance with the most recent data that are currently available (SRDI, 2010; Seal and Baten, 2012). According to the future climate change projections, the temperature is likely to increase which will inevitably lead to higher evaporation and further salinization (Shahid et al., 2013). Hasan et al. (2020) reported that due to climate change induced sea-level rise around 2098 km^2 land in the interior coast is likely to be inundated which could have immense impacts on salinity intrusion in the crop fields of the coastal areas of Bangladesh. Ever increasing salinization in the coastal areas can affect ecosystems to the extent that they no longer can provide "environmental services" to their full potential (Shahid et al., 2013; FAO-ITPS-GSP,

* Corresponding author at: 233 Frazier Rogers Hall, PO Box 110570, Gainesville, FL 32611-0570, USA.
E-mail address: vakhtang.shelia@ufl.edu (V. Shelia).

https://doi.org/10.1016/j.landusepol.2020.105159
Received 17 April 2020; Received in revised form 19 October 2020; Accepted 20 October 2020

2015).

Ensuring food security remains the top most priority of the Bangladesh government since its independence in 1971 (NSDS, 2013). The food security of Bangladesh largely depends on a good rice production, as this is the single most important crop and covers around 75 % of the total cropped area (BRRI, 2019). In Bangladesh, rice is grown in three distinct seasons, namely Aus, Aman and Boro. Among these seasons, Boro is the largest accounting nearly 54 % of the total rice production (BBS, 2019; BRRI, 2019). However, the Boro season rice cultivation is severely affected by climate change-induced natural disasters such as salinity intrusion, frequent droughts, and anthropogenic intervention (Chowdhury et al., 2011; Paul and Vogl, 2011).

It has also been predicted that due to the high salinity share of the rice-dominated crop sector, the GDP is likely to decrease by 3.1 % annually by the middle of this century (USAID, 2015). To keep the pace of sustained rice production, expanding its cultivation throughout the coastal areas attracted the highest prioritized policy agenda in Bangladesh (NAP, 2018). The coastal areas constitute around 30 % of the total land area of Bangladesh, and salinity remains the top most constrains for rice intensification (NAPA, 2009; NAP, 2018). Government organizations, including research and extension, provide full efforts with technical solutions such as salt-tolerant crops and embankment to address the salinization problems in the coastal areas (Hasan et al., 2018; Islam et al., 2019). For example, the Bangladesh government agencies have developed and promoted several salt-tolerant Boro season rice varieties for the coastal saline areas. Although, rice is recognized as a slightly salt-tolerant plant (Maas and Hoffman, 1977; Wassmann et al., 2009) salinity levels that exceeded 1.9 dS/m in the soil water have shown in some cases to significantly reduce the yield of rice (Grattan et al., 2002). The government agencies in Bangladesh claim that newly developed rice varieties can tolerate soil salinity up to 12–14 dS/m at the seedling stage and 8 dS/m at the reproductive stage (BINA, 2019; BRRI, 2019). However, environmental factors are more likely to affect yield of these varieties during the Boro season than genotypic factors (Islam et al., 2016). In addition, most of the cultivated rice varieties could not withstand unexpected intensification of soil salinity after strong cyclones, such as Sidr and Aila, resulting in a lower yield in subsequent years (Rabbani et al., 2013). Thus, it raises the uncertainty for the policymakers whether emphasizing technical solutions such as saline tolerant crops as a means for adaptation planning to address salinity problems would be sufficient in the coastal areas under the threats of climate change induced salinization. In addition, uncertainty about appropriate adaptation measures can result from the differences in the projections of climate change impacts on salinity intrusion at both regional and global scales (Nicholls and Cazenave, 2010). For example, climate change has a significant impact on global hydrological systems, which could result in erratic rainfall patterns, rapid snowmelt, and sea-level rise. Reduced dry season river flows combined with projected sea-level rise could accelerate saltwater intrusion in low-lying coastal areas in many parts of the world such as Bangladesh (IPCC, 2014; Hasan et al., 2020).

Addressing these uncertainties are critical for the policymakers for effective adaptation planning in which adaptation-tipping points (ATP) framework could play a pivotal role for better management outcomes (Selkoe et al., 2015; Nanda et al., 2018). ATP signifies a time range when critical limits, i.e., thresholds, of a management system are reached and beyond which the current strategy might fail to meet the objectives (Kwadijk et al., 2010; Werners et al., 2013). Thus, the most important requirement for the ATP approach is to determine the thresholds of a management system (Ahmed et al., 2015; Koukoui et al., 2015). For a biophysical system, the threshold level is considered to be irreversible or the point of no return (Milkoreit et al., 2018) compared to threshold levels in social and business dimensions which refer to a situation that signifies flexibility over a time range (Firth and Colley, 2006; Russill and Nyssa, 2009; Werners et al., 2013). In an agricultural system, the determination of the threshold from a farmer's perspective could potentially inform policymakers about need- based adaptation planning (Maddison, 2007). Several studies have shown that people's perceptions of any problems are shaped by their experiences based on how they are affected by these problems (Mertz et al., 2009; Tam and McDaniels, 2013).

Thus, understanding the farmers' perceptions about climate change issues or associated with the livelihood of small-holder farmers are potentially useful to inform policymakers so that they can plan for appropriate and relevant adaptation strategies (Gifford, 2011; Niles and Mueller, 2016; Hasan and Kumar, 2020a, 2020b). Inconsistency between farmers' perceptions and literature data on salinity issues could result in less effective policy to address salinity problem particularly for salinity adaptation planning in the coastal areas. Thus, understanding farmers' perceptions in relation to the salinity problem is to ensure that the policy would align with how the local farmers perceive this problem during rice cultivation in their fields. Several studies that have been conducted in the coastal areas of Bangladesh indicate that farmers have perceived an increase in salinity levels and temperature, a decline in precipitation and more frequent occurrences of drought in the coastal areas (Khan et al., 2014; Uddin et al., 2014; Shameem et al., 2015; Alam et al., 2017; Hasan and Kumar, 2019, 2020a, 2020b). However, studies to date have attracted little attention on farmers' perceptions of salinity and, when this problem is critical during Boro rice growing season. If this information is known, it could provide guidance for policymakers for adaptation decisions to address salinity problems. The objectives of this study, therefore, are:

i) to examine farmers' perceptions of climate change issues with emphasis on salinity during the Boro rice season;
ii) to determine which rice growth stages during the Boro season are most susceptible to salinity; and
iii) to assess the salinity tolerance threshold level of rice cultivation during the Boro season in southwestern Bangladesh.

2. Research methodology and study area

The conceptual research framework for this study includes different definitions such as adaptation tipping points (ATP), threshold of a system, and vulnerable growth stages of rice. These definitions are explained along with a discussion of how we determined the salinity tolerance threshold of rice during the Boro season in the study area.

2.1. Adaptation tipping points (ATP)

Adaptation tipping points (ATP) 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 certain actions are undertaken. ATP may provide information on whether and when a management strategy may fail and other strategies may be needed to avoid difficult circumstances or loss due to external factors such as climate change or social preferences (Kwadijk et al., 2010). This bottom-up approach to assess vulnerability of a system differs from traditional top-down approach in a sense that it is less dependent on climate projections as most of the top-down approaches to climate change adaptation rely on global climate change models (Ludwig et al., 2014). The classical top-down approach typically starts with one or more global climate scenarios and connects the plausible impacts on a system considering its physical vulnerability (Dessai and van der Sluijs, 2007). The bottom-up approach in contrast usually incepts with social-ecological vulnerability of a system, and looks at how these vulnerabilities are influenced by climate change. The bottom-up approach ends with identifying and evaluating options to reduce these vulnerabilities (Glick et al., 2011). According to Ludwig et al. (2014), the bottom-up adaptation approach is mostly concentrated on dealing with reducing socio-economic vulnerability through improving adaptive capacity. Thus, ATP is a typical bottom-up approach that provides information to policymakers regarding when and how to act to avoid unacceptable changes in a socio-ecological system due to climate change. It can also assist policymakers with appraising long-term and time-flexible adaptation planning (Riquelme-Solar et al., 2015; van Slobbe et al., 2016).

2.2. Salinity tolerance threshold level and vulnerable growth stages of rice

To apply ATP to climate change adaptation or management issues, the first step is to identify the threshold level of a system. For the study presented here, the salinity tolerance threshold was defined as the salinity concentration during the most vulnerable growth stage of Boro season rice that results in a 30 % reduction in yield. The vulnerable growth stage is the growth phase of rice plants that farmers perceive as the most critical and unmanageable to salt intrusion during the Boro season. We assume that above this salinity tolerance threshold level, Boro rice cultivation is unlikely to be economically viable, and other profitable land-use options might emerge as more attractive to the local farmers in the coastal areas of Bangladesh that has been reported in the literature (Ahmed et al., 2010; Paul and Vogl, 2011).

Data were collected on how farmers perceived climate change issues. Their responses were ranked according to how they relate those issues to rice cultivation and when these problems generally occur during the growing season. After studying these perceptions, we focused on the available scientific literature to determine the critical growth stages for rice under salinity stress. We also looked at the available literature to determine the effects of different salinity levels on rice yield and the salt concentration above which yield was significantly reduced. We then searched the literature to determine during which months these critical stages of Boro rice generally occur in the study area. Observed or recorded salinity levels in the study area for that particular time of the year were compared to the salinity data found in literature. Finally, the salinity tolerance threshold level for rice cultivation was identified by harmonizing the survey results with literature review data and expert opinion (Fig. 1).

2.3. Study area

This study was conducted in two locations of the sub-districts along the southwestern coast of Bangladesh. The southwestern coastal region constitutes three districts (e.g. Khulna, Satkhira, Bagerhat), which represent critical salinity dominant areas induced by climate change and human interventions (Kausher et al., 2012; Hossain et al., 2013; Ahmad, 2019). The Satkhira district (22°37′ N; 89°10′ E; 3.0–3.5 m above mean sea level; Climate Change Cell (CCC, 2009) was selected as the study area. This district represents a typical environment and livelihood scenario of the coastal area of the country. It is highly vulnerable to climate change-induced salinity intrusion and currently around 66 % of the district area is affected by different magnitudes of salinity (SRDI, 2010). In order to conduct household survey for data collection the Shyamnagar and Assasuni sub-districts of the Satkhira district were selected from a total of seven sub-districts (Fig. 2).

2.4. Data collection and analysis

A mixed approach combining both qualitative and quantitative research methods was used to conduct the present study. Qualitative research is an important method to investigate social phenomena (Green and Thorogood, 2009). Primary data were collected through a household survey using an interview schedule, focus group discussions and

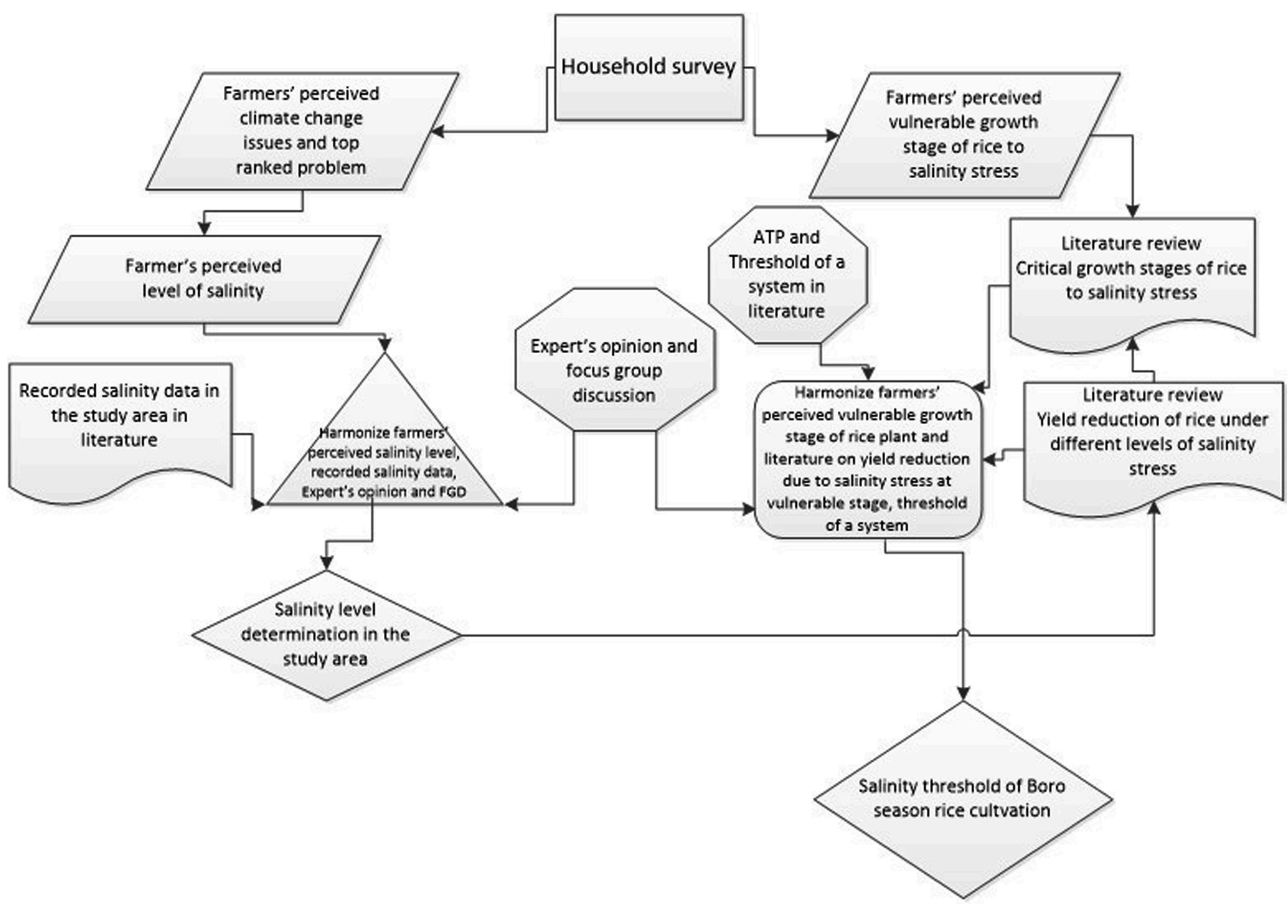

Fig. 1. Research framework.

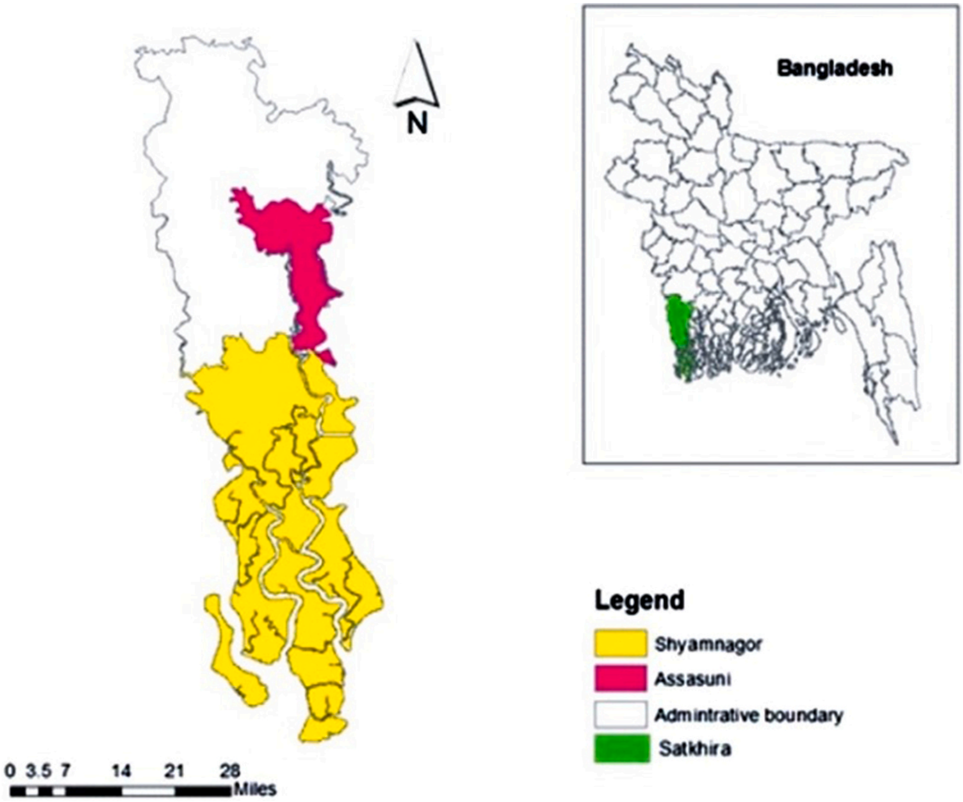

Fig. 2. Study area showing the Satkhira district (Right) in the coastal area of Bangladesh and the Shyamnagar and Assasuni sub-districts of the Satkhira district (Left).

key informant interviews with experts, which were conducted from August to October 2014.

A total of 54 households were randomly selected from the list of households provided by the sub-district agriculture office. Agriculture Officers of the respective sub-districts advised us the union, i.e., the smallest administrative unit of Bangladesh, and villages where salinity problems were acute. One member, e.g. the head of the household, from each household was selected as a respondent following a multistage stratified sampling procedure (Table 1). A similar technique was reported by Hasan and Kumar (2020a, 2020b) who studied farmers' perceptions of climate change in the coastal areas of Bangladesh. A pre-tested, semi-structured questionnaire and an interview schedule were used to gather the primary data from the selected household respondents. During data collection from the respondents, salinity levels were defined based on crop reaction to salinity and soil salinity class as described in the general interpretation of electrical conductivity (EC) values (SRDI, 2010). Farmers' perception of the salinity level at their field were categorized as low salinity, medium salinity and high salinity.

We conducted two focus group discussions (FGDs) in two sub-districts and 16 key informant interviews (KII). Informal interviews were conducted with key informants and experts such as academics from different fields, personnel from government and non-government organizations, and community members prior to and after the questionnaire survey was conducted in the field. Prior to conducting the survey, the key informants helped us on how and where relevant data could be found. After completion of the questionnaire and focus group discussions, informal interviews were also conducted with experts to validate farmers' perceptions on climate change related problems, especially farmers' perceptions on the most salinity sensitive growth stages of rice during the Boro growing season. Following data collection, the questionnaires were converted to a suitable digital format and then analyzed using SPSS software (Seale and Kelly, 2004; Bryman and Cramer, 2011).

In order to understand and interpret data from various sources (household surveys, focus group discussions, expert opinions, literature reviews, etc.) we used data harmonization process (Granda et al., 2010). Data harmonization refers to efforts provide a comparable view of data by combining data of varying file formats, naming conventions, etc. from different sources and studies. It takes an approach to data quality that involves to detect outliers, trends, and the cause and effect across data sets. This process is becoming more and more significant in research, as the volume and the need to share existing data is rapidly increasing.

3. Results

3.1. Demographic and socioeconomic status of the respondents

The average age of the respondents was 49 years and 42.6 % of the respondents were between the age of 41 and 50 (Table 2). Among the respondents, 31.5 % had a secondary level of education followed by 22.2

Table 1
Multistage random sampling and selection of the respondents.

Stage-1	Stage-2	Stage-3	Stage-4	Stage-5	Stage-6
Selected districts from the south-western coast (total districts)	Selected Sub-districts (total no. of sub-districts = 7)	Selected unions (total no. of unions)	Selected villages (total no. of villages)	Total number of households per village	Number of interviewed households (%)
Satkhira (3)	Assasuni	Pratap Nagar (11)	Purohitpur (18)	261	30 (11.5 %)
	Shyamnagar	Munshiganj (12)	Khutikata (16)	176	24 (13.6 %)

Table 2
Demographic and socioeconomic status of the respondents.

Category	Characteristics	% of the respondents
Age, years	30–40	18.5
	41–50	42.6
	51–60	29.6
	61–70	7.4
	71–80	1.9
Education	Illiterate	1.9
	Can only sign	9.3
	Primary	22.2
	Secondary	31.5
	SSC	16.7
	HSC	7.4
	Graduate	7.4
	Post-graduate	3.7
Occupation	Crop farming	85.2
	Shrimp farming	7.4
	Other (Fishing, etc.)	5.6
	Small business	1.9

Note: SSC - Secondary School Certificate (Year-10), HSC - Higher Secondary Certificate (Year-12).

% with only a primary level of education. Crop farming was the dominant occupation at 85.2 % followed by shrimp farming at 7.4 %.

3.2. Harmonization farmers' perception and literature data to determine present salinity level in the study area

The results from this study show that farmers in the study area know about changes in the rainfall pattern and an increase in temperature associated with climate change. Around 65 % of respondents ranked salinity as the primary natural hazard that they face, followed by erratic rainfall patterns as the second ranking (38 %) and the increase in temperature as the third ranking (48 %) (Fig. 3). 87 % of the respondents reported that the current salinity level in their fields was high while 9 % of the respondents reported salinity as moderate level, and around 4 % of the respondents said salinity in their area was at the low level. This study also examined farmers' perceptions of the causes of increased salinity. Results revealed that 45 % of the respondents stated that increased salinity was associated with natural disasters such as cyclone “Aila” in 2009. 23 % of the respondents said a cyclone in 1988 and the cyclone “Aila” in 2009 were the major natural causes linked to the increase in salinity (Fig. 4). Several other studies that have been conducted in different regions around the globe also indicated that farmers are well aware of climate change related issues (Mertz et al., 2009; Gandure et al., 2013; Maponya and Mpandeli, 2013; Le Dang et al., 2014; Udmale et al., 2014; Bahta et al., 2016). In addition, studies conducted in the coastal areas of Bangladesh also showed that farmers in these regions reported a higher level of salinity, an increase in temperature and erratic rainfall compared to few decades ago (Islam et al., 2019; Hasan and Kumar, 2020a, 2020b; Hasan et al., 2020).

The current literature suggests that salinity in the southwestern coastal areas of Bangladesh including the Satkhira district has risen sharply over the last few decades (SRDI, 2010; Seal and Baten, 2012). A sudden increase in salinity was reported following cyclone “Aila” in 2009, causing cropland to flood with saline water, which created waterlogging and resulted in an increase in salinity in the Satkhira district (Rabbani et al., 2013; Bangladesh Meteorological Department (BMD, 2019). Around 67 % of the cultivable land of the Satkhira district is affected by different magnitudes of salt intrusion and about 81 % of the total land of Shyamnagar and Assasuni sub-districts are affected by salt intrusion. Among the salt affected areas, around 84 % of the cultivated land of Assasuni and 91 % of the cultivable land the Shyamnagar sub-district are moderately saline to strongly saline with an EC above 8.0 dS/m (Table 3). Therefore, farmers' perceptions about the current salinity level align with the data from current research. Based on our survey results and harmonization of these observations with available data from the literature, it can be concluded that the present salinity level of the study area could be described as moderately saline to highly saline with an EC level that is greater than 8.0 dS/m.

3.3. Harmonizing survey results and literature data to identify the most vulnerable growth stage of rice to salinity stress

Farmers from the study area acknowledged that they face problems due to salinity during the Boro season with different sensitivities for the individual rice growth stages. The survey results showed that panicle emergence is the most vulnerable growth stage according to 71 % of respondent farmers (Fig. 5). They were also of the opinion that during the panicle emergence stage, a high salt concentration is unmanageable and that even a few days of a high salinity concentration during this stage could potentially result in a reduction in rice production (62 % of respondents) (Fig. 5). The perceptions from the focus group discussions and the opinion of experts also illustrated that the panicle emergence stage of rice is the most vulnerable growth phase and high salinity during this phase results in a drastic reduction in yield.

The review of literature showed that the response of rice to salinity varies for the different growth stages, and that varieties responded differently (Maas and Hoffman, 1977; Yoshida, 1981; Heenan et al., 1988; Joseph and Mohanan, 2013). Several studies have shown that the early vegetative and panicle emergence periods are the most sensitive to salinity (Heenan et al., 1988; Zeng et al., 2001; Shereen et al., 2005; Hakim et al., 2010; Ali et al., 2014; Ologundudu et al., 2014). Salinity stress during the panicle emergence stage results in less floret fertilization in the panicle and ultimately causes a reduction in grain yield

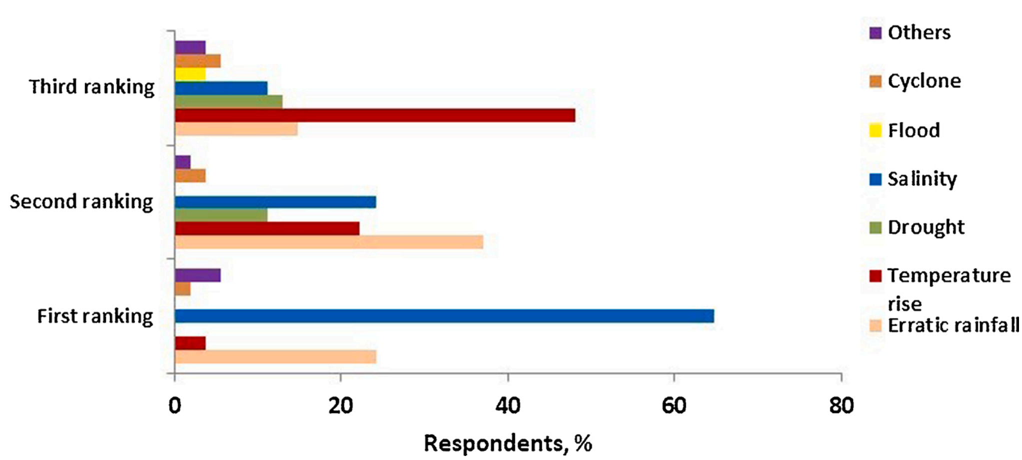

Fig. 3. Ranking of reported weather and climate issues in the study area.

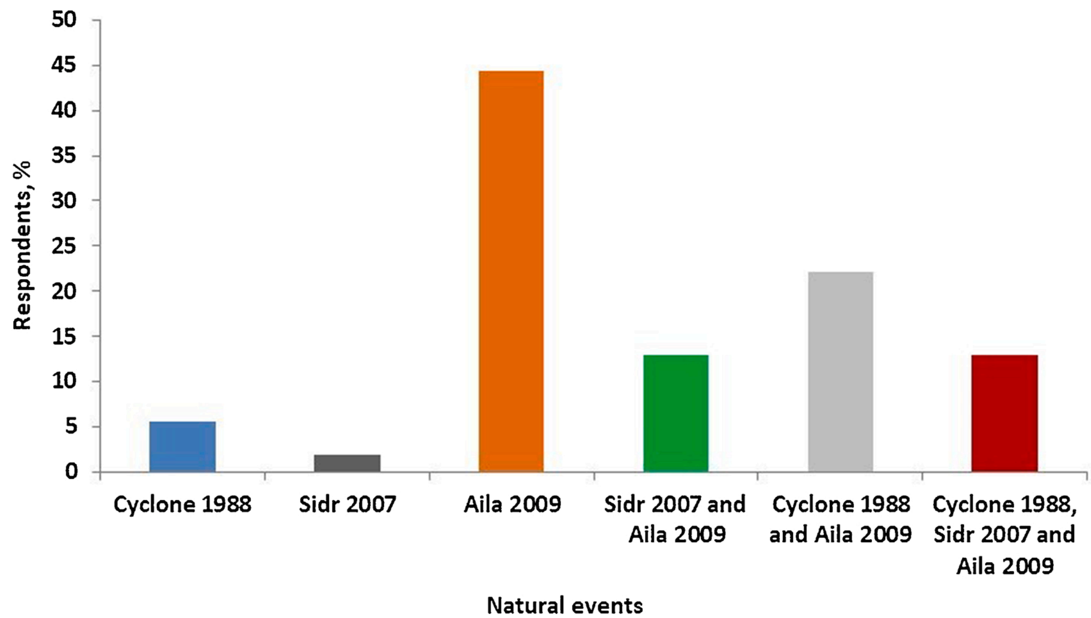

Fig. 4. Farmers' perception on the natural events associated with the increase of the salinity level.

Table 3
Salinity affected areas of the Satkhira district and their share in the sub-districts of the study area.

Name of sub-district & district	Total area ('000'ha)	Total saline area ('000' ha)	Soil Salinity classes and affected areas ('000' ha)				
			S1 EC, dS/m (2.0–4.0)	S2 EC, dS/m (4.1–8.0)	S3 EC, dS/m (8.1–12.0)	S4 EC, dS/m (12.1–16.0)	S5 EC, dS/m (> 16.0)
Assasuni	40,982	33,390 81 %	1980 6 %	3430 10 %	9770 30 %	10,040 30 %	8170 24 %
Shyamnagar	45,609	36,910 81 %	620 2 %	2630 7 %	7380 20 %	12,360 33 %	13,920 38 %
Satkhira district	229,607	153,110 67 %	30,000 19 %	31,960 21 %	30,650 20 %	31,920 21 %	28,580 19 %

Source: (SRDI, 2010)

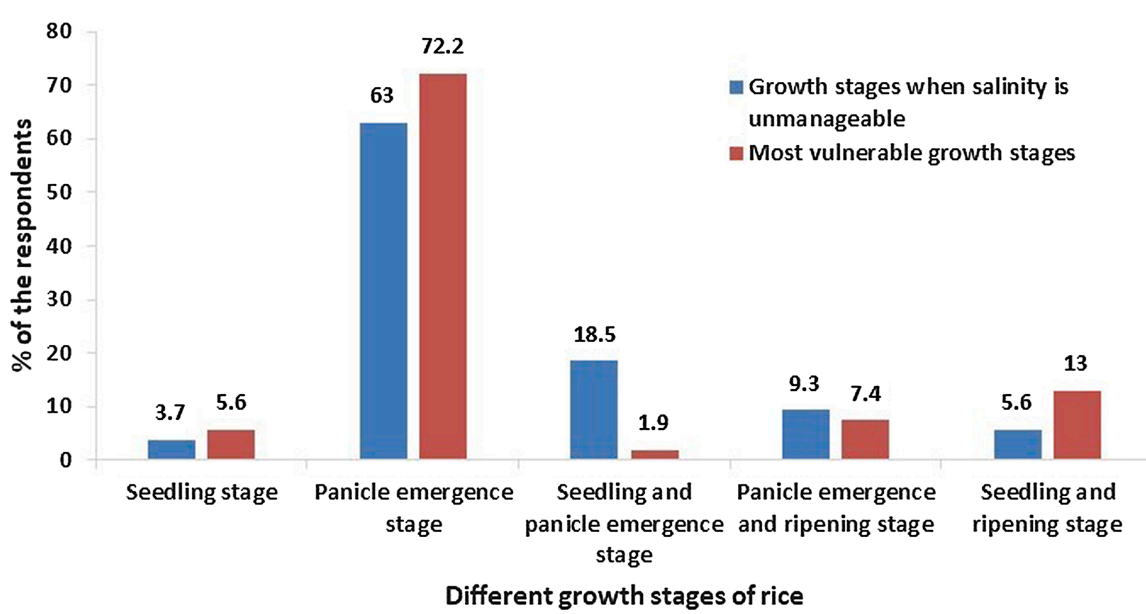

Fig. 5. Farmers' perceptions of the most vulnerable and unmanageable growth stages of rice to salinity.

(Pearson and Bernstein, 1959; Lutts et al., 1995; Alam et al., 2004; Mohammadi-Nejad et al., 2012). A recent study has shown that rice plants are most susceptible to salinity during the early growth stages, i.e., tillering and panicle emergence (Hoang et al., 2016). A salinity level of 6–8 dS/m significantly reduces the yield per panicle (Rad et al., 2012). A study conducted in Australia also showed that the early vegetative and reproductive development phases are the most susceptible to salinity stress (Heenan et al., 1988). Salinity stress above 8.0 dS/m during the early vegetative phase and between panicle initiation and the booting significantly reduced grain yield (Alam et al., 2004;

Hasanuzzaman et al., 2009). It also has been reported that a 20-day duration of a moderate, e.g., 4–5 dS/m, level of salinity stress is the most harmful between active tillering and panicle initiation, resulting in a significant reduction in grain yield (Zeng et al., 2001). Based on our survey results, focus group discussions and review of literature, we concluded that the panicle emergence stage of rice growing during the Boro season is the most vulnerable growth stage to salt intrusion.

3.4. Determination of salinity tolerance thresholds through harmonizing survey results and literature data

Rice is characterized as a slightly salt-tolerant crop up to an EC threshold of 3.0 dS/m (Maas and Hoffman, 1977; Wassmann et al., 2009). Different studies have indicated that rice yield is significantly reduced if the plants are stressed at salinity levels above 4.0 dS/m, especially during the panicle initiation stage (Grattan et al., 2002). Yoshida (1981) reported that yield was reduced by 50 % at a salinity level that range from 6.0 to 7.0 dS/m during the panicle emergence stage. Zeng and Shannon (2000) observed yield losses of 30 % at a salinity level of 3.9 dS/m and 50 % at a salinity level of 5.0 dS/m. Joseph and Mohanan (2013) showed that rice grain yield in India was significantly reduced at a salinity level of 4.5 dS/m for all studied varieties and that yield was reduced by 50 % at a salinity level of 6.4 dS/m. Another study conducted in Iran showed that a salinity stress of 8 dS/m at the panicle emergence stage reduced yield by 50 % (Rad et al., 2012). Hasanuzzaman et al. (2009) showed that the yield of salt-tolerant rice varieties in Bangladesh decreased by 30 % at a salinity level of 10 dS/m. However, studies on the effects of salinity levels during panicle emergence stage on the yield loss of newly released salt-tolerant rice varieties in Bangladesh are very limited.

In the area of our study, salinity concentrations in the field varied during different months of the year. Soil salinity started to increase in February, and it reached the highest level between 9.0–10.0 dS/m during mid-March to mid-April. The salinity level remained high during the rest of the growing season of Boro rice and from July to December, it decreased to around 1−2 dS/m (Climate Change Cell (CCC, 2009). In general, the reproductive phase of rice starts with panicle primordia initiation, at about 65–70 days after germination (Yoshida, 1981). In the study area, 40- to 45-day old Boro rice seedlings were transplanted into the main field from January to mid-February (FAO, 2008), and reached at the panicle emergence stage when the salt intrusion started to increase in the study area (Climate Change Cell (CCC, 2009; Ismail and Tuong, 2009). Thus, the panicle emergence stage of Boro rice generally occurred during the months of March to April when the salinity level reached its peak.

Based on farmers' perceived most vulnerable growth stage of rice grown during the Boro season and the known effects of salt stress on rice, the tolerance threshold level for soil salinity in the study areas was determined. Survey results showed that farmers' perceived the reproductive stages (e.g. panicle emergence) as the most vulnerable to salinity stress, which was found consistent with the literature. As we assumed 30 % yield loss could be the threshold for the farmers, we searched the available literature to show at what salinity level at least 30 % yield loss was reported. We found at least 30 % yield loss in rice when the reproductive stages were affected by salinity stress exceeding 4.0 dS/m. Thus, we identified the salinity tolerance threshold as 4−5 dS/m for traditional rice varieties as literature data were based on the rice crops regardless of tolerance to salinity. A limited research using salt-tolerant rice varieties reported 30 % or higher yield loss at a salinity level of 10.0 dS/m. In addition, government organizations (i.e. research and extension) claimed their salt tolerant varieties could tolerate up to 8.0 dS/m salinity stress during the reproductive stages. Thus, based on the farmers' perceived vulnerable growth stages, seasonal salinity trends in the study area, salinity tolerance threshold for new salt-tolerant varieties were identified as 8–10 dS/m. The salinity tolerance threshold levels represent bases of ATP for further development of management strategies for salinity intrusion regulation.

4. Discussion

The goal of this study was to explore farmers' perspectives of salinity problems during the Boro season rice cultivation. The findings of this study revealed that a vast majority of the farmers' perceived salinity as the major climate change induced problem followed by an increase in temperature and erratic rainfall. Most of farmers also perceived that the current salinity level in their field was high. These findings were found to be consistent with other studies that have been conducted in the coastal areas of Bangladesh that concluded that an increase in salinity, an increase in temperature, and abrupt rainfall are the current major impacts of climate change (Hossain et al., 2018; Hasan and Kumar, 2019, 2020a, 2020b). Our study also showed that farmers in the study area perceived that the recent major cyclones such as "Aila" in 2009 and "Sidr" in 2007 were associated with an increase in salinity. Our results are also consistent with the reported natural hazards in the coastal areas of Bangladesh that include enhanced salinity intrusion through massive inundation of farmers' fields (Rabbani et al., 2013). Our study found that farmers were more concerned about cyclone "Aila" in 2009 compared to cyclone "Sidr" in 2007, which is also consistent with the reports on cyclones that indicate that impact of Sidr was severe in the central and southeastern coastal areas of Bangladesh compared to Aila (BMD, 2019). Farmers are probably more concerned about the most recent practical experience with cyclones as these shape people's perceptions about disasters (Mertz et al., 2009; Weber, 2010).

The findings of this study show that the farmers in the study area perceived panicle emergence as the most vulnerable stage for salinity stress. Other research on the effect of salinity stress on the growth and developments of rice plants has indicated that reproductive growth phases of rice, including panicle emergence and flowering are the most sensitive to salinity (Zeng et al., 2001; Ali et al., 2014). This study also revealed that the farmers in the study area are well aware about climate change issues and that they perceived salinity as the major climate change induced problems during the Boro rice season. The temporal salinity distribution trends in the coastal areas of Bangladesh demonstrated that the high salinity period overlaps with the farmers' perceived salinity sensitive stages of rice plants (Climate Change Cell (CCC, 2009; Clarke et al., 2015). Since the present salinity level in most of the study region is already higher than the identified threshold, the tipping point for traditional varieties might already have been reached. For the newly released salt-tolerant varieties, the tipping point could be reached in the near future depending on salt intrusion scenarios.

This study demonstrated when and how salinity problems become relevant for the farmers and why alternative strategies should be developed by policymakers to address the salinity problems to support intensification of rice cultivation in the coastal areas of Bangladesh. Recent literature on the governance of adaptation to the potential negative impact of climate change also suggests that the process of adaptation should "start from adaptation problems in its decision context" (Kwadijk et al., 2010; Werners et al., 2013). In this study, we brought farmers perspectives of salinity problems to the science and policy level through face-to-face surveys and experts' opinion, and we identified the salinity threshold through applying the ATP concept. The approach of the present study for the determination of the salinity tolerance threshold is consistent with other studies that have identified the threshold of a biophysical system such as for flood management through interviewing relevant stakeholders, reviewing expert judgments, and harmonizing these results with available literature (Kwadijk et al., 2010; Werners et al., 2013).

The findings of this study could have significant implications for the policymakers in terms of adaptation decisions to address salinity problems in the coastal areas of Bangladesh. Despite the farmers' perspective of salinity problems in the study area, the government's response to salinity problems remains in technical top down solutions such as saline tolerant crops. As farmers' perceive that most salinity sensitive stages of rice overlap with the peak salinity in the coastal areas, research should emphasize high salt-tolerance during the panicle emergence stage in the variety development process. In addition, farmers' innovative adaptation measures such as earlier transplanting could be another adaptation approach to avoid the high salinity prevalence period during the reproductive stages of rice (Islam et al., 2019). In addition, encouraging local farmers to grow alternative crops and such as short duration vegetable crops could help to ensure farm-level food security in the coastal areas of Bangladesh (Hassan and Kumar, 2020a, 2020b). We considered the recommendations by the Research and Extension Service Department about the tolerance level of salt-tolerant Boro season rice varieties as a policy objective and determined when this policy objective may no longer be able to achieve its goal and fails due to climate change and societal preferences. This research could be an important step for long-term and holistic adaptation research and for identifying tipping points for adaptation to future salt intrusion scenarios. Timing of tipping points could be synthesized through harmonizing the identified salinity tolerance threshold using a systems approach with a process-oriented crop model, such as the Decision Support System for Agro-technology Transfer (DSSAT) (Hoogenboom et al., 2019). We defined the salinity tolerance threshold as the level at which the yield of rice was reduced by more than 30 %. However, these thresholds could be different since some farmers may shift to other alternative livelihoods when the yield reduction is smaller than 30 %, and some might continue with rice cultivation during the Boro season and accept the higher yield loss. Thus, further studies could survey a larger and more diverse farming community and a larger region in the coastal area of Bangladesh for a well-defined salinity tolerance threshold.

5. Conclusions

Salinization of coastal areas is a persistent problem worldwide, and policymakers are struggling in making adaptation decisions to address this issue. The finding of this study revealed that farmers' perceived that the salinity level has increased because of climate change, and that the current salinity level in their field is at a high level. They also perceived that the panicle emergence stage of rice is the most sensitive to salinity, which overlaps with the salinity peak during the Boro growing season. For potential adaptation to salinity, salt-tolerant rice varieties should have a high tolerance especially during the panicle emergence stage. The results from this study can help policymakers with setting priorities regarding adaptation for future salt intrusion scenarios under climate change. Further studies should examine the effectiveness of farmers' innovation practices such as earlier transplanting or planting alternative crops to address salinity problems in similar coastal environments around the globe.

CRediT authorship contribution statement

Md. Aminul Islam: Investigation, Data curation, Formal analysis, Writing - original draft. **Vakhtang Shelia:** Formal analysis, Writing - review & editing. **Fulco Ludwig:** Conceptualization, Formal analysis, Writing - review & editing, Funding acquisition, Supervision. **Lisa Lobry de Bruyn:** Formal analysis, Writing - review & editing. **M. Habib ur Rahman:** Formal analysis, Writing - review & editing. **Gerrit Hoogenboom:** Conceptualization, Methodology, Formal analysis, Writing - review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research was a part of MSc. in Climate studies at the Wageningen University, the Netherlands. The study was funded by the Netherlands Fellowship Programme (NFP) [NFP-MA. 13/5646] administered by theNetherlands Organization for International Cooperation in Higher Education (NUFFIC).

References

Ahmad, H., 2019. Bangladesh coastal zone management status and future trends. J. Coast. Zone Manag. 22 (1), 1–7.
Ahmed, N., Allison, E.H., Muir, J.F., 2010. Rice fields to prawn farms: a blue revolution in southwest Bangladesh? Aquac. Int. 18 (4), 555–574.
Ahmed, F., Gersonius, B., Veerbeek, W., Alam Khan, M.S., Wester, P., 2015. The role of extreme events in reaching adaptation tipping points: a case study of flood risk management in Dhaka, Bangladesh. J. Water Clim. Chang. 6 (4), 729–742.
Alam, M., Stuchbury, T., Naylor, R., Rashid, M., 2004. Effect of salinity on growth of some modern rice cultivars. J. Agron. 3, 1–10.
Alam, G.M., Alam, K., Mushtaq, S., 2017. Climate change perceptions and local adaptation strategies of hazard-prone rural households in Bangladesh. Clim. Risk Manag. 17, 52–63.
Ali, M.N., Yeasmin, Below L., Gantait, S., Goswami, R., Chakraborty, S., 2014. Screening of rice landraces for salinity tolerance at seedling stage through morphological and molecular markers. Physiol. Mol. Biol. Plants 20, 411–423.
Bahta, Y., Jordaan, A., Muyambo, F., 2016. Communal farmers' perception of drought in South Africa: policy implication for drought risk reduction. Int. J. Disaster Risk Reduct. 20, 39–50.
Bangladesh Meteorological Department (BMD), 2019. Government of the People's Republic of Bangladesh. http://live.bmd.gov.bd/p/Historical-Cyclones/.
BBS, 2019. Bangladesh Bureau of Statistics, Statistical Yearbook of Bangladesh, Statistics and Informatics Division, Ministry of Planning, Government of the People's Republic of Bangladesh. https://www.bbs.gov.bd.
BINA, 2019. Bangladesh Institute of Neuclear Agriculture. Saline Tolerant Varieties. http://www.bina.gov.bd/site/page/8375e58a-0ce3-4ae5-b158-49ed055c0071/-.
BRRI, 2019. Bangladesh Rice Research Institute. Annual Report. http://brri.portal.gov.bd/sites/default/files/files/brri.portal.gov.bd/page/b6531346_66a5_45e7_9cb0_d00c7c7009dc/Rice%20Area%2C%20Production%20and%20Yield%20in%20Bangladesh_29.01.2019.pdf.
Bryman, A., Cramer, D., 2011. Quantitative Data Analysis With IBM SPSS 17, 18 and 19. Routledge.
Chowdhury, Khairun, Md Arif, Salequzzaman, Yahya, Rahman, Md, Mizanur, M., 2011. Effect of combined shrimp and rice farming on water and soil quality in Bangladesh. Aquac. Int. 19, 1193–1206.
Clarke, D., Williams, S., Jahiruddin, M., Parks, K., Salehin, M., 2015. Projections of on-farm salinity in coastal Bangladesh. Environ. Sci. Process. Impacts 17 (6), 1127–1136.
Climate Change Cell (CCC), 2009. Adaptive Crop Agriculture Including Innovative Farming Practices in the Coastal Zone of Bangladesh. Climate Change Cell, DoE, MoEF; Component 4b, CDMP, MoFDM, Dhaka, Bangladesh.
Dessai, S., van der Sluijs, J.P., 2007. Uncertainty and climate change adaptation: a scoping study. In: Copernicus Institute for Sustainable Development and Innovation, Department of Science Technology and Society, Vol. 2007. Copernicus Institute, Utrecht University, 3584 CS Utrecht, The Netherlands.
FAO, 2008. Special Report: FAO/WFP Crop And Food Supply Assessment Mission To Bangladesh. Food and Agriculture Organization.
FAO-ITPS-GSP, 2015. Status of the World's Soil Resources. FAO-ITPS-GSP Main Report, Food and Agriculture Organization of the United Nations, Rome, Italy, pp. 125–127.
Firth, J., Colley, M., 2006. The Adaptation Tipping Point: Are UK Businesses Climate-proof? Acclimatise and UKCIP Oxford. https://www.sustainabilitywestmidlands.org.uk/wp-content/uploads/Are_UK_Businesses_Climate-proof_-_UKCIP_20061.pdf.
Gandure, S., Walker, S., Botha, J., 2013. Farmers' perceptions of adaptation to climate change and water stress in a South African rural community. Environ. Dev. 5, 39–53.
Gifford, R., 2011. The dragons of inaction: psychological barriers that limit climate change mitigation and adaptation. Am. Psychol. 66 (4), 290.
Glick, P., Stein, B.A., Edelson, N.A., 2011. Scanning the Conservation Horizon: a Guide to Climate Change Vulnerability Assessment. National Wildlife Federation, 901 E Street, Suite 400, Washington DC 2004.
Granda, P., Wolf, C., Hadorn, R., 2010. In: Harkness, J.A., Braun, M., Edwards, B., Johnson, T.P., Lyberg, L., Mohler, P.Ph., Pennell, B.-E., Smith, T.W. (Eds.), Harmonizing Survey Data, in Survey Methods in Multinational, Multiregional, and Multicultural Contexts. John Wiley & Sons, Inc., Hoboken, NJ, USA https://doi.org/10.1002/9780470609927.ch17.
Grattan, S., Zeng, L., Shannon, M., Roberts, S., 2002. Rice is more sensitive to salinity than previously thought. Calif. Agric. 56 (6), 189–198.
Green, J., Thorogood, N., 2009. In-depth interviews. Qual. Methods Health Res. 2, 93–122.
Hakim, M., Juraimi, A., Begum, M., Hanafi, M., Ismail, M.R., Selamat, A., 2010. Effect of salt stress on germination and early seedling growth of rice (Oryza sativa L.). Afr. J. Biotechnol. 9, 1911–1918.
Hasan, M.K., Kumar, L., 2019. Comparison between meteorological data and farmer perceptions of climate change and vulnerability in relation to adaptation. J. Environ. Manage. 237, 54–62.

Hasan, M.K., Kumar, L., 2020a. Meteorological data and farmers' perception of coastal climate in Bangladesh. Sci. Total Environ. 704, 135384.
Hasan, M.K., Kumar, L., 2020b. Perceived farm-level climatic impacts on coastal agricultural productivity in Bangladesh. Clim. Change 1–20.
Hasan, M.K., Desiere, S., D'Haese, M., Kumar, L., 2018. Impact of climate-smart agriculture adoption on the food security of coastal farmers in Bangladesh. Food Secur. 10, 1073–1088. https://doi.org/10.1007/s12571-018-0824-1.
Hasan, M.K., Kumar, L., Gopalakrishnan, T., 2020. Inundation modelling for Bangladeshi coasts using downscaled and bias-corrected temperature. Clim. Risk Manag. 27, 100207 https://doi.org/10.1016/j.crm.2019.100207.
Hasanuzzaman, M., Fujita, M., Islam, M., Ahamed, K., Nahar, K., 2009. Performance of four irrigated rice varieties under different levels of salinity stress. Int. J. Integr. Biol. 6, 85–90.
Heenan, D., Lewin, L., McCaffery, D., 1988. Salinity tolerance in rice varieties at different growth stages. Aust. J. Exp. Agric. 28, 343–349.
Hoang, T., Tran, T., Nguyen, T., Williams, B., Wurm, P., Bellairs, S., Mundree, S., 2016. Improvement of salinity stress tolerance in rice: challenges and opportunities. Agronomy 6, 54.
Hoogenboom, G., Porter, C.H., Boote, K.J., Shelia, V., Wilkens, P.W., Singh, U., White, J. W., Asseng, S., Lizaso, J.I., Moreno, L.P., Pavan, W., Ogoshi, R., Hunt, L.A., Tsuji, G. Y., Jones, J.W., 2019. The DSSAT crop modeling ecosystem. In: Boote, K.J. (Ed.), Advances in Crop Modeling for a Sustainable Agriculture. Burleigh Dodds Science Publishing, Cambridge, United Kingdom, pp. 173–216. https://doi.org/10.19103/AS.2019.0061.10).
Hossain, M.S., Uddin, M.J., Fakhruddin, A.N.M., 2013. Impacts of shrimp farming on the coastal environment of Bangladesh and approach for management. Rev. Environ. Sci. Biotechnol. 12 (3), 313–332.
Hossain, P.R., Ludwig, F., Leemans, R., 2018. Adaptation pathways to cope with salinization in south-west coastal region of Bangladesh. Ecol. Soc. 23 (3) https://doi.org/10.2307/26799149.
IPCC, 2014. Climate change 2014: synthesis report. In: Pachauri, R.K., Meyer, L.A. (Eds.), Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team. IPCC, Geneva, Switzerland, 151 pp.
Islam, M., Sarker, M., Sharma, N., Rahman, M., Collard, B., Gregorio, G., Ismail, A., 2016. Assessment of adaptability of recently released salt tolerant rice varieties in coastal regions of South Bangladesh. Field Crops Res. 190, 34–43.
Islam, M.A., Bruyn, L.L.D., Warwick, N.W., Koech, R., 2019. Farmers' perceptions of salinity for ensuring food security: evidence from coastal rice-growing areas of Bangladesh. Multidiscipl. Digital Publ. Inst. Proc. 36 (1), 15.
Ismail, A., Tuong, T., 2009. Brackish water coastal zones of the monsoon tropics: challenges and opportunities. Nat. Res. Manage. 113–121.
Joseph, E.A., Mohanan, K., 2013. A study on the effect of salinity stress on the growth and yield of some native rice cultivars of Kerala state of India. Agric. Fish 2, 141–150.
Kausher, A., Kay, R.C., Asaduzzaman, M., Pual, S., 2012. Climate change and sea-level rise: the case of the coast. In: Warrick, R.A., Ahmad, Q.K. (Eds.), The Implications of Climate and Sea-Level Change for Bangladesh. Springer Science & Business Media, London, pp. 335–405.
Khan, M.M.H., Bryceson, I., Kolivras, K.N., Faruque, F., Rahman, M.M., Haque, U., 2014. Natural disasters and land-use/land-cover change in the southwest coastal areas of Bangladesh. Reg. Environ. Change 15 (2), 241–250.
Koukoui, N., Gersonius, B., Schot, P.P., van Herk, S., 2015. Adaptation tipping points and opportunities for urban flood risk management. J. Water Clim. Chang. 6 (4), 695–710.
Kwadijk, J.C., Haasnoot, M., Mulder, J.P., Hoogvliet, M.M., Jeuken, A.B., van der Krogt, R.A., van Oostrom, N.G., Schelfhout, H.A., van Velzen, E.H., van Waveren, H., 2010. Using adaptation tipping points to prepare for climate change and sea level rise: a case study in the Netherlands. Wiley Interdiscip. Rev. Clim. Change 1, 729–740.
Le Dang, H., Li, E., Bruwer, J., Nuberg, I., 2014. Farmers' perceptions of climate variability and barriers to adaptation: lessons learned from an exploratory study in Vietnam. Mitig. Adapt. Strateg. Glob. Chang. 19 (5), 531–548.
Ludwig, F., van Slobbe, E., Cofino, W., 2014. Climate change adaptation and Integrated Water Resource Management in the water sector. J. Hydrol. 518, 235–242.
Lutts, S., Kinet, J., Bouharmont, J., 1995. Changes in plant response to NaCl during development of rice (Oryza sativa L.) varieties differing in salinity resistance. J. Exp. Bot. 46, 1843–1852.
Maas, E.V., Hoffman, G.J., 1977. Crop salt tolerance–current assessment. J. Irrig. Drain. Div. 103, 115–134.
Maddison, D., 2007. The Perception of and Adaptation to Climate Change in Africa. The World Bank, Washington, D.C.
Maponya, P., Mpandeli, S., 2013. Perception of farmers on climate change and adaptation in Limpopo Province of South Africa. J. Hum. Ecol. 42 (3), 283–288.
Mertz, O., Mbow, C., Reenberg, A., Diouf, A., 2009. Farmers' perceptions of climate change and agricultural adaptation strategies in rural Sahel. Environ. Manage. 43 (5), 804–816.
Milkoreit, M., Hodbod, J., Baggio, J., Benessaiah, K., Calderón-Contreras, R., Donges, J. F., Mathias, J.-D., Rocha, J.C., Schoon, M., Werners, S.E., 2018. Defining tipping points for social-ecological systems scholarship-an interdisciplinary literature review. Environ. Res. Lett. 13, 033005.
Mohammadi-Nejad, G., Singh, R., Arzani, A., Sabouri, H., Gregorio, G., Rezaie, A., 2012. Evaluation of salinity tolerance in rice genotypes. Int. J. Plant Prod. 4, 199–208.
Nanda, A., Beesley, L., Locatelli, L., Gersonius, B., Hipsey, M.R., Ghadouani, A., 2018. Adaptation tipping points of a wetland under a drying climate. Water 10 (2), 234.
NAP, 2018. New Agriculture Policy, Department of Agricultural Extension. Ministry of Ag-riculture, Government of the Peoples' Republic of Bangladesh. http://dae.portal.gov.bd/sites/default/files/files/dae.portal.gov.bd/policies/d88c827b_f01b_4b42_89a2_34d7212adea2/NAP%202018.pdf.
NAPA, 2009. National Adaptation Plan of Action. Ministry of Environment of Forest. http://nda.erd.gov.bd/files/1/Publications/CC%20Policy%20Documents/NAPA2005.pdf.
Nicholls, R.J., Cazenave, A., 2010. Sea-level rise and its impact on coastal zones. Science 328, 1517–1520.
Niles, M.T., Mueller, N.D., 2016. Farmer perceptions of climate change: associations with observed temperature and precipitation trends, irrigation, and climate beliefs. Glob. Environ. Chang. Part A 39, 133–142.
NSDS, 2013. National Sustainable Development Strategies. General Economics Division, Ministry of Planning, Government of the People's Republic of Bangladesh. https://policy.asiapacificenergy.org/sites/default/files/National-Sustainable-Development-Strategy.pdf.
Ologundudu, A.F., Adelusi, A.A., Akinwale, R.O., 2014. Effect of salt stress on germination and growth parameters of Rice (Oryza sativa L.). Not. Sci. Biol. 6.
Paul, B.G., Vogl, C.R., 2011. Impacts of shrimp farming in Bangladesh: challenges and alternatives. Ocean Coast. Manag. 54, 201–211.
Pearson, G.A., Bernstein, L., 1959. Salinity effects at several growth stages of rice 1. Agron. J. 51, 654–657.
Rabbani, G., Rahman, A., Mainuddin, K., 2013. Salinity-induced loss and damage to farming households in coastal Bangladesh. Int. J. Glob. Warm. 5, 400–415.
Rad, H.E., Aref, F., Rezaei, M., 2012. Rice growth and yield components respond to changes in water salinity stress. World Appl. Sci. J. 20, 997–1007.
Riquelme-Solar, M., Van Slobbe, E., Werners, S., 2015. Adaptation turning points on inland waterway transport in the Rhine River. J. Water Clim. Change. 6, 670–682.
Russill, C., Nyssa, Z., 2009. The tipping point trend in climate change communication. Glob. Environ. Chang. Part A 19, 336–344.
Seal, L., Baten, M.A., 2012. Salinity Intrusion in Interior Coast: a New Challenge to Agriculture in South Central Part of Bangladesh. A working draft, Climate Change, Biodiversity and Disaster Risk Reduction Unit, Unnayan Onneshan-The Innovators, enter for Research and Action on Development.
Seale, C., Kelly, M., 2004. Coding and analysing data. Res. Soc. Culture 2, 304–321.
Selkoe, K.A., Blenckner, T., Caldwell, M.R., Crowder, L.B., Erickson, A.L., Essington, T.E., et al., 2015. Principles for managing marine ecosystems prone to tipping points. Ecosyst. Health Sustain. 1 (5), 1–18.
Shahid, S.A., 2013. Developments in salinity assessment, modeling, mapping, and monitoring from regional to submicroscopic scales. In: Shahid, S.A., Abdelfattah, M. A., Taha, F.K. (Eds.), Developments in Soil Salinity Assessment and Reclamation – Innovative Thinking and Use of Marginal Soil and Water Resources in Irrigated Agriculture. Springer, Dordrecht\Heidelberg\New York\London, pp. 3–43.
Shahid, S.A., Zaman, M., Heng, L., 2018. Soil salinity: historical perspectives and a world overview of the problem. Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques. Springer, Cham. https://doi.org/10.1007/978-3-319-96190-3_2.
Shameem, M.I.M., Momtaz, S., Kiem, A.S., 2015. Local perceptions of and adaptation to climate variability and change: the case of shrimp farming communities in the coastal region of Bangladesh. Clim. Change 133 (2), 253–266.
Shereen, A., Mumtaz, S., Raza, S., Khan, M., Solangi, S., 2005. Salinity effects on seedling growth and yield components of different inbred rice lines. Pak. J. Bot. 37, 131–139.
SRDI, 2010. Soil resources development institute. Saline Soils of Bangladesh. Government of the People's Republic of Bangladesh. http://srdi.portal.gov.bd/sites/default/files/files/srdi.portal.gov.bd/publications/bc598e7a_df21_49ee_882e_0302c974015f/Soil%20salinity%20report-Nov%202010.pdf.
Tam, J., McDaniels, T., 2013. Understanding individual risk perceptions and preferences for climate change adaptations in biological conservation. Environ. Sci. Policy 27, 114–123.
Uddin, M.N., Bokelmann, W., Entsminger, J.S., 2014. Factors affecting farmers' adaptation strategies to environmental degradation and climate change effects: a farm-level study in Bangladesh. Climate 2 (4), 223–241.
Udmale, P., Ichikawa, Y., Manandhar, S., Ishidaira, H., Kiem, A.S., 2014. Farmers' perception of drought impacts, local adaptation and administrative mitigation measures in Maharashtra State, India. Int. J. Disaster Risk Reduct. 10, 250–269.
USAID, 2015. USAID Office of Food for Peace Food Security Country Framework For Bangladesh FY 2015-2019 (accessed on 02/07/2020). https://www.usaid.gov/sites/default/files/documents/1866/Bangladesh%20_FSCF_FINAL.pdf.
van Slobbe, E., Werners, S.E., Riquelme-Solar, M., Bölscher, T., van Vliet, M.T., 2016. The future of the Rhine: stranded ships and no more salmon? Reg. Environ. Change 16, 31–41.
Wassmann, R., Jagadish, S., Heuer, S., Ismail, A., Redona, E., Serraj, R., Singh, R., Howell, G., Pathak, H., Sumfleth, K., 2009. Climate change affecting rice production: the physiological and agronomic basis for possible adaptation strategies. Adv. Agron. 101, 59–122.
Weber, E.U., 2010. What shapes perceptions of climate change? Wiley Interdiscip. Rev. Clim. Change. 1, 332–342.
Werners, S.E., Pfenninger, S., van Slobbe, E., Haasnoot, M., Kwakkel, J.H., Swart, R.J., 2013. Thresholds, tipping and turning points for sustainability under climate change. Curr. Opin. Environ. Sustain. 5, 334–340.
Yoshida, S., 1981. Fundamentals of rice crop science. Int. Rice Res. Inst.
Zeng, L., Shannon, M.C., 2000. Salinity Effects on Seedling Growth and Yield Components of Rice.
Zeng, L., Shannon, M.C., Lesch, S.M., 2001. Timing of salinity stress affects rice growth and yield components. Agric. Water Manag. 48, 191–206.