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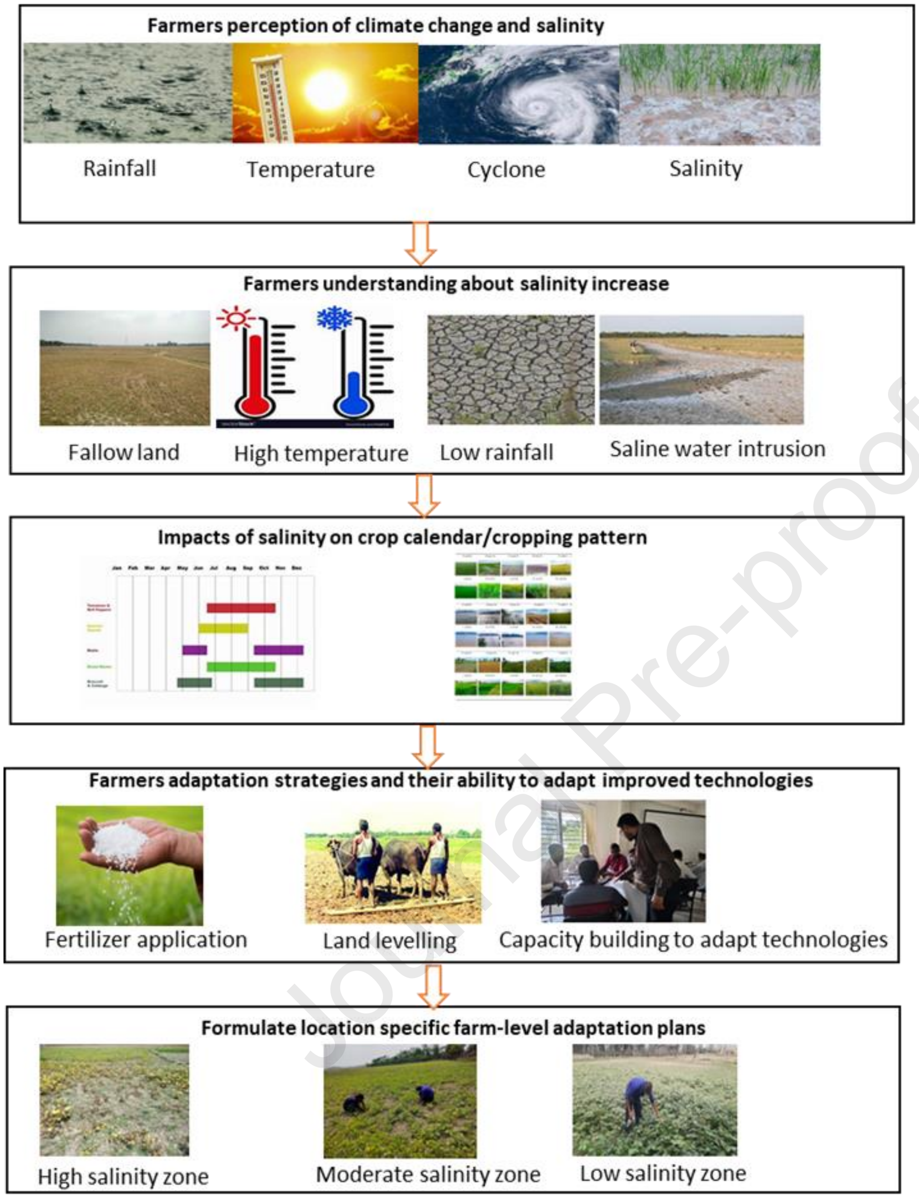
Graphical Abstract



The significance of farmers' climate change and salinity perceptions for on-farm adaptation strategies in the south-central coast of Bangladesh

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Abstract: Climate change contributes to a rise in salinity levels in the coastal regions of Bangladesh, notably impacting agricultural productivity. Therefore, crop-level adaptation strategies against salinity are crucial to increase productivity. In this study, our objective is to explore farm-level adaptation to climate change-induced salinity in the south-central coastal area of Bangladesh, considering the farmers' perception of climate change and salinity ingress as well as their adaptation strategies. Subsequently, we compare our findings with climatic and salinity data acquired from secondary sources. The study area was partitioned into three distinct zones delineated by proximity to the coastline, and primary data was collected from 475 households within these salinity zones using a multistage random sampling technique. Data collection was carried out using semi-structured questionnaires, which had been pretested on the respondents' perceptions for validity and reliability. The results indicate that while farmers possess an awareness of long-term alterations in climatic conditions, such as changes in temperature and precipitation, they often fail to attribute these changes to climate change explicitly. They could perceive changes in salinity over time but had difficulty perceiving cyclonic events. Farmers realize the risks posed by hydroclimatic variability and extreme weather events. Interestingly, while farmers may not be taking explicit measures to address perceived climatic changes, we discern that they are indeed modifying their agricultural and farming practices, such as fertilizer application, land leveling, and freshwater application. Traditional farming systems increase vulnerability and reduce persistence. In pursuit of enhanced resilience, households must implement various adaptation strategies for resilient farming practices. Moreover, our findings indicate that farmers are interested in adopting diverse adaptation strategies that require technical and financial support, particularly for the smallholders. In conclusion, this research provides valuable information for formulating climate change adaptation policies in the context of coastal agriculture in Bangladesh.

Keywords: Climate change, Climate change perceptions, Salinity, Agricultural Productivity, Cropping pattern, Coastal Bangladesh

1. Introduction

The global climate change has emerged as one of the most significant challenges of the 21st century [1]. Its far-reaching effects on various sectors at the local levels, particularly in agriculture, have triggered a growing concern among policymakers and researchers worldwide, especially in regions susceptible to hydroclimatic variability [2,3]. Hence, climate change will likely be a significant impediment to sustainable agriculture and worldwide food security [4].

Bangladesh, a country renowned for its agricultural productivity and dependence on farming for livelihoods, faces unique challenges due to its geographic location and climatic characteristics [3]. The coastal areas of Bangladesh, encompassing about 32% of the country [5,6] are particularly exposed to the adverse effects of climate change, including rising sea levels, salinity intrusion, increased temperatures, altered precipitation patterns, cyclones, and heightened frequency of extreme weather events [7]. For instance, according to Imran et al. [8] there was a rise of 3°C in the annual daily maximum temperature and 1°C in the annual daily minimum temperature between 1981 and 2020. Moreover, increases in soil and water salinity are closely linked to changes in water dynamics in coastal areas. Due to climate change and water diversion from major rivers, soil and water salinity levels have been increasing in these regions [9,10]. In the southwestern coastal regions, about 20% of cultivated land has been affected by salinity over the past four decades (1973-2009) [11]. Additionally, Bhuyan et al. [12] reported that soil salinity increased by over 60% during the dry periods in the south-central coastal area from 1973-2021, negatively impacting cropping patterns (annual crop cycles in specific geographic locations) and leading to decreased crop yields [3,13]. Consequently, changes in land use patterns occur every year. Hasan and Kumar [14] observed that from 1970-2017, about 10% of total crop yield loss in the coastal areas was due to climate change and salinity. Additionally, cyclones or storm surges hit every year, increasing salinity levels. For example, following Cyclone 'Aila' in 2009, farmers faced elevated salinity levels in their agricultural land [15]. These climatic shifts not only jeopardize crop yields but also challenge the socio-economic stability of the communities reliant on agriculture.

The farmers in the coastal area mainly depend on seasonal weather for their agricultural practices [16]. Moreover, seasonal farming practices correlate strongly with climate variability across spatial and temporal scales [17]. While salinity has been recognized as a significant issue, it hasn't received the same level of focus as floods and cyclones in the field of climate change discussions [18]. Salinity is mainly affected during the dry seasons (November-May), while it remains low during the wet season (June to October) [12,19]. Typically, salinity levels increase from inland areas toward the coast, as seafront areas are regularly inundated with tidal water, and salt is deposited directly into the topsoil surface [12]. In coastal regions, the production of major crops is severely impacted by salinity, which directly affects the farmers' livelihoods [20]. There are three crops growing in the coastal area, namely *rabi* (16th October-15th March), *kharif-1* (16th March-30th June), and *kharif-2* (1st July-15th October). It is noteworthy that salinity-related challenges are predominantly experienced during the *rabi* and some parts of the *Kharif-1* season. As a result, the cropping intensity (number of crops produced in a given agricultural year) in the coastal areas is lower than in other parts of the country [21]. In the south-central coastal regions, farmers adapted to the increasing salinity effects on crops in various conventional ways, such as cultivating short-duration non-rice crops instead of rice cultivation [22], land leveling, applying fertilizers, etc.

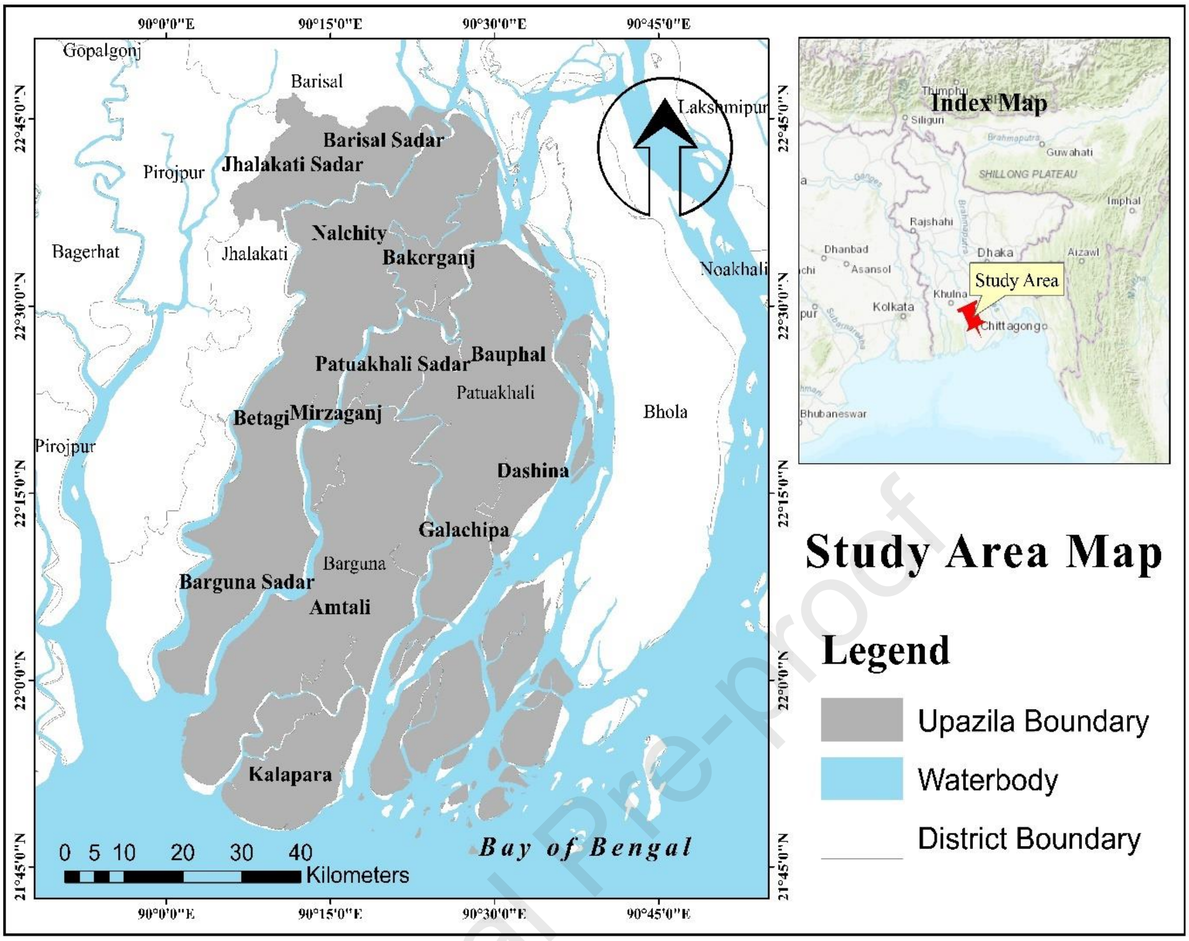
Adaptation stands as a pivotal approach capable of mitigating the gravity of climate change's effects on agricultural systems and food production [23]. The adaptation process has two crucial elements: perception and the formulation of adaptation strategies [24]. The efficacy of these adaptation strategies, however, depends on a comprehensive understanding of how farmers perceive the climate change impact outlook [23]. Incorporating plan adaptation strategies for changes in salinity levels at the local level is frequently overlooked when formulating nationallevel adaptation policies [25]. Discrepancies between farmers' perceptions and literature data regarding climate change issues may hinder the development of effective policies, especially in the context of salinity adaptation planning in the coastal regions [26]. Hence, it is crucial to initially evaluate whether farmers have observed and can relate long-term alterations in climatic processes and their influence on salinity. This assessment guides and supports the development of suitable policies in a specific context.

So far, several studies (for example, [26,27]) have been carried out in the selected south-central coastal areas of Bangladesh, focusing on climate change perception. However, a comprehensive analysis of the entire south-central coastal zone is conspicuously absent. Although various recent studies conducted in the southwestern region [28,29] and the south-central coastal areas [16,25,26,30] have examined farmers' perceptions of crop-level adaptation against climate change. Nevertheless, they did not mention the location-specific farmers' perception of salinity and adaptation practices. It is important to note that adaptation measures to combat salinity in one location may be ineffective in other locations [13]. Therefore, zone-specific information is essential for comprehensive adaptation planning in the study area. To our knowledge, this study is the first attempt to conduct farmers' interviews based on salinity zones (low, medium, and high salinity). Considering the situation, the overall research objective is to explore farm-level adaptation to climate change-induced salinity in the south-central coastal area of Bangladesh. The specific purposes are to: i) assess farmers' perceptions of climate change factors (temperature, rainfall, and cyclones) contributing to changes in salinity levels, ii) evaluate farmers' perceptions of changes in salinity levels over time, iii) examine farmers' perceptions of the causes of increasing salinity and their adaptation strategies in different salinity zones, iv) explore the coastal farmers' perception of the effect of salinity on crop calendar/cropping pattern, and v) assess the farmers' ability to adapt recommend possible suggestions for salinity adaptation. We anticipated that the insights derived from this research will inform evidence-based decision-making, ultimately assisting researchers and policymakers in developing tailored adaptation strategies for smallholder farmers.

2. Methodology

2.1. Study area, sampling methods, and data collection

The study was conducted in the four districts of the south-central coastal area of Bangladesh (Patuakhali, Borguna, Jalakhati, and Barishal) (Fig.1A). These geographical zones exhibit an elevation ranging from approximately 1 to 3 meters above sea level [31] and are predominantly enclosed by embankments (polders) to protect the land from tidal water inundation [32]. Agriculture serves as the primary source of sustenance for the majority of people residing in rural areas [31]. The principal crop in these regions is rice and pulses [33]. Salinity (soil and water) is a foremost hydrological problem in the projected area, mainly affecting dry-season crops [12,13]. Besides, the area is also susceptible to severe weather occurrences such as intense pre-monsoon storms and cyclones, leading to subsequent issues such as waterlogging or flooding [34]. Previously [12], we divided the study area into three zones of equal distances from the east-west direction. These zones were categorized as the high salinity zone (0-40 km), the moderate salinity (41-80 km), and the low salinity zone (81-120 km). Subsequently, in this study we interviewed farmers within these designated salinity zones (Fig. 1B).



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Pirojpur
Jhalakati Sadar
Nalchity
Bagerhat
Jhalakati
Bakerganj
Noakhali
Patuakhali Sadar
Bauphal
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Pirojpur
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Kalapara
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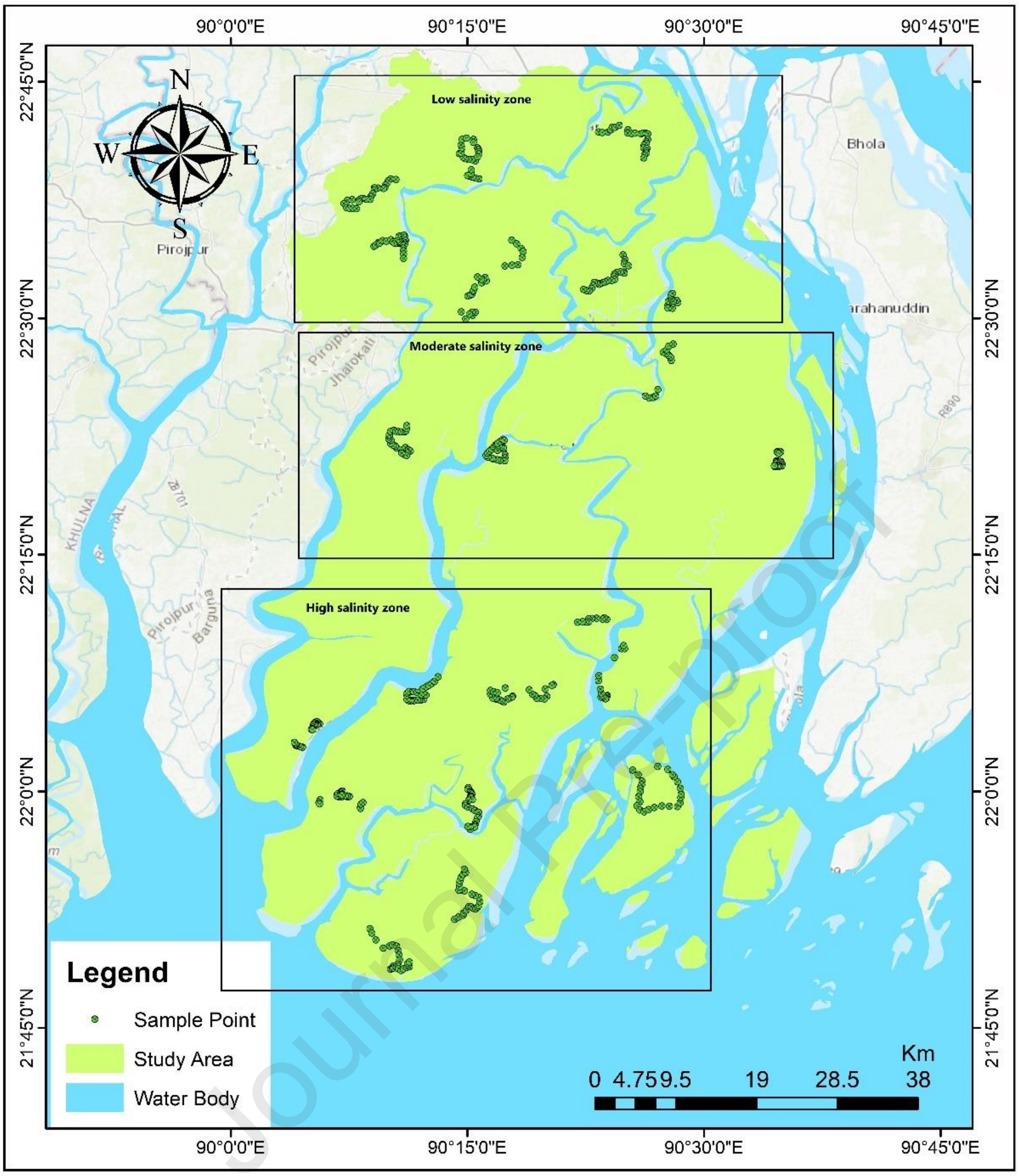
Siliguri
Guwahati
SHILLONG PLATEAU
Imphal
Rajshahi
Dhanbad
Asansol
Dhaka
Aizawl
Study Area
Khulna
Kolkata
Chittagong
Bhubaneswar
Study Area Map
Legend
Upazila Boundary
Waterbody
District Boundary

A



B

Fig. 1. Geographical location of the study area (A) and sample collection point (B)

An exhaustive roster of households in the designated villages along the coastal area was initially obtained from the Sub-Assistant Agricultural Officers (SAAOs) for the projected areas. Then, primary data were collected through structured questionnaires comprised of open-ended and closed-ended questions. While conducting farmer interviews, we employed the open-access online interview platform KoboToolbox (accessible at www.kobotoolbox.org) to gather primary data (from November to December 2022). Prior to the commencement of the actual survey, the questionnaires underwent a pretesting phase on a subset of chosen households within the selected region. Consequently, requisite adjustments were implemented based on the findings from the pretest. Regarding climate perception-related questions, we focused on farmers aged 30 years and older. This study calculated sample size using Eq. (1) [35]:

$$n = \frac{NZ^2 p\,(1-p)}{Nd^2 + Z^2 p\,(1-p)} \quad (1)$$

Where,

n = calculated sample size (384)

N = total number of households (291297)

Z = confidence level (95% confidence level is 1.96)

P = population proportion (0.50, this maximizes the sample size)

d = error margin of 5% (0.05)

The study necessitates a minimum sample size of 384; we collected data from 475 households.

A total of 475 households were randomly selected from the south-central coastal area through a multistage stratified random sampling method (Table 1). Previously, few published research papers used this method to collect household samples [15,20,29,36,37,38]. Individual households were then sampled randomly and data were collected via face-to-face interviews [39]. A single member, typically the household head, was designated as a respondent from each household [29]. In cases where the head was unavailable, another knowledgeable senior member of the family or household was approached to provide responses. The questionnaire was systematically divided into various categories (see Supplementary Material), namely, demographic characterization, assessments of climate change in different climatic variables and salinity perception, agricultural cropping strategies, adaptation strategies against salinity, 173 willingness to adapt recommended adaptation practices and their adaptation capacity as well as the feasibility of the model results, which were obtained from our previous research [13,40].

175 **Table 1. Multistage stratified random sampling**

Stage-1 Selected districts in the south-central coastal area (total districts=4)	**Stage-2** Selected Sub-district (total number of sub-district)	**Stage-3** Selected unions (total no. of unions)	**Stage-4** Selected village (total no. of villages)	**Stage-5** Number of interviewed households
Patuakhali	**Dumki (8)	Pangasia (5)	Chargorobdi (24)	5
	**Bauphal (8)	Dhulia, Kachipara, and Kalaiya (14)	Ayla, Baherchar, Jhilna, Aynabaz (146)	27
	**Dasmina (8)	Bahrampur (6)	Bagura, East bagura, Baharampur (55)	18
	**Sadar (8)	Itbaria (12)	Durgapur, Gilabunia, West Durgapur, West Itbaria (124)	25
	**Mirzagonj (8)	Deuli Subidkhali and Hosnebad (6)	Doklakhali, Jolisha, Goalbari (73)	25
	**Galachipa (8)	Galachipa, Golkhali and Panpatty (12)	Pokkhia, Paschim Ratandi, Baro gabua, Choto gabua, Chorkhali, Uttor Charkhali (227)	25
	***Kalapara (8)	Latachapli, Dulaser, Baliatali, and Tiakhali (12)	Azimpur, Taherpur, Misripara, Notunpara, Baraharpara, Gongamoti, Baliatoli, Char Baliatali, Lemupara, Tulatoli, Modhupara, Karkhanapara, Rojupara, Badurtoli, Itbaria (239)	75
	***Rangabali (8)	Chhoto Baishdia (6)	Choto Baishdia, Noyavangon, Sajir Howla, Madarbunia, Gohinkhali, Horiddrakhali, Howlader, Vuiyar Howla (93)	25
Borguna	***Amtoli (6)	Holodia, Arpangasia, and Amtali (7)	Tepura, Purbo Chilla, Toktabunia, Uttor Tarikata, Arpangasia, and Daskhin Poschim Amtoli (181)	50
	***Borguna (6)	Baliatal (10)	Basuki, Chaltatoli, Mytha, Amtola, Bainshamarto, Monosatoli, and Lotakata (191)	25
	***Taltali (6)	Barabagi, Chhotabagi, and Kariibaria (7)	South Gandamara, Sardaria, West jharakhali, Borobaizora,	25

			Chatonpara, Khazurarpol, Zakirtabak, and Satan Para (74)	
Jalakhati	*Nalchity (4)	Ranapasha, Subidpur, Bhairabpasha, Dapdapia, and Gabkhan Dhansiri, Suktagarh, and Mathbari (10)	Amtoli, Nolbunia, Subidpur, Satpakia, Bohorompur, Notullabad, Noiri, Haripasha, Gabkhan, Binnapara, Kanunia, Begum, Srimontokathi, Indurpasha, Hilakathi, and Dohorsongkor (138)	86
Barishal	*Bakerganj (10)	Niamati, Rangasree, Dudhal, and Garuria (14)	Ramnagar, Seota, Dahokathi, Birangal, Sundarkathi, Meyor, Dhaporkathi, and Vanderkathi (172)	39
	*Barisal Sadar (10)	Char Kowa and Chandpura (10)	Char Kowa, Noyani, Raipur, Khontakhali, and Kundialpar (110)	25

*= Low salinity zone, **= Moderate salinity zone, and ***= High salinity zone

Information on the number of districts, sub-districts, unions, and villages were obtained from SAAO's, BBS [33], and BBS [41]

The collected primary data concerning farmers' perception of climate change (*i.e.*, summer temperature, winter temperature, and rainfall) were compared with observed data (Bangladesh Meteorological Department) over the past ten years. Since farmers may not accurately perceive long-term weather trends [14,42], we focused our analysis on this decade-long period. Similarly, the farmers' viewpoints on cyclones/storm surges were assessed with data from the Bangladesh Meteorological Department (BMD) and existing literature [43,44]. Moreover, the data concerning salinity perceptions were contrasted with the published report of the Soil Resource Development Institute [11] and the data presented in Bhuyan et al. [12]. Finally, the quantitative data were summarized in Microsoft Excel spreadsheets for further analysis and interpretation. We analyzed the linear relationship between historical rainfall and temperature with time. Additionally, we studied farmers' responses to perceived climatic events and increased salinity, along with their adaptation strategies, in the context of climate change and salinity impacts. Utilizing survey data, we compiled findings for all households involved in the study, employing various methods, including calculating frequencies, percentages, and averages and presenting the results through tables. When interpreting the data, the farmers' responses were expressed as percentages. These percentages also indicate statistical significance. In a previous study, Hasan and Kumar [27] utilized a comparable methodology to evaluate farmers' perceptions of climate change and salinity.

3. Results

3.1. Demographic characteristics

We surveyed 200, 131, and 144 respondents from the high, moderate, and low salinity zones, respectively (Table 2). Most respondents were within the 30–55 years age group. The educational level indicated that only a small percentage had education beyond the secondary level. Specifically, in the high, moderate, and low salinity zones, 82%, 81%, and 84% had primary education, while 15%, 16%, and 15% had secondary education, respectively. The majority of respondents were smallholders (>50%), with agriculture (>80%) being their primary occupation. Additionally, most farmers had between 10 and 30 years of farming experience.

Table 2: Demographic characteristics of the respondents

Variables	High salinity zone (n=200)		Moderate salinity zone (n=131)		Low salinity zone (n=144)	
Age (years)	N	%	N	%	N	%
30-45	88	40	43	33	74	51
46-55	61	30	46	35	52	36
56-65	38	20	26	20	17	12
Above 65	13	10	16	12	1	1
Education						

Primary education (1-5)	164	82	106	81	120	84
Secondary Education (6-10)	30	15	21	16	22	15
Higher Secondary or above (>11)	6	3	4	3	2	1
Farming Experience (years)						
10-20	75	38	23	18	58	40
21-30	72	36	57	44	52	36
31-40	38	19	33	25	30	21
Above 40	15	8	18	13	4	3
Primary Occupation						
Agriculture	161	80	109	83	101	70
Others	39	20	22	17	43	30
Land ownership						
Landless (0.02 ha)	24	12	5	4	16	11
Marginal (0.02–0.2 ha)	36	18	11	8	30	21
Small (0.2–1.0 ha)	113	57	94	72	92	64
Medium (1.0–3.0 ha)	26	13	21	16	6	4
Large (>3.0 ha)	1	1	-	-	-	-

3.2. Climate variability in the study areas

Figure 2 depicts a thirty-year trend (1992-2021) in average summer and winter temperatures, revealing a steady increase over the years. Additionally, there has been a gradual decrease in yearly rainfall (Fig. 3). Furthermore, we observed that in the low-salinity zone, the drier months (November-April) exhibited a negative trend, except for November, December, and April (Fig. 4A). In the moderate and high-salinity zone, the drier months, except for December, displayed a negative trend (Fig. 4B). Moreover, in the low salinity regions, among the months with higher precipitation (May-October), July, September, and October showed a positive rainfall trend (Fig. 4A). Conversely, within areas designated as moderate and high salinity zones, only July and October displayed a positive trend in rainfall (Fig. 4B).

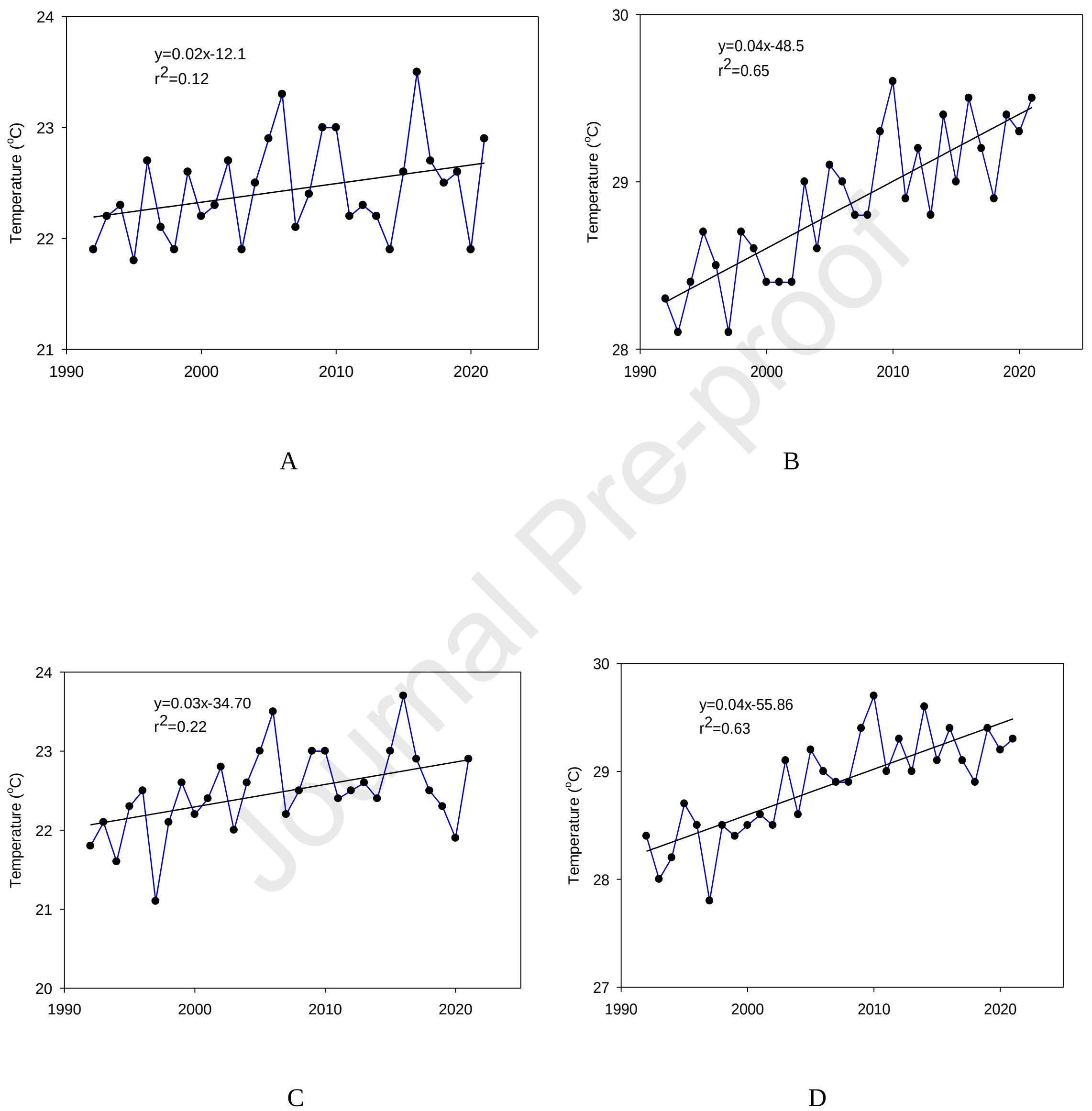
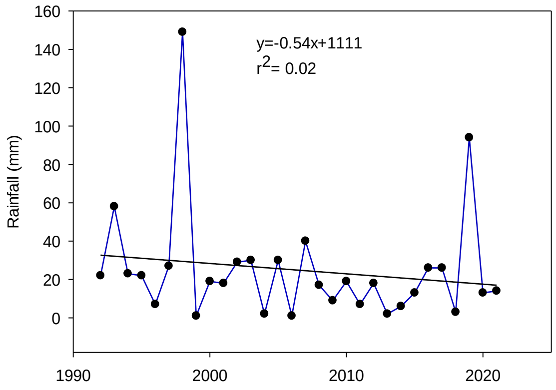
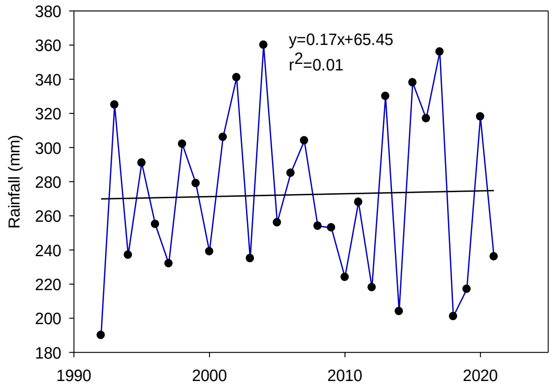


Fig. 2. Observed yearly temperature trend (1992-2021) (Source: BMD). Panels A and B represent the winter and summer temperature trends for the low salinity zone. Panels C and D represent the winter and summer temperature trend for the moderate and high salinity zones.





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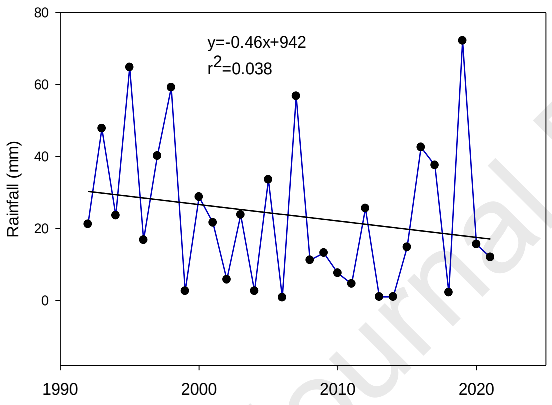
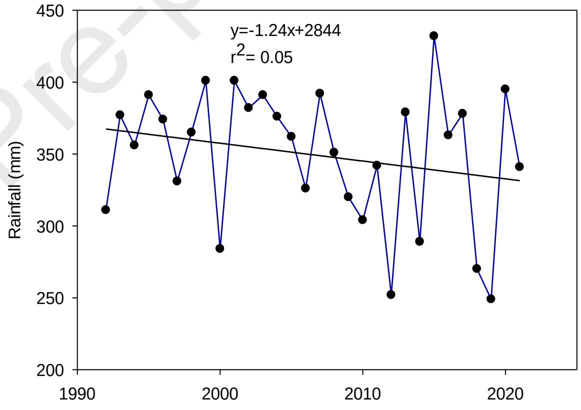
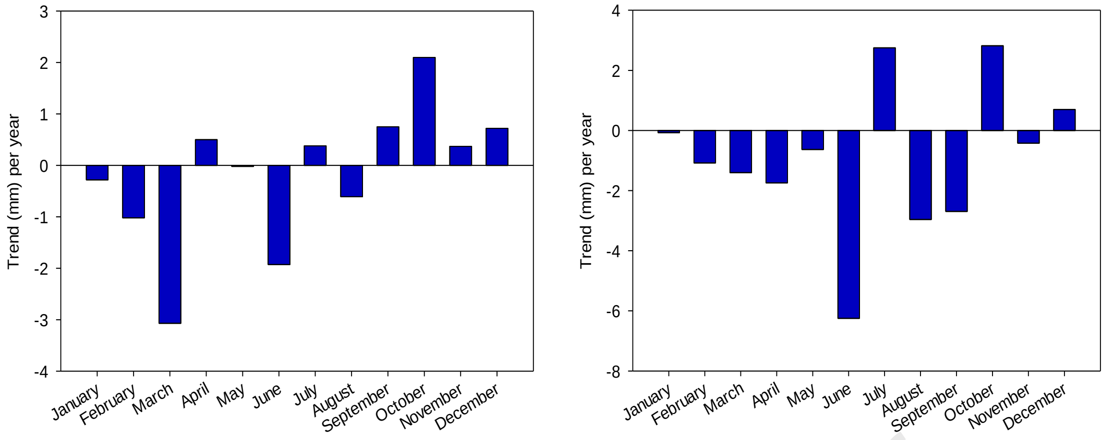




C D

Fig. 3. Observed yearly rainfall trend (1992-2021) (Source: BMD). Panels A and B represent the drier and wetter months trends for the low salinity zone. Panels C and D represent the drier and wetter months trends for the moderate and high salinity zones.



A B

Fig. 4. Observed monthly rainfall trend (1992-2021) (Source: BMD). Panel A represents the monthly rainfall trend of the low salinity zone; Panel B represents the monthly rainfall trend of the moderate and high salinity zones.

3.3. Farmers perception of climate change and salinity

Perception of Temperature

The majority of participants across all salinity zones reported a noticeable increase in mean summer (April-September) and winter temperatures (October-March) (Table 3). Regarding summer temperatures, most of the farmers in all salinity zones noticed that summer temperatures started to increase early (>50%), temperatures were comparatively higher than expected (>95%), and lasted for longer durations than average (>75%). In contrast, a large proportion of farmers noted a delayed onset of winter (>85%), significantly higher winter temperatures (>95%) than usual, and a gradual decrease in the duration of winter (>95%). Only a small percentage of farmers perceived a reduction in the magnitude and duration of summer temperatures and an increase in winter temperatures.

Perception of rainfall

Farmers in all salinity zones observed variations in the timing and distribution of rainfall (Table 3). The general perception is that rainfall is declining. A significant portion of respondents in both the high-salinity zone (78%) and the low-salinity zone (51%), for instance, reported that they observed the rainy season occurring later than expected. In contrast, in the moderate salinity zone, nearly half of the farmers (48%) believed there were no changes in the timing of the rainy season.

A significant number of farmers in the high-salinity zone, however, reported a decrease in both the magnitude (95%) and duration (99%) of rainfall. Following this, in the moderate salinity zone, 79% of respondents noted a reduction in magnitude, while 80% observed a decrease in duration. In the low-salinity zone, 79% of farmers reported a decline in magnitude, and 83% observed a reduction in duration.

Perception of cyclones/storm surges

The occurrence of cyclone/storm surges every year is a common phenomenon for coastal farmers. 83%, 70%, and 100% of respondents of the high, moderate, and low salinity zones noted that cyclones occurred as usual during the peak summer months (Table 3). In both the high and low salinity zones, the majority of farmers (>95%) believed that the severity (magnitude) of past cyclones remained similar to the present, with their durations (intensity) (>97%) also unchanged. However, in the moderate salinity zone, 70% of respondents believed there were no changes in the onset of cyclones, and 46% and 57% of farmers (significant portions) reported that the magnitude and duration of cyclones remained constant.

Perception of salinity

Table 3 shows that almost all farmers perceive changes in salinity levels over time. In the high salinity zone, salinity poses the most significant challenge during dry periods. Among farmers (majority) in this zone, 53% noted an early onset of salinity, 70% reported increasing salinity, and 45% perceived a longer duration of salinity periods (Table 3). In the moderate (62%) and low salinity zones (86%), most farmers observed that salinity levels began to rise as the dry season progressed. They also believed that salinity levels increased each year. Consequently, 64% of farmers in the moderate zone and 52% in the low salinity zone perceived increased salinity magnitude. Furthermore, the majority of farmers (95%) in the low salinity zone did not consider salinity a significant issue in their cropland, and they reported that the duration of salinity periods remained unchanged. Similarly, 64% of respondents in the moderate salinity zone perceived no changes in the duration of salinity periods.

Table 3: Farmers' perception of climate change and salinity

Salinity zone	**Parameters**	**Respondent (%)**								
		Onset			**Magnitute**			**Duration**		
		Early	Late	No change	Increase	Decrease	No change	Long	Short	No change
High (n=200)	Summer Temperature	72	-	28	96)	3	1	93	7	1
	Winter Temperature	1	94	6	2	98	1	2	98	-
	Rainfall	7	78	16	2	95	3	-	99	1
	Cyclone/storm surge	17	1	83	2	4	95	3	1	97
	Salinity	53	5	43	70	23	7	45	16	39
Moderate (n=131)										
	Summer Temperature	53	2	45	97	3	-	79	4	17
	Winter Temperature	3	88	9	8	90	2	2	96	2
	Rainfall	5	48	47	9	79	11	1	80	19
	Cyclone/storm surge	26	4	70	26	28	46	15	28	57
	Salinity	31	7	62	64	25	11	10	26	64

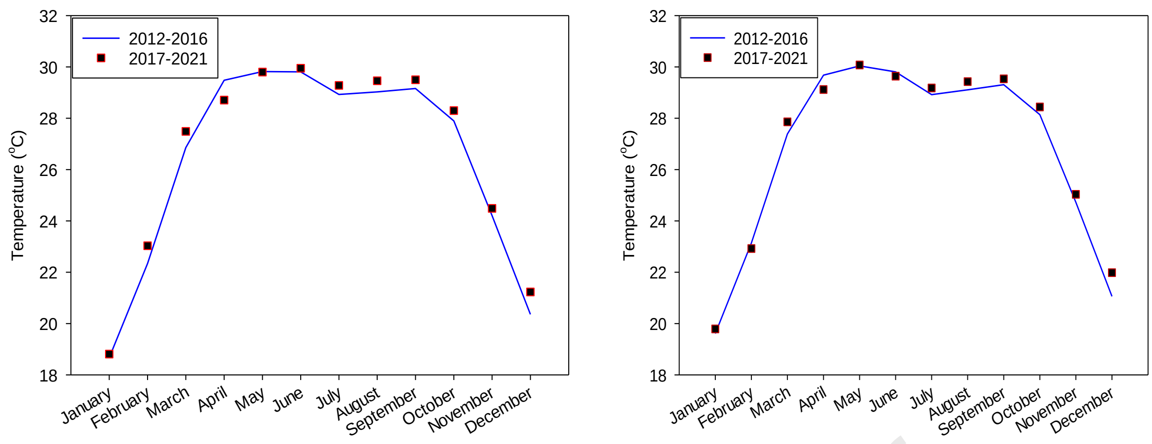
Low (n=144)	Summer Temperature	62	1	37	99	1	-	96	-	4
	Winter Temperature	1	94	5	1	98	1	-	98	2
	Rainfall	-	51	49	1	79	20	-	83	17
	Cyclone/storm surge	-	-	100	1	4	95	1	1	98
	Salinity	14	-	86	52	6	42	1	4	95

Summer temperature (April-September) and Winter temperature (October-March)

Note: due to rounding, some of the group's total 101%

3.4. Comparison between farmer perceptions and the scientific observation

This study examines farmers' perceptions of climate change concerning rainfall, temperature, soil salinity, and cyclones, comparing them with meteorological data and various scientific reports. Across all salinity zones, most farmers perceived an increase in both summer and winter temperatures, as well as a more extended summer season and a shorter winter season (Table 3). To validate these perceptions, the temperature changes were compared to the monthly mean temperatures of the recent five-year period (2017-2021) and a previous five year (2012-2016) (Fig. 5A and B). The temperature gradually increased in summer (April-September) and winter months (October-March), with the duration of the winter season gradually decreasing (Fig. 5A and B). Hence, the farmers' assessment of summer and winter temperatures aligned with the scientific findings in the study area.



A B

Fig. 5. Observed monthly temperature change (Source: BMD). Panel A represents seasonal changes in temperature for the low salinity zone; the blue solid line shows the five-year average temperature of 2012-2016, and the red dotted line shows the five-year average temperature of 2017-2021. Panel B represents seasonal changes in temperature for the high and moderate salinity zone; the blue solid line shows the five-year average temperature of 2012-2016, and the red dotted line shows the five-year average temperature of 2017-2021.

Concerning rainfall, most of the farmers (>70%) on the south-central coast perceived that the magnitude and duration of rainfall declined (Table 3). The meteorological data show (Fig. 6A and B) that across all salinity zones in recent years (2017-2021), there has been decreasing rainfall in both the drier (November-April) and wetter months (May-October) compared to the previous records (2012-2016), except for April, October, November, and December. Majority of the farmers in the high, moderate, and low salinity zones reported that the timing of rainfall had changed (Table 3). This change is particularly noticeable during the dry season when the absence of rain causes cropland to become parched and salinity levels to increase. Meteorological data indicate a more erratic rainfall pattern during the dry periods, with some years experiencing higher rainfall while others have seen little to no rain (Fig. 6A and B). Moreover, there has been a delay in the onset of rainfall during the monsoon to early monsoon period (May-June) in recent years compared to the period from 2012 to 2016 (Fig. 6A and B). Therefore, farmers' perception of rainfall coincided with the observed data.

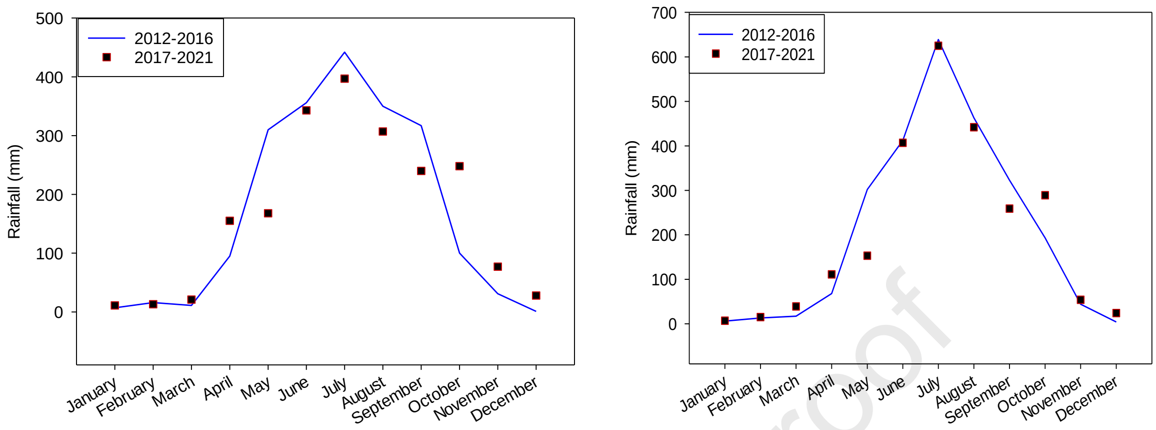


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Fig. 6. Observed monthly rainfall change (Source: BMD). Panel A represents seasonal changes in rainfall for the low salinity zone; the blue solid line shows the five-year average temperature of 2012-2016, and the red dotted line shows the five-year average temperature of 2017-2021. Panel B represents seasonal changes in rainfall for the high and moderate salinity zone; the blue solid line shows the five-year average temperature of 2012-2016, and the red dotted line shows the five-year average temperature of 2017-2021.

Most farmers assumed that cyclones do not occur yearly, the nature of the damage has remained the same, and there has been no change in magnitude compared to the past (Table 3). Scientific reports and data from the Bangladesh Meteorological Department (BMD), however, indicate that one or two severe cyclones/storm surges strike the coastal areas each year (Table 4). Note that in 2021, the coastal regions experienced two cyclones (Table 4). These cyclones not only inflicted damage to the infrastructure, but also caused significant crop destruction [44]. The magnitude of storm surges is variable, but it has increased compared to the past (Table 4). Therefore, the opinions expressed by the farmers in the interviews were inconsistent with the scientific observations (Table 4)

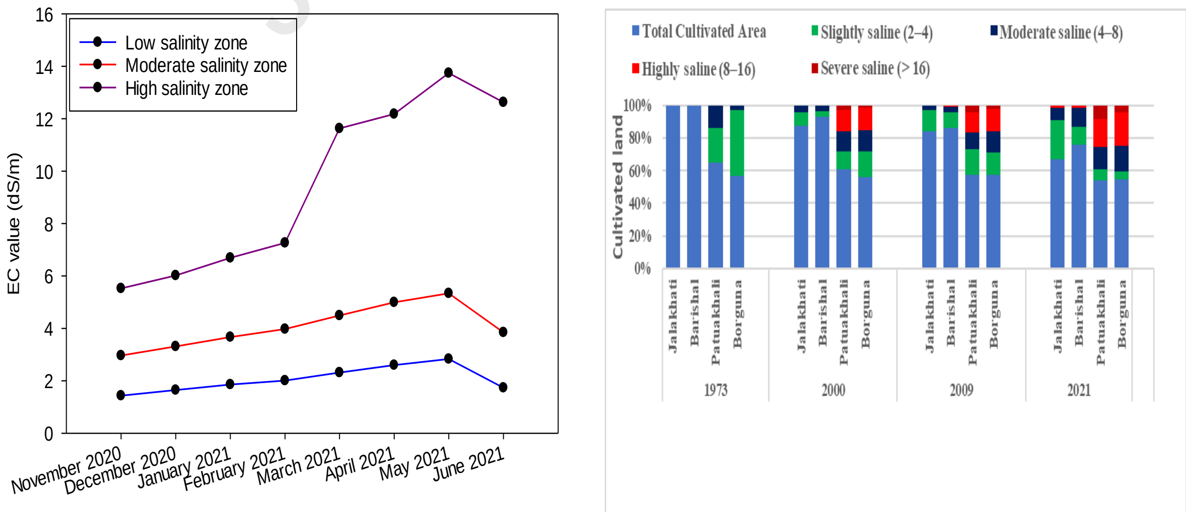
Table 4: Major cyclones/storm surges are affected in the south-central coastal area of Bangladesh

Cyclones/storm surges	Year of occurrence	Maximum wind speed (km/hr)	Surge height (m)
Sidr	2007	223	3.0-5.0
Aila	2009	90	3.0
Mohasen (cyclonic storm)	2013	100	2.0
Fani	2019	215	1.5
Amphan (super cyclone)	2020	240	3.0-5.0
Yass	2021	150	2.0-2.5
Jawad	2021	88	3.0

Source: BMD, CARE [43], and Rahman and Uddin [44]

Salinity levels in the south-central region varied across different salinity zones (Bhuyan et al., 2023a). Concerning soil salinity, half of farmers in all salinity zones (>52%) perceived a continuous increase in salinity levels over time (Table 3). Most farmers (53%) in the high salinity zone, however, reported that salinity started affecting their land early (from late November to early December), and the duration of salinity periods increased (Table 3). Farmers also mentioned that salinity persisted in their fields until the end of May (before the onset of the monsoon). In contrast, in the low and moderate salinity zones, most farmers believed that salinity levels began to rise (late) every year starting in January, reaching their peak in May. Moreover, farmers in these zones perceived that salinity levels began to decrease at the end of May. There were no changes in the timing of salinity fluctuations (Table 3). Due to the absence of salinity time series data at our study locations, we relied on a recent study [12] to support the farmers' perceptions of monthly salinity variations. This study found that in high salinity zones, soil salinity levels started to increase in November (exceeding the threshold limits >4.0 dSm^{-1}

for crops) and peaked in May. Nevertheless, salinity levels began to decline in June, yet salinity levels (~10 dSm^{-1}) remained unsuitable for crop cultivation (Fig. 7A). Conversely, in moderate and low salinity regions, salinity increases from January and gradually declines after May. Therefore, the farmers' perceptions align with the findings of this study (Fig. 7A). Additionally, in our previous research [12] and an SRDI report [11], we found that in 1973, the Jhalakhati and Barisal districts (low salinity zone) had no areas affected by salinity. By 2021, however, 45% and 30% of their total cultivated land, respectively, had been impacted by salinity. Similarly, in both the Patuakhali and Borguna districts (moderate and high salinity zones), approximately 85% of the total cultivated land was affected by salinity in 2021. In contrast, in 1973, the figures were 53% for Patuakhali and 75% for Borguna (7B). Moreover, the dry season maximum monthly salinity levels have also increased over time (Table 7C). Similarly, farmers in areas with moderate to high salinity levels generally perceive an elevation in the salinity levels within their crop fields compared to the past (Table 3). Thus, farmers' observations regarding alterations in soil salinity are consistent with the findings derived from observed data and existing literature (Fig. 7B and C).



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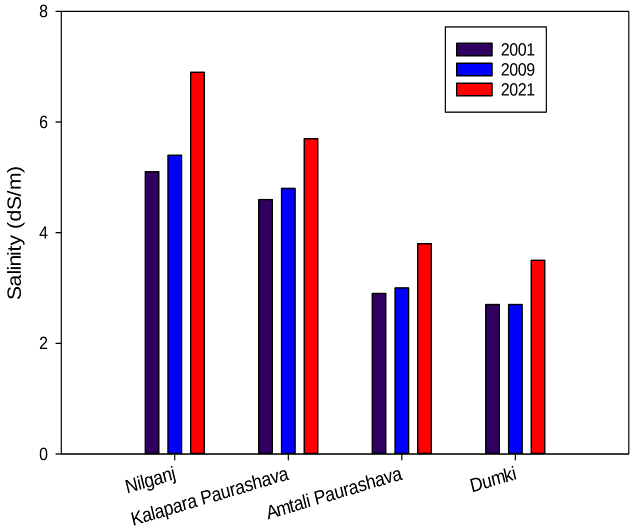

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Fig. 7. Observed salinity levels in the south-central coastal area. Panel A represents the monthly (dry periods) mean salinity variations in various salinity zones [12]. Panel B represents areas affected by soil salinity between 1973, 2000, 2009, and 2021 (measured) in the south-central coastal regions. Each bar graphically represents the varying percentages (%) of land affected by salinity [11,12]. Panel C represents the historical variation of dry season maximum monthly salinity in various union (small administrative units) of the south-central coastal area [10,12].

3.5. Perception of causes of increasing salinity

The farmers' understanding of the factors contributing to the rise in salinity is not consistent across all three salinity zones (Table 5). Nonetheless, we observed that the perceptions within the high and moderate salinity zones are quite similar. In these salinity zones, farmers identified 1-3 factors contributing to the increase in salinity (Table 5). Most farmers (40%) perceived high temperatures and lower rainfall as responsible for increasing salinity. Other dominant factors included were fallow land (high salinity 29% and moderate salinity 21%) and only high temperature (high salinity 16% and moderate salinity 11%). On the other hand, in the low salinity zone, most farmers (52%) believed that only high temperatures were the primary cause of increasing salinity. Like the other two salinity zones, farmers in this area also thought high temperatures and lower rainfall (34%) could contribute to rising salinity levels. The third leading cause was low rainfall (12%).

Table 5. Farmers' perception of causes of increasing salinity in the south-central coastal area

Causes of incresing salinity	Respondents (%)		
	High salinity zone (n=200)	Moderate salinity zone (n=131)	Low salinity zone (n=144)
High temperature and lower rainfall	40	40	34
Fallow land/dry land	29	21	-
High temperature	16	11	52
Saline water intrusion	7	10	1
Lower rainfall	7	6	12
High temperature and saline water intrusion	1	7	1
High temperature, lower rainfall, and saline water intrusion	1	2	-
Lower rainfall, and saline water intrusion	-	2	-
High temperature and lower rainfall	-	1	-

Note: due to rounding, some of the group's total 101%

3.6. Effect of salinity on cropping pattern/crop calendar

In the south-central coastal area, crops were cultivated mainly in three seasons: *kharif-1*, *kharif-2*, and *rabi*. Farmers have steadfastly adhered to their traditional cropping methods, showing no inclination to alter their practices in the past 5-10 years. Through interviews with these farmers, we have identified 11, 13, and 8 distinct cropping patterns in the high, moderate, and low salinity zones, respectively (Table 6). Rice is their main crop, primarily cultivated to ensure their food security. In all salinity zones, the *Kharif-2* season is mainly devoted to the cultivation of T. *aman* rice. Within the high salinity zone, the *rabi* season often witnesses substantial fallow land, while the dominant crops on the remaining land were mungbean and watermelon. In the moderate salinity zone, the primary crops were mungbean and *boro* rice, while a few farmers kept their land fallow (11%). In the low salinity zone, the prominent crops included mungbean, *boro* rice, and chilli. During the *Kharif-1* season, farmers in all salinity zones were generally unresponsive in cultivating crops due to salinity and the late harvesting of the preceding crop. However, only a very small percentage (2%) of farmers in the high salinity zone cultivate *aus* rice. So, in the high salinity zone, the predominantly followed cropping patterns (out of 11) were Fallow-T. *aman*-Fallow (31%), Fallow-T. *aman*-Mungbean (25%), and Fallow-T. *aman*-Watermelon (22%). Similarly, the primary cropping patterns in the moderate salinity zone were Fallow-T. *aman*-Mungbean (46%), Fallow-T. *aman*-Boro rice (28%), and Fallow-T. *aman*-Fallow (11%). Moreover, in the low salinity zone, the first and second dominant cropping patterns were similar to those in the moderate salinity zone. The third dominant cropping pattern was Fallow-T. *aman*-Chilli (7%).

Given the anticipated impacts of future climate change and rising salinity levels, farmers in high salinity zones are contemplating changes to their cropping patterns (Table 6). A significant majority (84%) intend to leave their land fallow during the rabi season, as they believe that sustaining existing crops may become challenging in the future. However, a minority (8%) plan to continue cultivating mungbean. In moderate and low salinity zones, farmers are relatively less concerned about the potential effects on their current cropping patterns. Nevertheless, some are considering alterations to their dry-season crops, primarily driven by economic considerations. For instance, farmers intend to replace chilli with mustard in the low salinity zone (Table 6).

Table 6 : Effect of salinity on cropping pattern/crop calendar in different salinity zones

Zone	Period	*Cropping pattern/crop calender	Respondents (%)
High salinity (n=200)	Present and past (last 5-10 years)		
		Fallow- T. *aman* rice -Fallow	31
		Fallow- T. *aman* rice -Mungbean	25
		Fallow- T. *aman* rice -Watermelon	22
		Fallow- T. *aman* rice - Grasspea	7
		Fallow- T. *aman* rice -Boro rice	5
		Fallow- T. *aman* rice -Potato	5
		Fallow- T. aman rice -Groundnut	3
		Fallow- T. *aman* rice -Chilli	3
		Fallow- T. *aman* rice -Sunflower	1
		Aus rice- T. *aman* rice -Groundnut	1
		Aus rice- T. *aman* rice -Mungbean	1

	Future (farmers except)	Fallow- T. *aman* rice -Fallow	84
		Fallow- T. *aman* rice -Mungbean	8
		Fallow- T. *aman* rice -Chilli	3
		Fallow- T. *aman* rice -Sunflower	3
		Fallow- T. *aman* rice -Groundnut	2
		Fallow- T. *aman* rice -Lentil	1
		Fallow- T. *aman* rice -Maize	1
Moderate salinity (n=131)	Present and past (last 5-10 years)		
		Fallow- T. *aman* rice -Mungbean	46
		Fallow- T. *aman* rice -*Boro* Rice	28
		Fallow- T. *aman* rice -Fallow	11
		Fallow- T. *aman* rice -Chilli	5
		Fallow- T. *aman* rice -Watermelon	2
		Fallow- T. *aman* rice -Groundnut	2
		Fallow- T. *aman* rice -Cowpea	2
		Fallow- T. *aman* rice -Grasspea	1
		Fallow- T. *aman* rice -Sweet potato	1
		Fallow- T. *aman* rice -Brinjal	1
		Fallow- T. *aman* rice -Potato	1
		Fallow- T. *aman* rice -Bitter gourd	1
		Fallow- T. *aman* rice -Peanut	1
	Future (farmers expect)	Fallow- T. *aman* rice -Mungbean	43
		Fallow- T. *aman* rice -*Boro* Rice	32
		Fallow- T. *aman* rice -Fallow	11
		Fallow- T. *aman* rice -Chilli	4
		Fallow- T. *aman* rice -Watermelon	2
		Fallow- T. *aman* rice -Groundnut	2
		Fallow- T. *aman* rice-Mustard	2
		Fallow- T. *aman* rice -Grasspea	1
		Fallow- T. *aman* rice -Sweet Potato	1
		Fallow- T. *aman* rice -Brinjal	1
		Fallow- T. *aman* rice -Potato	1
		Fallow- T. *aman* rice -Bitter gourd	1
		Fallow- T. *aman* rice -Peanut	1
		Fallow- T. *aman* rice -Sunflower	1
Low salinity (n=144)	Present and past (last 5-10 years)	Fallow- T. *aman* rice -Mungbean	51
		Fallow- T. *aman* rice -*Boro* rice	34
		Fallow- T. *aman* rice -Chilli	7
		Fallow- T. *aman* rice -Sweet potato	2
		Fallow- T. *aman* rice -Brinjal	2
		Fallow- T. *aman* rice -Bitter gourd	2
		Fallow- T. *aman* rice -Snake gourd	1
		Fallow- T. *aman* rice -Grasspea	1
	Future (farmers expect)	Fallow- T. *aman* rice -Mungbean	37
		Fallow- T. *aman* rice -*Boro* rice	33
		Fallow- T. *aman* rice -Mustard	13
		Fallow- T. *aman* rice -Chilli	7
		Fallow- T. *aman* rice -Sweet potato	2
		Fallow- T. *aman* rice -Bitter gourd	2
		Fallow- T. *aman* rice -Sweet gourd	2
		Fallow- T. *aman* rice -Maize	2
		Fallow- T. *aman* rice -Brinjal	1

	Fallow- T. *aman* rice -Grasspea	1
	Fallow- T. *aman* rice -Lentil	1

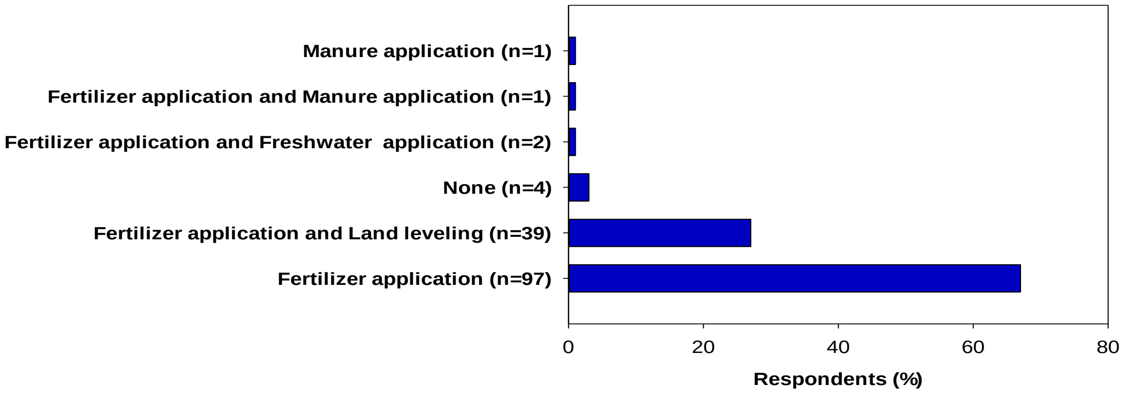
*Cropping pattern/crop calendar: *Kharif 1-Kharif 2 -Rabi*

Three rice growing season: *Aus* (April-July), Transplanted (T.) *Aman* (July-November), and *Boro* (November-April)

Note: due to rounding, some of the group's total 101%

3.6 Farmers' adaptation strategies

All the households in the three salinity zones implemented adaptive measures based on their extensive knowledge, prior experiences, and personal perceptions. These measures aimed to mitigate the adverse impacts of salinity and other climate change-related challenges. Figure 8 illustrates that each household chose to adopt at least one adaptation strategy for sustaining their agricultural practices and overall livelihoods. Subsequently, these adaptations were categorized into five-six primary outcomes (Fig. 8 A, B, and C). In all salinity zones, fertilizer application and land leveling were common/dominant adaptation practices. Moreover, we also tested the farmers' capacity to adopt novel salinity-adaptation technologies (Table 7) and the feasibility of model-driven solutions from our previous research (Table 8). Our findings revealed that a substantial proportion of farmers (>50%) in all the salinity zones expressed a willingness to adopt the recommended technologies, with some of them being able to do so without any required skills (Table 7). However, a significant portion (>50%) of the farming community needed more capabilities/skills to implement these strategies effectively (Table 7). Upon evaluating the farmers' reactions to the model-generated outcomes, it was evident that the majority of them (>50%) responded positively to the results produced by the model (Table 8).



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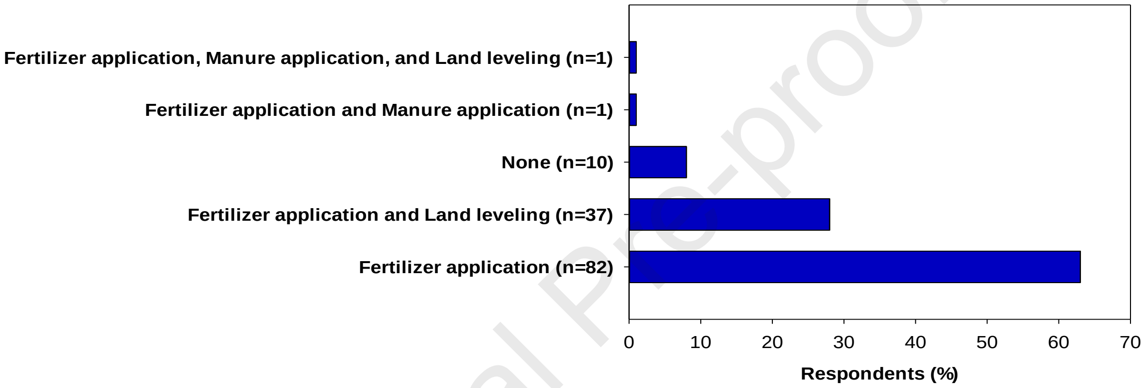

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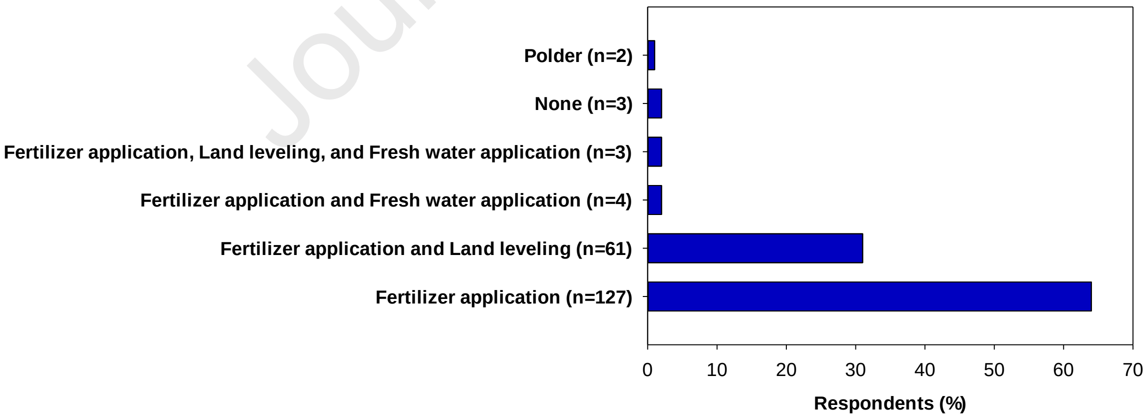

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Fig. 8. Farmers' adaptation strategies of low (A), moderate (B), and high (C) salinity zones

Table 7: Evaluated farmers' willingness to adopt recommended adaptation practices and their capacity for adaptation

Zone	Name of the strategies	Wanted to use these technologies		Ability/skills to use these technologies	
High salinity (n=200)		**Yes (%)**	**No (%)**	**Yes (%)**	**No (%)**
	Shifting Sowing/planting time	75	25	4	96
	Salt-tolerant rice varieties	80	20	77	23
	Changes in cropping pattern	79	21	4	96
	Apply fresh water	90	10	3	97
	Water harvesting	80	20	1	99
	Relay cropping	78	22	24	76
	Deep tillage	78	22	1	99
	Mulching	82	18	7	93
	Agricultural transformation (Agriculture to livestock/ shrimps/fish culture)	2	98	1	99
Moderate salinity (n=131)					
	Shifting Sowing/planting time	70	30	40	60
	Salt-tolerant rice varieties	84	16	55	45
	Changes in cropping pattern	78	22	36	64
	Apply fresh water	82	18	63	37
	Water harvesting	76	24	1	99
	Relay cropping	62	38	70	30
	Deep tillage	79	21	12	88
	Mulching	51	49	48	52
	Agricultural transformation (Agriculture to livestock/ shrimps/fish culture)	26	74	27	73
Low salinity (n=144)					
	Shifting Sowing/planting time	69	31	40	60
	Salt-tolerant rice varieties	94	6	44	56
	Changes in cropping pattern	92	8)	37	63
	Apply fresh water	98	2	94	6
	Water harvesting	97	3	26	74
	Relay cropping	53	47	68	32
	Deep tillage	94	6	19	71
	Mulching	52	48	67	33
	Agricultural transformation (Agriculture to livestock/ /shrimps/fish culture)	15	85	39	61

Table 8: Verified the feasibility of recommendations derived from the crop model

Zone	Suggestions	Response (%)	
		Yes	**No**
High salinity (n=200)			
	Installment of polders with a sluice gate to protect the crop field from direct inundation of tidal saline water	99	1
	Cultivate short-duration HYV *aman* rice instead of local *aman* rice. So that *boro* rice can be sowed/planted earlier and be less affected by salinity.	100	-
	Sowing/planting salt tolerant *boro* rice varieties fifteen days earlier than farmers or recommended practice	86	14
Moderate salinity (n=131)			
	Installment of polders with a sluice gate to protect the crop field from direct inundation of tidal saline water	100	-
	Cultivate short-duration HYV *aman* rice instead of local *aman* rice. So that boro rice can be sowed/planted earlier and be less affected by salinity.	100	-
	Sowing/planting salt tolerant boro rice varieties fifteen days earlier than farmers or recommended practice	51	49
Low salinity (n=144)	Installment of polders with a sluice gate to protect the crop field from direct inundation of tidal saline water	100	-
	Cultivate short-duration HYV *aman* rice instead of local *aman* rice. So that boro rice can be sowed/planted earlier and be less affected by salinity	98	-
	Sowing/planting salt tolerant *boro* rice varieties fifteen days earlier than farmers or recommended practice	56	44

4. Discussion

4.1. Farmers' perceptions of climate change and salinity

This study focused on identifying farmers' perceptions of climate change and salinity in the south-central coastal area. Farmers must initially recognize the consequences of climate change to implement suitable adaptation measures, reducing their susceptibility and bolstering the overall resilience of the agroecological system [23,45]. Local perspectives offer crucial foundational data for comprehending individual vulnerability to climate hazards, a necessity for the successful development and execution of policies [46]. This study found that most farmers observed an increasing trend in both summer and winter temperatures, total rainfall variability, and changes in salinity levels (Fig. 5, Fig. 6, and Table 5). This result is consistent with the findings of Hasan et al. [47] and Kabir et al. [48], who reported that most farmers in Borguna and Patuakhali Sadar perceived changes in temperature, rainfall, and salinity over time. Moreover, we observed that farmers did not completely understand the intensity and severity of cyclones or storm surges. This result is opposite to the previous study [48]. Farmers realize that climate change and salinity influence the crop calendar, standing crops, and freshwater resource availability. Moreover, most farmers reported that *kharif-2* and *rabi* crops have been adversely affected by cyclones in recent years. They also noted that sometimes excessive rainfall at times delays *aman* rice (*kharif-2*) transplanting and it has the potential to affect fertilizer application. However, despite their recognition of seasonal changes in precipitation, temperature patterns, and salinity alterations, a substantial proportion of farmers refrained from adapting their farming approaches. During the interviews, it became evident that many farmers were unaware that seasonal changes in rainfall, temperature patterns, the gradual increase in salinity levels, and the intensification of cyclones were attributed to climate change. It should be noted that agriculture extension services in the projected area were insufficient for a significant portion of farmers [49,50]. Several studies [5,16,30,51] have shown that farmer households who did not receive visits from extension agents were less likely to recognize climate change. We discussed the details in the following section 4.4.

4.2. Farmers' perception of causes of increasing salinity

Salinity is one of the major environmental hazards on the south-central coast [9]. According to reports by Bhuyan et al. [12] and Salehin et al. [19], the increasing salinity in the south-central coastal area can be attributed to several interconnected factors, including climatic variability (such as rising sea levels and irregular rainfall), tidal flooding, capillary rise of salt, cyclones, and storm surges, as well as a reduction in upstream freshwater flow and poor polder management. In the low salinity zone, most farmers perceive high temperatures as the primary factor of increasing salinity levels, with lower rainfall being the second most dominant factor. However, farmers' perceptions of the causes of increasing salinity did not substantially vary in moderate and low salinity zones. Most farmers in these zones perceive that both high temperatures and low rainfall are equally responsible for the increasing salinity. Additionally, they identify fallow or dry land as a significant contributing factor. A previous study [52] interviewed farmers in only a few locations and found that farmers perceive fallow land and high temperatures as the main factors responsible for increasing salinity. Conversely, our study enhances insights into farmers' perceptions of salinity alteration across all the Upazilas (small units of districts) in the south-central coastal area. Overall, most farmers on the south-central coast believe that low rainfall, high temperatures, and dry or fallow land are leading factors contributing to the increasing salinity levels (Table 5). They attribute this phenomenon to high temperatures leading to soil drying out and salt emerging from groundwater (capillary rise). The lack of rainfall exacerbates the issue, accumulating white crust or salt on the soil surface. Their concept aligned with [12,13,19]. Besides these factors, sea level rise reduces the freshwater flow of the rivers, and saltwater from the rivers can intrude further inland into coastal aquifers and groundwater systems [10]. Consequently, new areas are inundated with saline water with time, decreasing cultivated land every decade on the south-central coast [11]. Regrettably, only a small percentage of farmers recognize this factor (Table 5), however, they are unaware that cyclones and storm surges are responsible for increasing salinity levels.

Coastal farmers experience one or two heavy cyclones every year (Table 4). For instance, in 2021, two cyclonic events occurred, in 2022, and most recently, in May 2023, Bangladesh experienced the impact of a severe cyclone. These cyclones damaged standing crops, infrastructure (houses) and caused erosion or damaged the polders. Subsequently, saltwater flooded farmland and infiltrated the soil, leaving behind salt deposits when the floodwaters receded.

4.3. Salinity impact on cropping pattern or crop calendar

In the south-central coastal area, climate change and spatio-temporal salinity variations significantly impact crop calendars or cropping patterns [53,54]. In low-lying regions, waterlogging and unfavorable soil conditions also impede the development of cropping systems [55]. Climate variations are expected to impact the economic viability and appropriateness of crop selection and farming practices in the Delta region, posing significant difficulties for agricultural communities [56]. We observed that Fallow-T.*aman*-Fallow was the most dominant cropping pattern in the high salinity zone, while in the moderate to low salinity zone, it was Fallow-T. *aman*-Mungbean (Table 6). Previous studies [57,58] reported that most south-central coastal areas remain fallow during the dry period. Nevertheless, they did not discuss the zone-specific variations in cropping patterns. In this research, we provide insights into how salinity impacts cropping patterns across various salinity zones in the study area. Since agriculture is the primary livelihood activity (>80%) (Table 2), it directly impacts the income and food security of smallholder farmers. Farmers in high-salinity regions anticipate a future increase in salinity levels, leading them to consider leaving their land fallow during the *rabi* and *kharif-1* seasons (Table 7). They also noted that waterlogging and irregular rainfall patterns adversely affect *kharif-1* crop cultivation. Previously (section 3.4), we discussed that salinity levels in the high salinity zone increase with time. Additionally, Dasgupta et al. [10] predicted a potential increase of about 10% to 30% in salinity levels in the south-central coastal area by

2050. So, the cropping intensity in the south-central coastal zone is relatively lower, primarily due to the presence of fallow land during the dry period in the high salinity zone.

To increase the cropping intensity in the high salinity zone, *rabi* and *kharif-1* seasons should be under crop cultivation. Therefore, suitable crops need to be selected considering the climatic conditions. The crop selection represents a crucial managerial choice to enhance long-term yield consistency in the coastal region [53]. The interventions focused on intensifying cropping systems effectively led to the development of new and enhanced existing cropping systems [56]. It increases sustainability, involving the cultivation of various plant species or crop varieties in alternating seasons within the same year [59]. Mungbean is one of the most popular crops in the *rabi* season on the south-central coast after T.*aman* rice (*Kharif-2*) (Table 7). It is a short-duration crop (60-75 days) and requires no tillage. Farmers also cultivated mungbean in the high salinity zone, where land is not directly inundated with tidal water or surrounded by polders. Farmers also cultivated mungbean in the high salinity zone, where land is not directly inundated with tidal water or surrounded by polders.

Unfortunately, the currently cultivated mungbean varieties have a low yield potential and are occasionally affected by cyclones or heavy rainfall [60]. Therefore, high-yielding mungbean varieties can be introduced in the high salinity zone, where long duration (~155 days) *boro* rice cultivation is not feasible due to salinity. Besides, sunflowers have shown promise as a viable crop option in saline-prone areas [55,60]. Sunflower exhibit the ability to endure moderate salinity and drought conditions, and its relatively short growth cycle (~100 days) allows it to avoid the peak salinity periods, typically occurring from March to May. Similarly, Mandal et al. [61] found that the timely initiation of *rabi* crops, such as sunflower, following the wet season rice cultivation (*T.aman*), led to increased productivity in the cropping system. *Aus* rice cultivation was absent across the entire salinity zone (Table 6), primarily due to flash floods and the late harvesting of the *rabi* crops, notably *boro* rice, coinciding with the peak salinity levels in March and April (high salinity zone). In this case, short growth duration *aus* rice variety (*e.g., BRRI dhan65*, duration 95-100 days) should be selected. Otherwise, it delays the land preparation for *aman* rice cultivation. Bhattacharya et al. [21] stated that integration of *aus* rice into the crop calendar could be achieved if farmers opt for the cultivation of short-duration *rabi* crops (*e.g.,* maize, sunflower, mungbean, winter vegetables, etc.) instead of *boro* rice. Additionally, in areas with moderate to low salinity levels, high-yielding saline-tolerant *boro* rice varieties have emerged as the second most prevalent crop, following mungbean. This phenomenon is primarily attributed to ample freshwater sources and salinity levels that remain below the threshold levels [12,13]. So, salinity management and enhanced cropping intensity are imperative in high-salinity zones, in this case, *Aus*-T. *aman- Rabi* crops (short duration) pattern is a suitable option. Agricultural development strategies of Bangladesh primarily focus on boosting *boro* rice production during the dry season to replace fallow periods [58], even though recent finding [62] suggest that farmers might prefer for growing pulses and maize. Therefore, to increase the *boro* rice production in the south-central coastal area, in a previous study [13], we identified a few adaptation options, namely, polder (or dyke/embankment) with sluice gate management, shifting of planting time of salt-tolerant *boro* rice, and cultivating short duration HYV (high yielding variety) *aman* rice instead of local or traditional varieties. The typical maturation period for local *aman* rice, occurring from late December to early January, poses a hindrance to the land preparation for dry season crops [13,55,63]. When sowing is delayed, it subjects the crop to soil dryness, salinity, and potentially to heat stress as the season progresses [55]. Since these adaptation options are cost-effective, most farmers have expressed their willingness to adopt these adaptation strategies in the future (Table 8). Hence, another viable option is to practice the Fallow-T. *aman-Boro* rice rotation. Note that farmers' have no affinity to cultivate *aus* rice in the *kharif-1* season. This preference stems from a minimal inclination towards choosing *aus* rice as an intensification option due to the limited time available for land preparation after *boro* rice cultivation. Additionally, a rice-based cropping pattern tends to increase production costs, including fertilizer, irrigation, seeds, pesticides, labor, and more expenses, making it less feasible for smallholder farmers. In order to implement these adaptations, it is necessary to provide financial support to farmers from the government [64]. More details are discussed in the following section 4.4.

Likewise, in moderate and low salinity zones, the *Aus*-T.*aman-Rabi* crop rotation (including mungbean, sunflower, maize, or other winter vegetables) and the Fallow-T. *aman-Boro* rice system is considered the most favorable choice. Additionally, it is possible to implement an *Aus*-T.*aman-Boro* rice rotation, as rice is not significantly impacted by salinity. Similarly, in our previous research [13,40], we observed that existing saline-tolerant rice varieties give the maximum yield in both the moderate and low salinity zones, whereas their yield is notably reduced in the high salinity zone. This observed trend is expected to persist into the future (2050s and 2080s) [40]. However, similar to high salinity zones, most farmers do not prefer this three-rice-based approach due to concerns about production costs.

Considering the effects of future climate change and salinity effect, short-duration or early planting dry season crops would be a suitable option because they can escape the peak salinity levels and high temperatures during their growth and development stages [40]. Salinity may continue to increase in the future. It has been observed [13,40] that the cultivation of crops within low and moderate salinity zones will not be significantly impacted in the future. Accounting for the impact of sea-level rise and long-term adaption planning, the construction of polders is essential for both low and high-salinity zones, and any damaged polders should be repaired to safeguard the cropland [13]. We discuss the adaptation details in the following section 4.4.

4.4. Adaptation to salinity in agriculture

The agriculture sector is primarily vulnerable to climate change-induced salinity in the south-central coastal area of Bangladesh [12,13]. Most farmers in this area are characterized as smallholders with limited educational attainment (Table 2). Smallholder farmers are the most sensitive to climate change-related risks due to their limited adaptive capacity [38,65]. Adopting adaptive measures represents a crucial strategy capable of mitigating the extent of climate change and salinity intrusion repercussions on agricultural systems and food production [20]. We also observed that in all the salinity zones, farmers commonly use fertilizers such as gypsum and Muriate of Potash (MOP) to combat salinity problems (Fig. 5). This result aligned with Khanom et al. [67], Kumar et al. [68], Roy et al. [69], and Ziaul Haider and Zaber Hossain [66]. They indicate that most coastal farmers consistently utilize fertilizers to mitigate salinity problems. The excessive application and misuse of fertilizers results in a progressive increase in soil salinity [70,71]. At the same time, it increases the cost of production and pollutes the environment [66]. It appears that farmers' lack a systematic comprehension of the potential adverse consequences is associated with the utilization of chemical fertilizers. Some farmers apply two or three adaptation strategies at a time, relying on their indigenous knowledge (Fig. 8). Based on the farmers' opinions (especially in the moderate and high salinity zones), those adaptation practices did not completely alleviate the salinity problems. Unfortunately, despite most farmers having more than ten years of farming experience (Table 2), they did not employ any improved or scientifically approved technologies such as adjusting sowing/planting times, implementing freshwater harvesting or changing cropping patterns (Fig. 8). The primary factors contributing to this phenomenon include farmers' tendencies to emulate their neighbors or other farmers, along with their limited interactions with the extension service workers [68]. Besides, only a few educated farmers actively seek guidance on their farming practices from these extension service workers. In the context of Bangladesh, combating natural disasters such as the adverse impacts of salinity (soil and water) on agriculture requires implementing suitable and pioneering technologies [30]. It is essential to grasp farmers' inclinations regarding different technologies to ensure the success of agricultural development investments [62]. This research tested farmers' abilities to adopt suitable adaptation techniques (Table 7). Similar adaptation strategies were evaluated across all salinity zones, providing insights into the farmers' knowledge base and their potential to embrace novel technologies. Interestingly, most farmers wanted to adopt these techniques, but only some can adapt or have already adapted, while most have no ability to adapt. This observation aligns with the findings of Islam et al. [26], Mazumder and Kabir [30], and Shahjahan Mondal et al. [51], who noted that farmers require the acquisition of specific skills to assimilate and implement novel technological innovations effectively. So, they need additional skill development programs, including training and educational initiatives. Similarly, they need timely information on weather/climate change and salinity. Climate information services have already been employed in the southwestern region (*i.e.,* Khulna district) [68]. These services have proven beneficial, particularly for smallholder farmers [68]. However, there is currently an absence of salinity prediction data within these services. Therefore, it is imperative to incorporate salinity information into the existing climate information services, particularly for its application in the south-central coastal area. Moreover, there are various saline-tolerant varieties developed by the Bangladesh Rice Research Institute (BRRI), Bangladesh Institute of Nuclear Agriculture (BINA), and Bangladesh Agricultural Research Institute (BARI). However, only a limited number of varieties have been implemented in practice, and the level of adoption remains relatively low due to increasing salinity levels over time [51]. Likewise, during field visits/farmers' interviews, we observed that saline-tolerant rice varieties have not gained widespread acceptance among farmers. Instead, farmers continue cultivating locally adjusted varieties, and only a few cultivate salt-tolerant rice varieties (e.g., *BRRI dhan47 and BRRI dhan67*) [13]. There is clear evidence of a disparity between research outcomes and their adoption by farmers [51]. To bridge this gap, it is imperative to enhance agricultural extension services, strengthen research initiatives, improve coordination, and build the capacity of service providers.

A collaborative effort between the agricultural extension services and the non-governmental organizations (NGOs) is vital to address this challenge comprehensively. Their role in demonstrating and disseminating innovative adaptation technologies boosts farmers' confidence in considering these alternatives. For long-term adaptation planning, the government should invest, *e.g.*, construction of new polders (discussed in an earlier section), credit facilities for the stallholders farmers, subsidies on agricultural commodities, crop insurance services, strengthening the research, etc. Bangladesh's governments are actively involved in developing comprehensive climate change and salinity adaptation policies for coastal regions, including the ambitious Delta Plan 2100. One of the plan's objectives is to ensure climate-resilient agriculture for sustainable food security in the coastal area. To effectively mitigate the adverse impacts of climatic changes, governments should formulate adaptation policies tailored to specific zones within coastal regions. The planning and implementation of these strategies should also consider existing adaptations that farming households are practicing in their farmlands [72]. Our study can serve as a baseline for these activities. It is important to note that, before implementing any policy, priority should be given to farmers' preferences and easily accessible technologies.

4.5. Limitations and scope for further research

Both male and female farmers contributed equally to agricultural activities on the south-central coast. In this study, we interviewed individuals who were willing to share information, without targeting any specific gender. Furthermore, we did not assess the impact of climate change-induced salinity on household incomes. Apart from temperature, rainfall, cyclones, and salinity, we did not investigate other climate change factors such as droughts, rising sea levels, and floods. Future research should focus on these crucial issues.

5. Conclusion:

This study revealed that coastal agricultural farmers frequently encountered adverse climatic occurrences, such as unpredictable rainfall patterns, seasonal temperature patterns, cyclones/storm surges, and salinity issues. Most farmers reported observing changes in summer and winter temperatures, alongside reduced rainfall patterns during the dry and wet seasons, compared to the past. They observed a consistent rise in annual temperatures, aligning with our findings from local meteorological data and scientific reports. Their recognition of heightened salinity levels was in accordance with existing research. Nevertheless, farmers believed that the intensity of cyclones exhibited unchanged, a contention not substantiated by the information acquired from the Bangladesh Meteorological Department (BMD) and corresponding reports. According to farm households in the research area, changes in the different climatic patterns (*e.g.*, rainfall, temperature, salinity, and cyclones) have adversely impacted agricultural activities in recent years. Salinity is a predominant factor in decreasing crop yield and cropping intensity. The primary adaptation strategies embraced by participants in the study region encompassed alterations in fertilizer usage and land leveling. However, they perceived these adaptation measures as insufficient to alleviate salinity problems. It is imperative to raise consciousness and capacity-building activities among farmers about these climate change-related vulnerabilities and ensure the provision of necessary resources to implement adaptation measures on their farms effectively. The salinity impact on crop calendars varies across different salinity zones. Therefore, zone-specific crop-level adaptation plans are needed to increase crop productivity in the study area. Government authorities should enact policies to facilitate and incentivize farm households to embrace advanced adaptation strategies in their agricultural practices. Overall, the outcomes of this research carry significant policy implications for adopting climate change and salinity adaptation strategies and increasing farm production.

Ethics Statement

The ethics approval number is PSTU/IEC/2023/46, issued by Institutional Ethical Committee (IEC) of Patuakhali Science and Technology University (PSTU), Bangladesh.

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.

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Highlights

- Most farmers in south-central coastal areas are smallholders with limited education
- Farmers' views on climate change factors and salinity align with scientific data
- Salinity predominantly affects the crop calendar
- Farmers' current adaptation practices are insufficient to alleviate salinity issues
- To enhance resilience in agriculture, households need diverse adaptation strategies

Declaration of interests

☒ 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.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: