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Insight and explore farming adaptation measures to support sustainable development goal 2 in the southwest coastal region of Bangladesh

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Abstract

Farming adaptation in low-lying coastal areas of Bangladesh is mandatory due to increasing impacts of climate change on agriculture. The study evaluated farmers' perception on climate-related hazards, climate variables and factors. Further, the study identified different existence sustainable farming adaptation measures. The final outcomes are concluded throughout synergic data analysis, quantitative including climatic and environmental data, and qualitative from farmers' perception. Eight focus group discussions, 200 household surveys and six key informant interviews were carried out to receive farmers' perception on climate change and impacts of agriculture. Results revealed that farmers' perception and climate data analytical outcomes for decreasing annual precipitation and increasing temperature are highly correlated, whereas 20-year (1995–2015) climate data from 11 meteorological stations showed that annual precipitation is decreased 548 mm, and atmospheric annual mean temperature is increased 1.06 °C. Crop model showed a change in cropping seasons, where the autumn and late autumn are no longer existing and monsoon season is moving toward the winter. Farmers' are migrating their occupations which showed the seasonal livelihood calendar and choosing shrimp and crab cultivation nowadays. Pearson Chi-square independence test identified the significant relationship between 24 independent and 4 dependent variables. This statistical analysis identified five key factors, including climatic, social, environmental, economic and physical, for farming adaptation due to climate change. The study exposed that farmers are adapted 11 adaptations strategies introduced by the local farming community, governmental and non-governmental officials. However, according to farmers' communities these measures are not well managed. Therefore, this study explored the farmers' needs for better sustainable farming adaptation strategies based on climatic data scenarios. In conclusion, the outcomes will support to achieve SDG 2 for southwest coastal areas in Bangladesh.

Keywords Climate change · Coastal Bangladesh · Farming adaptation · Chi-square test · Sustainable development goal

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1 Introduction

The importance of farming adaptation for agriculture owing to climate change has already been acknowledged in adaptation science. In fact, farming adaptation for agriculture leads to ensure food security and sustainable livelihoods globally (IPCC 2014). Most of the previous and recent understanding in farming adaptation for climate change originated based on early and ongoing climatic events, e.g., floods, droughts, weather (temperature and precipitation) and climatic extremes to different extents during the last decades (IPCC 2019; Brida and Owiyo 2013; Singh et al. 2013). However, in the last decade, farming adaptation has increased its interest to the farmers' community spectacularly and has been playing a significant key role especially in agricultural sector globally.

Adaptation is an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC 2001). In addition, adaptation is one of the policy options for reducing the negative impact of climate change either through measures that enhance society's resilience or actions that expand the range of coping strategies. This policy focus may be directed at certain aspects of a national development strategy, at specific geographical areas or at important sectors of the national economy, e.g., agriculture (Burton et al. 2004; Adger et al. 2003; Kurukulasuriya and Mendelsohn 2006a). Agricultural adaptation to climate change involves producing more food where needed, reducing or sharing risk and improving governance (Godfray and Garnett 2014). Agricultural adaptation to climate change will require technological and non-technological solutions and governance; private sectors and multiscales play a key role to take better adaptation practices for agriculture. Further, due to the link between agriculture and climate change, farming adaptation is closely linked to climate variables. Whenever changes in climatic variables, i.e., increase in temperature, erratic rainfall pattern and variations in frequency and intensity of extreme climatic events are taken together, adaptation represents a critical nexus of processes and cycles in the earth climate system.

Bangladesh is a predominantly agricultural country, and more than half of its populations are directly or indirectly related to farming activities (Alam and Moral 1997). Therefore, agricultural sector contributes the dominant share of the Gross Domestic Product (GDP) of Bangladesh which is ∼21% and employs ∼48.1% of the working force (BBS 2008). Despite its high contribution to the overall economy, this sector is challenged by climate-related catastrophe, i.e., flood, drought, cyclone, storm surge, saline intrusion and wind storm (Christiansen et al. 2011; Rahman et al. 2007). In this case, farmers' communities are now experiencing severe climatic variation in temperature and rainfall in low laying waterlogged areas of Bangladesh. Being an agricultural country, coastal areas of Bangladesh cover 19 districts encompassing a land area of 47,201 km^2 (32% of total area of the country) (Baten et al. 2015). However, in recent decades coastal agricultural land is affecting by salinity intrusion (Gowing et al. 2006) and tidal inundation (Nicholls et al. 2007). Climate change cell 2007 identified salinity intrusion is the pressing problem for yield reduction in coastal agriculture and found that in the past 830,000 million hectares of land were affected by soil salinity at different degrees in coastal region of Bangladesh. It estimated that net reduction of 0.5 million metric ton of rice production would take place due to 0.3 m sea level rise in coastal areas of Bangladesh (World Bank Bangladesh 2000). In an addition, IPCC report from 2001 recognized that by 2050 rice production in Bangladesh could decline by 8% compared to the year of 1990. In this circumstance, rising interest of farming adaptation is essential for farmers' community of Bangladesh, especially in

coastal areas. Agriculture is the primary land use practice in the southwest coastal region of Bangladesh. However, in the last two decades farming yield is affecting due to climate change, changes of climatic variables (Uddin et al. 2017) and human activities (Ali 2006). In an addition, the southwest coastal areas of Bangladesh are substantially impacted by prolonged inundation (Ayers et al. 2017; Ahmed and Akter 2017), e.g., cyclone Aila 2009 and cyclone Sidr 2007, surface and groundwater salinity (Ayers et al. 2016; Akter 2017), loss of land due to riverbank erosion and increased drought, which are enhancing risks for agricultural productivity. Moreover, droughts, soil and water salinity and prolonged inundation have changed suitability for rice farming, which is the most profitable agricultural product in this coastal area.

Previous study found that spatiotemporal variability of rainfall has an adverse effect on rain-fed agriculture in the southwest Bangladesh. Even so, local variety of rice (*Bengali name: Boro and Aman*) cultivation is reduced due to climatic variations in rainfall and temperature in present years (Hossain et al. 2014; Christiansen et al. 2011). As an example, after Cyclone Sidr, total production of Aus (local and HYV) decreased from 3606 tons in 2007 to 2955 tons in 2008 in Satkhira District (BBS 2009). Similar findings were reported in the total production of Aman and Boro rice varieties in Satkhira. Another study indicated that rotating land use practice (i.e., shrimp farming in the dry season and rice farming in wet season) and increasing salinity are potential causes for decreasing farming yield in the southwest coastal region of Bangladesh (Ayers et al. 2017).

Adaptation strategies are essential to ensure sustainable agriculture. Due to alarming changes in climate variables, adaptation in climate change, especially in agriculture, is urgent globally. As an example, Bangladesh is highly recognized mega delta under climate change threat among others all over the world (Agrawala et al. 2003). However, development of large-scale adaptation strategies is complex and bias-oriented because the analysis is based on different individual communities and large-scale climate variability. At a local scale, adaptation strategies are very specific and highly dependable on individual local community farming practice and specific regional climate settings. In the southwest Bangladesh, farming adaptation is essential due to harsh climate change impact. Many studies have been conducted to assess adaptation practices in the southwest coastal region of Bangladesh, but all are individual in context of different scales and sectors. The previous studies have gaps to link local farming practice, climate change in regional scale and farming adaptation strategies in context of local sustainability. Still, no study found the most effective farming adaptation strategies (i.e., individual adaptation or community-based adaptation or organized-based adaptation) considering regional climate change, local farming practice and how farmers are coping with climate change in the study area.

Therefore, the study focused on farming adaptation measures for climate change at a local scale. Two unions (a union is a geographical area mapped with more than one village in Bangladesh) of Tala and Mangalkot upazila (a upazila is a geographical area mapped with more than one union in Bangladesh) were selected for this study where the farming activities are suffering by climate change, and farmers are practicing individual and organized-based farming adaptation strategies to sustain their agricultural production. However, the farmers' community agreed that the existing farming adaptation strategies are insufficient.

Consequently, to fulfill the study aims, the study tried to identify sustainable adaptation practices for agriculture in low-lying areas of the southwest coastal region of Bangladesh. The study findings may apply to support the sustainable development goal (SDG) 2: 'End hunger, achieve food security and improved nutrition and promote sustainable agriculture' for coastal areas in Bangladesh. Through this consideration of particular study

aims and future application, the study worked on three predefined objectives: (a) to identify the numerous climatic events and factors which are influencing coastal agriculture, (b) to assess the spatiotemporal variability of temperature and precipitation change from 1995 to 2015 in regional scale and their relation with climate and farming activities and (c) to identify the sustainable farming adaptation measures in the study areas based on the analytical outcomes of objective 1 and 2.

2 Materials and methods

2.1 Study area

The study areas were selected in Mangalkot union (258.53 km^2) of Jessore district and Tala union (344.15 km^2) of Satkhira district of the southwest coastal region of Bangladesh (Fig. 1). Geographically, Satkhira district extends 21° 36′ and 22° 54′ north latitudes and 88° 54′ and 89° 20′ east longitudes and Jessore district extends 22° 48′ and 23° 22′ north latitudes and 88° 51′ and 89° 34′ east longitudes (BBS 2001). Geologically study areas are in an active tectonism area of Bengal delta, sea level fluctuation and tidal action of Bengal delta. Due to the active tidal delta, hydrology is controlling by the Ganges–Brahmaputra river system (Auerbach et al. 2015; Rashid 1991). Lithological features mainly silt, clay and fine sand as well as stable elevation due to subsidence rates and accretion rates being comparable (Wilson and Goodbred 2015; Allison et al. 2003).

The particular areas have been selected due to its climatic vulnerability aspects, diverse farming activities and decreasing farming yield. In recent decades, these areas are suffering from increasing salinity problem due to shrimp and crab aquaculture and longtime inundation in low-lying areas as well as for coastal hydrological regimes. Whereas, low elevation with the flat terrain vulnerable to sea-level rise, deltaic topography, and upwards funnel seawater affects climate-related disasters in the study areas. In addition, climatic stresses such as temperature increase, salinity intrusion into agricultural soil and groundwater, and an increase in the occurrence and intensity of climatic events such as floods, cyclones, storm surges and riverbank erosion result in climate change in the study areas (Agrawala et al. 2003).

2.2 Data collection and analysis

Primary data were collected from the reconnaissance survey, eight focus group discussions (FGD) (4 FGDs for each study area) and 200 households (HHs) (100 HHs for each study area) with respondents (farmers and farming-related personnel). For FGD and HHs, this study selected farmers whose primary occupation is agriculture, average farming age (farming age = farming period) is in-between 20–25 years and who has farming experience with extreme climatic events in last two decades. FGDs were conducted for general discussion on climate change, farming activities, farming adaptation, framers' perception and farmers' future needs. FGDs helped to generalize the farmers' perception and needs for better farming adaptation measures. HHs included a number of questions related to climate change, agriculture and farming adaptation in a chronological sequence. This questionnaire helps to assess general information about farmers (e.g., age, education, occupation, primary and secondary source of income) farming information (e.g., farm area, farming age, farming experience, land use practices, yield production and use of organic/inorganic pesticides and herbicides), climate-related information (e.g., temperature, precipitation, floods,
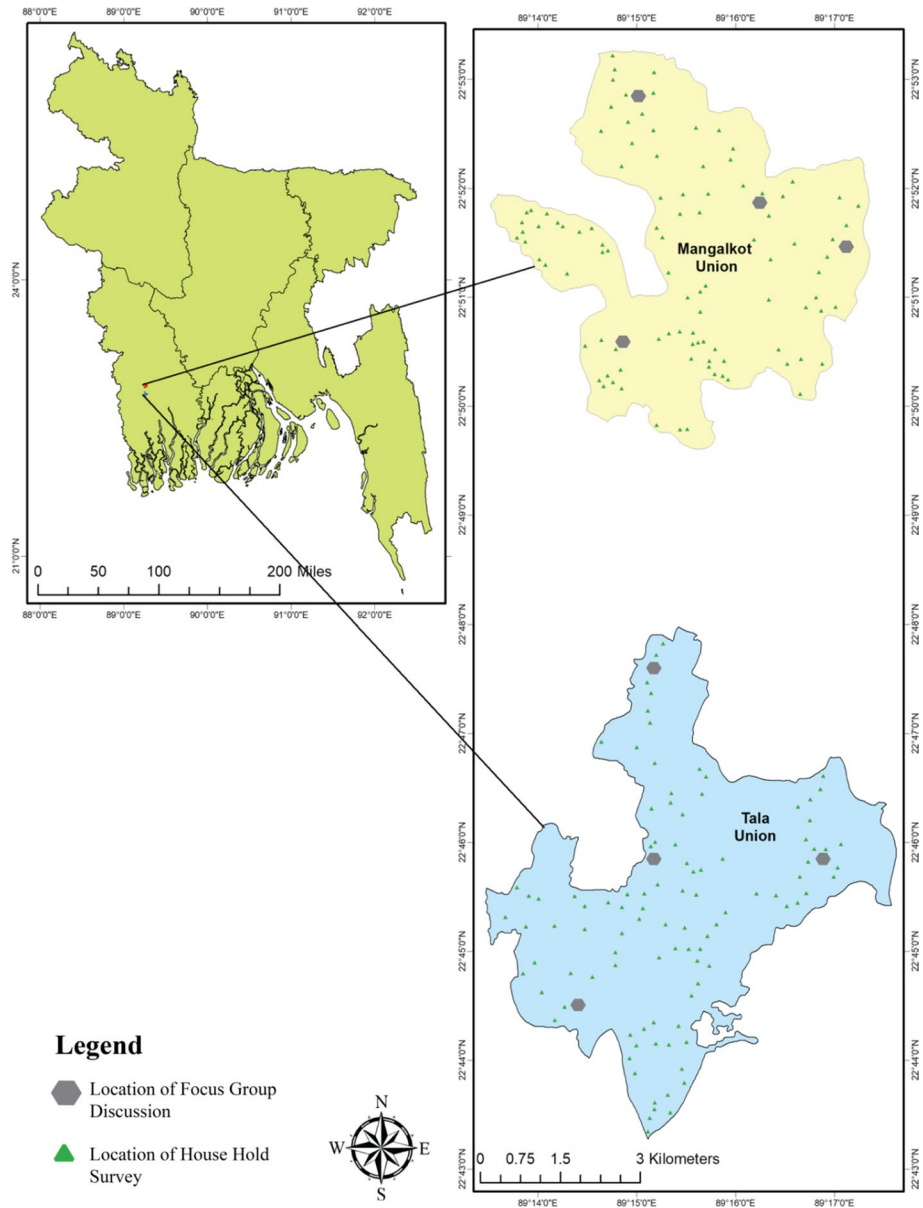
Fig. 1 Map of the study area with geological locations of household survey (HHs) and focus group discussion (FGD) locations

drought and salinity) and other miscellaneous information (e.g., changes of livelihood pattern, farmers income and local adaptation strategies). Six key informant interviews (KII) (3 KIIs for each study area) were conducted due to validate the information obtained from the questionnaire survey with skilled personnel in farming in the study areas. KIIs included local agricultural officers (i.e., Keshabpur and Tala Upazila), Soil Resource Development

Institute (SRDI) officers, school teachers and upazila chairpersons. Secondary data on farming yield, meteorological data and agro-hydrological data of farmlands were collected from agricultural extension offices (i.e., Keshabpur and Tala Upazila), SRDI and meteorological office of Khulna division of Bangladesh. Problem matrix is a tool to rank the climate changes as problems for farming adaptation by farmer's perception on intensity and frequency of these climatic events. Problem matrix summarizes the most and lest problem or climate change events through a numerical ranking system based on farmers' perception. Problems list was provided to each farmers and asked it separately into five categories (i.e., very high, high, moderate, low and very low). Problems frequency was collected through questionnaire survey with farmers. After that, score was calculated by multiplying the problem values with problem frequency in Eq. (1). Two seasonal calendars were established based on the climate-related hazards and different livelihood activities considering the year before 1990 to the present timescale.

$$\text{Score} = \text{Value of problem category} \times \text{frequency} \tag{1}$$

where problem category value is 1 (very low), 2 (low), 3 (moderate), 4 (high) and 5 (very high). Frequency range is 0, 1, 2 and 3.

2.3 Geoinformatics application

The study applied the kriging interpolation model (Oliver 1990; Jassim and Altaany 2013; Van Beers and Kleijnen 2003; Van Beers 2005) to interpolate the point data of precipitation and temperature over the study areas and to see the changes over time from 1995 to 2015. Precipitation and temperature change models are based on annual precipitation and annual mean temperature data (1995–2015) from 11 meteorological stations in Bengal delta (Fig. 2). The data were analyzed with 10 years temporal resolution with a general statistical explanation as—minimum, maximum, mean, standard variation, variance and with general bar diagram by 3rd ordered polynomial regression Eq. (2) (Kenney and Keeping 1962).

$$y = \alpha_0 + \alpha_1 x + \alpha_2 x^2 + \alpha_3 x^3 + \cdots + \alpha_n x_n^n \tag{2}$$

where $x, x^2, x^3, \ldots, x^n$ is independent variables, y is dependent variables which indicates predicted outcome value for polynomial model, $\alpha_0, \alpha_1, \ldots, \alpha_n$ is regression coefficient for each degree, n is predictors raised to the power of i (i.e., $i = 1-n$), $n = 2$ is a polynomial forms which indicate quadratic expression and $n = 3$ is cubic expression.

Distribution of mean annual precipitation and atmospheric temperature has also made for Bengal delta by the kriging interpolation algorithm with 10-year temporal resolution and approximately 100 km ground resolution depends on the position of the 11 meteorological stations in Bengal delta. The study used ordinary kriging method because of the simulation for spatial data and minimizes the variance of the estimation error (Van Beers and Kleijnen 2003), also to compare the changes in study areas with the changes in delta over time based on climate. In addition, this method helped to see the distribution and changes of temperature and precipitation over the time in study areas. Further, this method helped to understand the relation between climate change (only in annual mean temperature and annual precipitation) and farming activities with different farming adaptation measures.
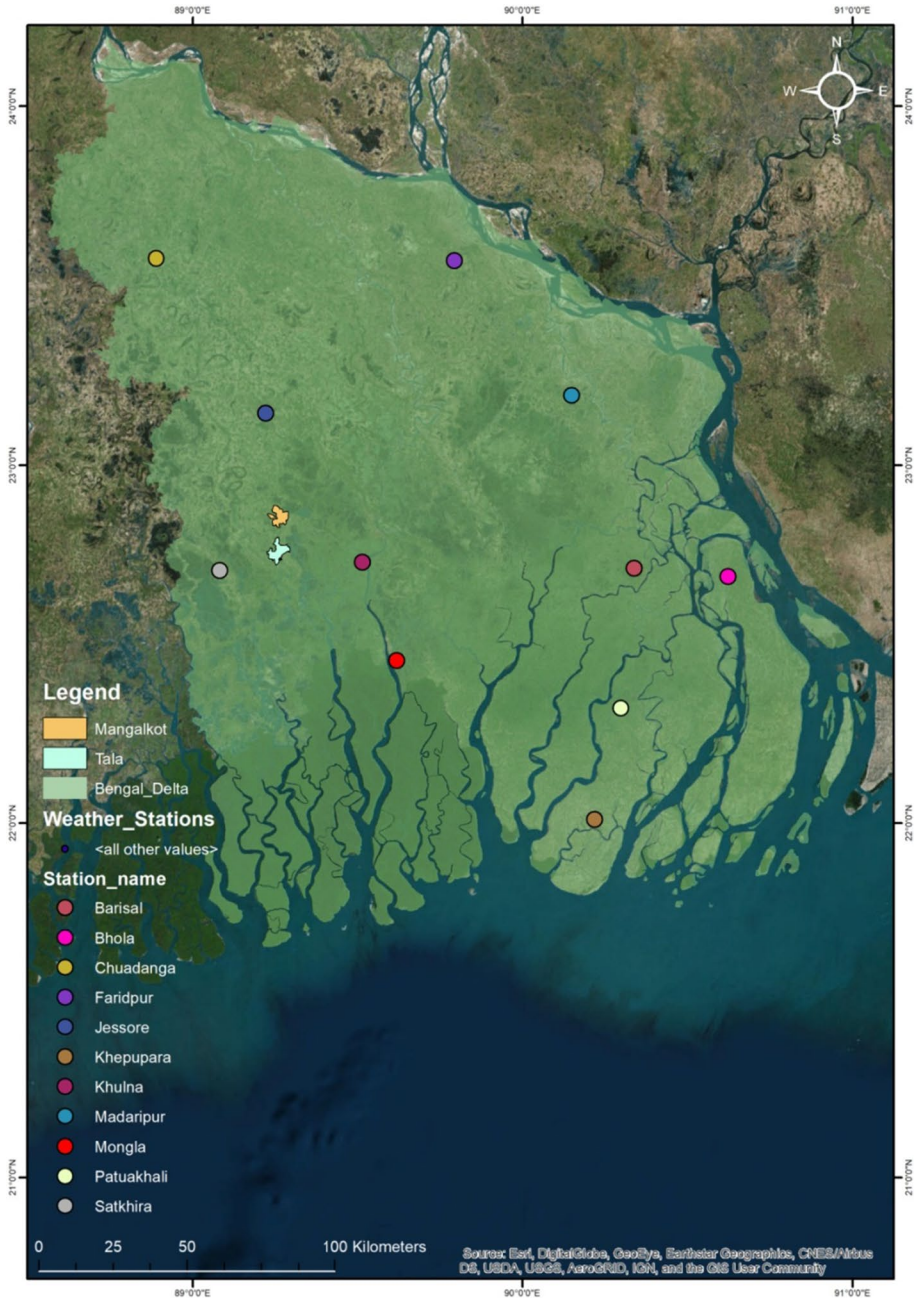
Fig. 2 Eleven (11) weather stations around study area in Bengal Delta

2.4 Multivariate statistical application

To gain a better understanding of the collected data, statistical models are applied in the data analysis. Statistical models are based on the best fit of the model, which relies on the null hypothesis (H_0) that an effect is absent while the alternative hypothesis (H_1) is the opposite (Field 2009). The acceptation or rejection of the null hypothesis depending on the probability value (p value), which can be related to the confidence interval (95%) around the average value of a response variable t, is tested (Field 2009). In this study, null hypothesis (H_0) is formulated as 'there is no relationship between the two variables' and the alternative hypothesis (H_1) states 'there is a relationship between the two variables.'

The study applied multivariate statistical analysis as 'Pearson Chi-square independence test' Eq. (3), because it helps to understand the significant relationship of 4 dependent variables (DVs) and 24 independent variables (IVs) of different climatic, social, economic, environmental and physical factors with probability values. This method helped to distinguish between DVs and IVs and developed the relation between DVs and IVs with statistical significance. The DVs and IVs are defined through the response of the respondents (e.g., farmers) collected by the HHs and FGDs. Stratified random sampling technique has been applied for sample size determination Eq. (3) (Kothari 1990) within each category of this study. Total 200 samples were surveyed in these study areas.

$$n = \frac{z^2 pqN}{e^2(N-1) + z^2 pq} \tag{3}$$

where n = sample size, z = the value of the standard variant at a given confidence level, p = sample proportion, $q = 1 - p$, e = acceptance error and N = population size for the strata.

2.5 Climate data analysis

The study analyzed precipitation and temperature data from 1995 to 2015. The analyzed data are presented by daily mean annual precipitation and temperature. The study considered 11 weather stations in the Bengal delta (Fig. 2) for data collection and to see the change of climatic patterns of this delta. Moreover, the study considered two closest weather stations as the representative climate data stations for the study areas and made a comparison of changes in climate data between the Bengal delta and study areas.

3 Results

The farmers' experience has been suggested that agricultural production from last two decades is adversely affected by climate change mostly beside agricultural inputs, e.g., fertilizers, pesticides and fungicides from human activities. Farmer's perception has also been suggested that low land areas are mostly affected by numerous floods, which lasts even more extended period than in past and creating waterlogging in the study areas. As a result, local rice production (*Bengali Name: Aus and Aman*) is radically decreasing in study areas. Most of the farmers' response was positive (answered as 'Yes') about the
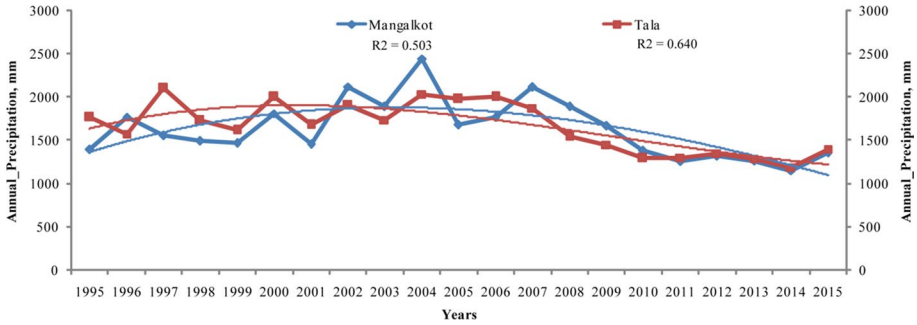
Fig. 3 Trend analysis of annual precipitation (mm/year) of the study areas from 1995 to 2015

Table 1 Annual precipitation (mm/year) in 1995, 2005 and 2015

Stations	1995 (mm/year)	2005 (mm/year)	2015 (mm/year)
Bengal Delta			
Faridpur	2006	1650	1400
Madaripur	2189	1905	1493
Chuadanga	1519	1482	1021
Jessore	**1397**	**1678**	**1191**
Khulna	2046	1982	1416
Mongla	1797	2406	1457
Satkhira	**1765**	**1982**	**1395**
Barisal	2258	1943	1603
Bhola	2038	2366	1694
Khepupara	3510	3348	2716
Patuakhali	3059	2703	2167
Mean	**2144**	**2131**	**1596**
SD	630	541	472
Var.	397,077	292,771	222,589
Min	1397	1482	1021
Max	3510	3348	2716

Bold value in the table indicates the weather stations of the study areas, the values belongs to weather stations of the study areas, and the mean values of the Bengal delta

increase in temperature and unpredictable pattern of precipitation which has impacted on agriculture production.

3.1 Climatic variables

3.1.1 Precipitation and temperature

Figure 3 shows the trend analysis of annual precipitation (mm/year) from 1995 to 2015 in study areas. It clearly showed that the annual precipitation is decreasing in study areas due to climate change in the last decades. In fact, local yield production is also decreasing
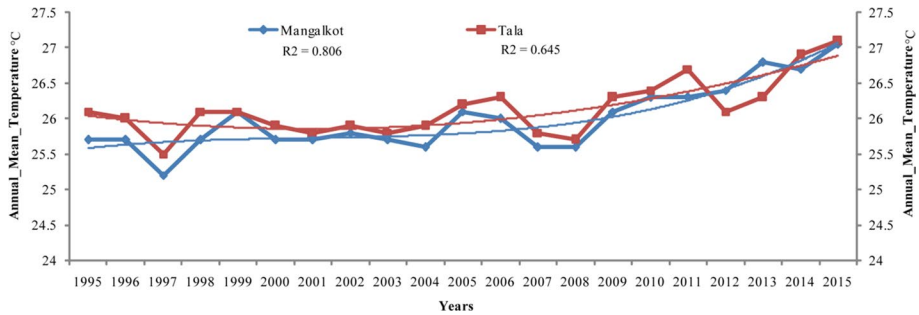
Fig. 4 Trend analysis of annual mean temperature (°C) of the study area from 1995 to 2015

in study areas. For this, farmers are now changing their cropping sequences in context of climate change in study areas. The statistical analysis reveals that in 2005, annual precipitation was high (mean 1678 mm/year) in Jessore district and Satkhira district (mean 1982 mm/year), respectively (Table 1). Conversely, the Bengal delta, including the study areas, indicated the annual precipitation was high in 1995 (mean 2144 mm/year). Figure 4 shows that the annual mean temperature is increasing gradually in study areas. Farmers experience also revealed that an increase in temperature with erratic rainfall pattern may lead to drought condition which may be caused yield reduction in the study areas. The statistical analysis discloses that in 2015 the annual mean temperature was 26.8 °C in Jessore district and 27 °C in Satkhira district (Table 2). On the other hand, the Bengal delta, including the study areas, indicated the same outcome where annual mean temperature was high in 2015 (mean 26.87 °C), respectively (Table 2).

Table 2 Mean annual temperature (°C) in 1995, 2005 and 2015

Stations	1995 (°C)	2005 (°C)	2015 (°C)
Bengal Delta			
Faridpur	25.8	26	26.8
Madaripur	25.6	25.8	26.9
Chuadanga	25.2	25.6	26.3
Jessore	**25.7**	**26.1**	**26.8**
Khulna	25.9	26.4	27.1
Mongla	26.4	26.5	27.3
Satkhira	**26.1**	**26.2**	**27.0**
Barisal	25.6	25.9	26.7
Bhola	25.7	25.8	26.6
Khepupara	26.2	26.3	27.2
Patuakhali	25.8	26	26.9
Mean	**25.82**	**26.06**	**26.87**
SD	0.35	0.28	0.28
Var.	0.11	0.08	0.08
Min	25.2	25.6	26.3
Max	26.4	26.5	27.3

Bold value in the table indicates the weather stations of the study areas, the values belongs to weather stations of the study areas, and the mean values of the Bengal delta
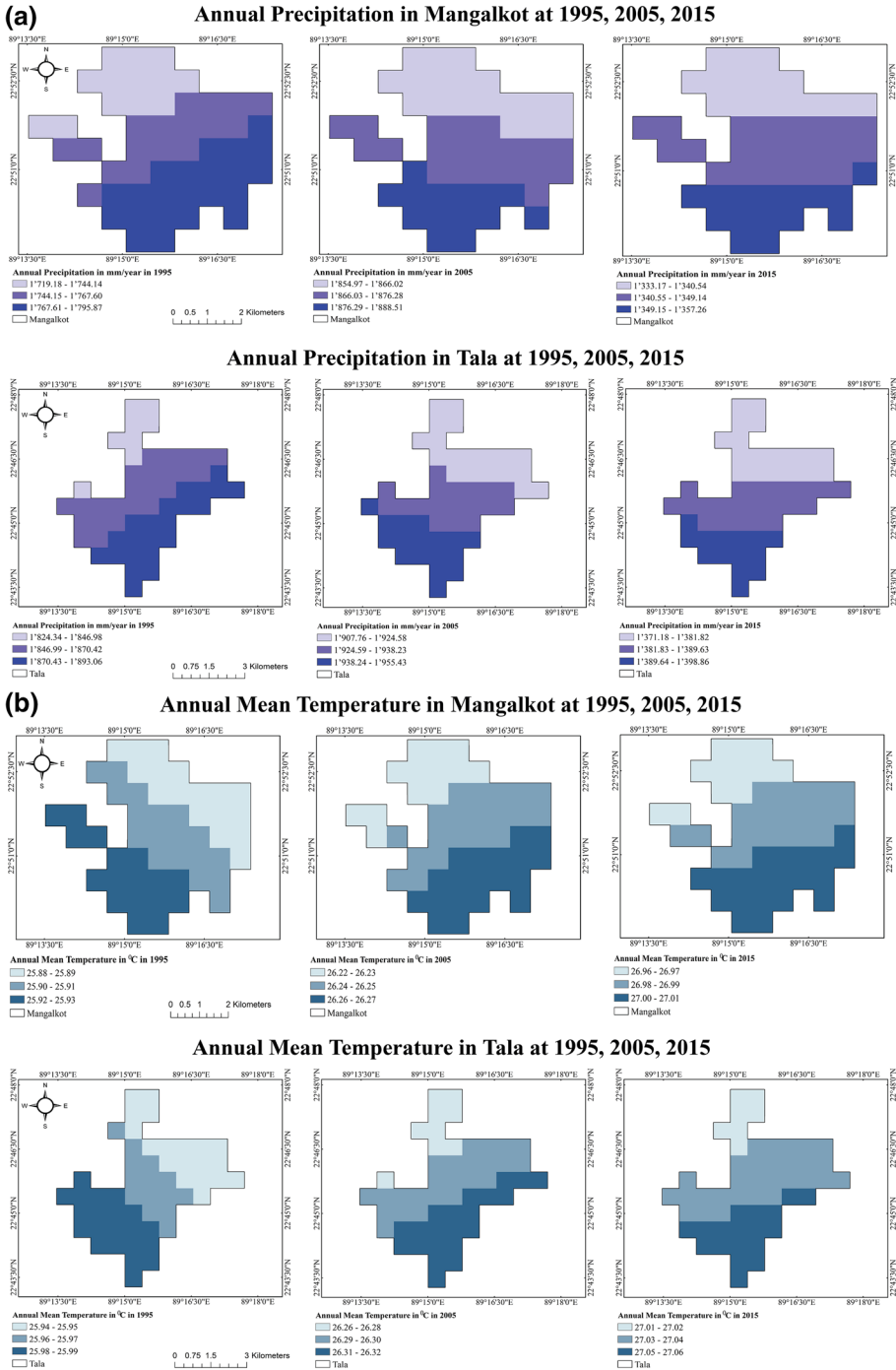
Fig. 5 **a** Annual precipitation (mm/year) change model of Mangalkot and Tala union from 1995 to 2015. **b** Annual mean temperature (°C) change model of Mangalkot and Tala union from 1995 to 2015. *Note* HYV, high yield variety; T. Aman, Transplant Aman; B. Aman, Bona Aman

3.1.2 Annual precipitation change model in 1995, 2005 and 2015

Figure 5a shows the annual precipitation change model of study areas with ten years temporal resolution from 1995 to 2015. In Mangalkot union, annual precipitation was 1719.18–1795.87 mm/year in 1995 and 1333.17–1357.26 mm/year in 2015 which was lower than the precipitation of the Bengal delta (2144 mm/year in 1995 and 1596 mm/year in 2015) (Table 1). In Tala union, annual precipitation was 1824.34–1893.06 mm/year in 1995 and 1371.18–1398.86 mm/year in 2015. In 2005, annual precipitation was higher in Mangalkot (1854.97–1888.51 mm/year) and in Tala (1907.76–1955.43 mm/year) and in the Bengal delta was higher in 1995 (2144 mm/year) (Table 1). Nevertheless, annual precipitation was higher in Tala than in Mangalkot.

3.1.3 Annual mean temperature change model in 1995, 2005 and 2015

In Mangalkot union, the annual mean temperature was higher from 1995 (25.88–25.93 °C) to 2015 (26.96–27.01 °C) (Fig. 5b). And same result was illustrated in Tala union in 1995 (25.94–25.99 °C) to 2015 (27.01–27.06 °C) (Fig. 5b). In the Bengal delta annual mean temperature was also higher from 1995 (25.82 °C) to 2015 (26.87 °C) (Table 2). Nevertheless, annual mean temperature was higher in Tala than in Mangalkot.

3.2 Social factors

3.2.1 Social status of farmers

Supplementary Table 1 provides the social status of farmers in study areas (e.g., higher, mid and root level farmers). The root level farmers are 52% in Mangalkot union and 55% in Tala union, whereas mid-level farmers are 43% and 41%, respectively. Therefore, this study found that root level farmers are high in study areas.

3.2.2 Living period and farming age of farmers

Supplementary Table 2 shows the age of farming and living period of farmers. The average farming age is 33 years in Mangalkot union and 29 years in Tala union, whereas average living period is 45 years in Mangalkot and 42 years in Tala union simultaneously.

3.2.3 Level of education

Supplementary Table 3 discloses the level of education where most of the farmers are completed their primary and secondary level education in study areas. Very few of them completed their higher secondary education but none of them have university education.

3.3 Economical and environmental factors

Farmers have marked economic factors as the main constraint to acquire the climate change adaptation measures. Only off-farm income stained as a responsive factor to adapt climate

Crops	Kharif-1				Kharif-2				Robi			
	Magh-Falgun	Falgun-Chotro	Chotro-Baisak	Baisak-Jostho	Jostho-Ashar	Ashar-Sraban	Sraban-Bhadro	Bhadro-Asshin	Asshin-Kartik	Kartic-Aghraon	Aghraon-Posh	Posh-Magh
	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan
Kharif-1 (K1)												
Aus (HYV)												
Aus (Ufshe)												
Aus (Local)												
B.Aman												
Vegetables (K1)												
Jute												
Kharif-2 (K2)												
T.Aman (HYV)												
T.Aman (Ufshe)												
T.Aman (Local)												
Vegetables (K2)												
Robi (R)												
Boro (HYV)												
Boro (Ufshe)												
Boro (Local)												
Wheat												
Vegetables (R)												
Potato												
Bangladesh, 1995												
Mangalkhot												
Tala												

Fig. 6 Crop calendar. *Source*: Bangladesh Agricultural Department; Agricultural Extension Office Keshabpur and Tala Upazila, 2013

change, whereas saltwater shrimp cultivation is the most used option as off-farm income in the study areas. This study found that 70% farmers of Tala union are involved in off-farm activities and 44% in Mangalkot union (Supplementary Table 4). The geological places of farming lands are complex to develop climate change adaptation measures in study areas. The study found that changes in cropping time (Fig. 6) and increasing salinity in water and soil are the most tinted factors for climate change adaptation response.

3.4 Physical factors

The study revealed that land use practice is an important factor to consider for climate change adaptation. Because of agriculture, shrimp and crab cultivation is a major livelihood activities in study area (Figs. 6, 8 and Table 4). As well as irrigation system, soil moisturizing and numerous farming practices methods are important variables to control adaptation response in study areas. The study found that in Tala union 100% farmers are using shallow tubewell for their farming activities, whereas 90% in Mangalkot union. In addition, farmers are using numerous systems as soil digging, water supply and fertilizer, and also agricultural tips for their soil moisturizing methods in study areas (Supplementary Table 5 and Supplementary Table 6).

3.5 Farmer's perception and risk assessment

During field investigations through questionnaire survey (HHs, FGDs and KIIs), farmers' communities exposed different ranks of different major climatic events (Table 3). These

Table 3 Problem matrix for climatic hazards in study areas

Problem[a]	Category[a]	Frequency per year	Score[b]	Rank
Change of temperature	Very high (5)	3	15	1
Change of Precipitation	Very high (5)	3	15	1
Cyclone and storm surges	High (4)	2	8	2
Drought	Moderate (3)	1	3	3
Fog	Very low (1)	0	0	5
flood	High (4)	2	8	2
Waterlogging	High (4)	2	8	2
Water salinity	High (4)	2	8	2
Soil salinity	High (4)	2	8	2
Scarcity of drinking water	High (4)	2	8	2
Riverbank erosion	High (4)	2	8	2
Pest and disease attack	Low (2)	1	2	4

[a]Numbers in the parenthesis indicate the category value, [b]Score = Value of problem category × frequency

climatic events are affecting the farmers' livelihoods, employment opportunities and annual yield in study areas. These climatic events are considered as problems and ranked in problem matrix (Table 3) from the farmers' opinion. Table 3 reveals that change in temperature and change in precipitation are the major climatic problems in the study areas, which are ranked 1 (very high) in problem matrix, whereas cyclone and storm surges, flood, waterlogging, water salinity, soil salinity, scarcity of drinking water and riverbank erosion are ranked 2 (high) in the problem matrix. Drought is ranked 3 (moderate), and pest and disease attack is ranked 4 (low) in the problem matrix. Here, fog is ranked 5 (very low) means it has no impact in problem matrix.

Based on problem matrix, a seasonal calendar for climate-related hazards is established in Fig. 7. In present, change in temperature is predictable from mid-April till early July, and in past it was only predictable in May. Change in precipitation is now predictable from early January to mid-February and from early May till early September, whereas in past it was predictable in end of May to July and in January only. Compared to past, seasonal occurrence time of cyclone and storm surges is extended (Fig. 7). Drought, flood, waterlogging, water salinity, soil salinity and riverbank erosion events are prolonged since 90s. However, duration of fog is shortening after 90's.

Table 4 and Fig. 8 show the trend of different livelihood activities and seasonal livelihood calendar which are constructed by farmer's opinions. Very often cyclones, floods and salinity are increased round the years and affecting farmers' livelihood by creating sort of livelihood problems in study areas. The livelihood trends are demonstrating that shrimp and crab cultivation has introduced in the present timescale, which was not before 90s, and it will be retained highly considerable livelihood occupation among farmers in future. In recent time, duck raring and poultry occupation are popular livelihood activity and provides additional income. Even day labor and rickshaw puller works are increasing in the study areas. Due to extreme climatic events, farmer's communities are facing their adaptive capacity with climate change. Figure 8 shows that fishing opportunity is decreasing which was profitable occupation before 1990s.
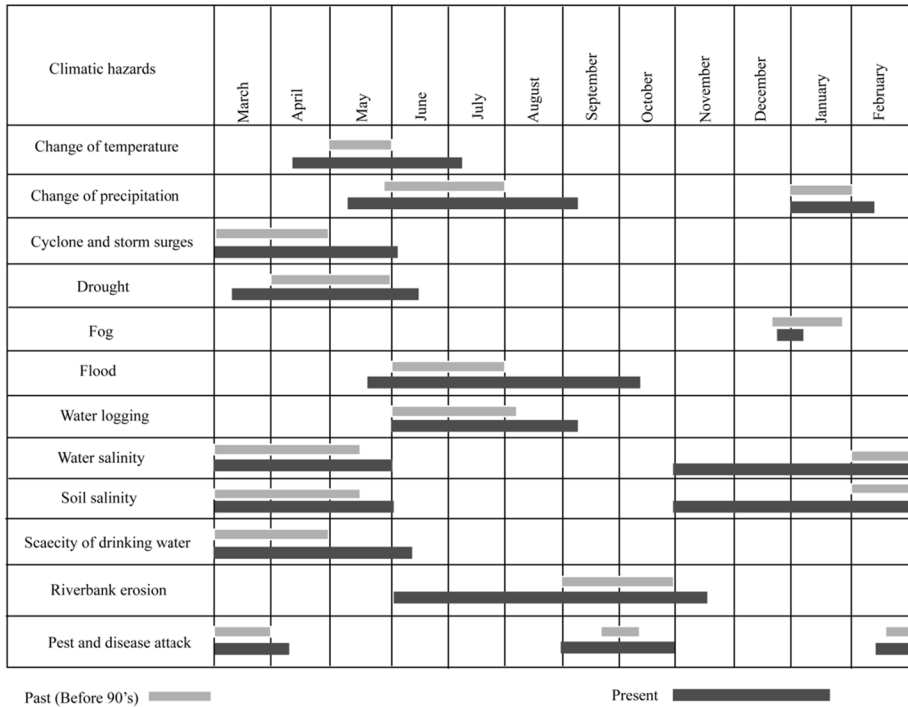
Fig. 7 Seasonal calendar for climate-related hazards

Table 4 Trends of different livelihood activities in the study areas

Livelihood activity	Past	Present	Future
Shrimp cultivation	Rare	Increase	Increase
Crab cultivation	Rare	Increase	Increase
Fishery	Common	Decrease	Decrease
Day Labor	Rare	Increase	Increase
Duck raring and poultry	Common	Increase	Increase
Rickshaw puller	Rare	Increase	Increase

3.6 Diversity in the cropping sequence

Figure 6 illustrates the cropping sequence in study areas through the comparison with country level cropping cycle. The cropping calendar for the study areas divided the cropping period into three cropping seasons—Kharif 1 (summer season crops), Kharif 2 (rainy season crops) and Robi (winter season crops). The crop calendar shows the changes in cropping seasonality based on the cropping calendar of Bangladesh 1995 (MoA 2010). All three cropping seasons are shifted drastically. Framers' communities are marking this shifting cropping practice based on changes in different climate events (Fig. 7) and this is considered from the climate data analysis (Figs. 3, 4, 5a, b), where dry and wet seasons are extended but winter season is shortened. Due to this change, farmers are discouraged from cultivating winter crops. Most of them prefer fish farming in winter due to prolonged wet
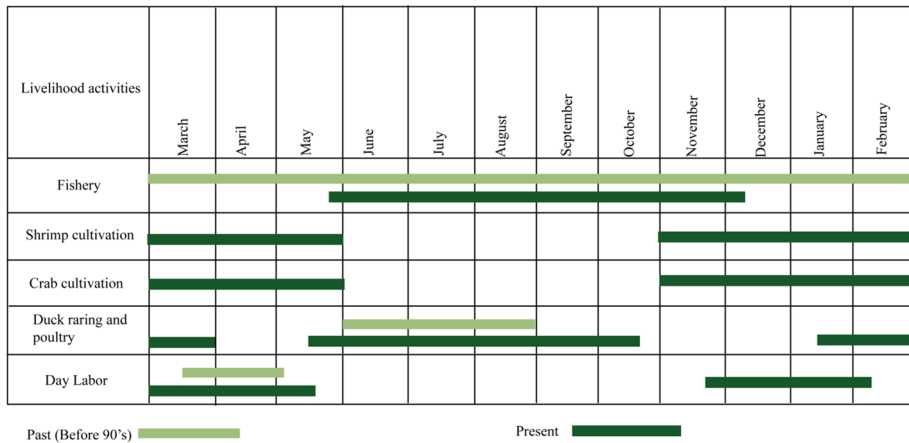
Fig. 8 Seasonal calendar for different livelihood activities

period and waterlogging. Figure 6 shows the clear shifting of the cropping seasons, where farming in autumn and late autumn no longer exists.

3.7 Dependent and independent variables for farming adaptation measures

The study provided an overview of the 'Pearson Chi-square test' and indicates the significant relationship ($p < 0.05$) between two categorical variables, DVs and IVs in Table 5. Based on changes in different climate events, DVs 1 'factor to response for climate change adaptation' has significant relation (sig. 0.01), (sig. 0.03) with annual precipitation (IV 1) and annual temperature (IV 2). The participated farmers have changed their farm practices during the last decades in study areas due to the changing temperature and precipitation. Nowadays farmers are become more interested to receive weather forecasting information from mobile phone over from television in study areas. In this case, DVs 4 'factors to help to develop climate change adaptation' has made a relationship (sig. 0.02) with weather forecasting system (IV 8). Price of farming commodities and products plays a key role for adaptation practices in study areas, so DVs 1 'factor to response for climate change adaptation' has a strong significant relation (sig. 0.01, sig. 0.01 and sig. 0.02) with price of commodities and product, even with economical class of farmers (IV 9, IV 11 and IV 12). Due to climate change, sea level rise and human behavior alteration, the environmental factor showed significant dependency of DVs on different IVs where DVs 1 'factor to response for climate change adaptation' has made a strong significant relationship (sig. 0.03, sig. 0.002) with an increase in soil and water salinity (IV 15). In addition, DVs 4 'factors to help to develop climate change adaptation' exposed a strong relationship (sig. 0.001) with geological place of farming (IV 13). Moreover, DVs 4 'factors to help to develop climate change adaptation' have strong relationship (sig. 0.008, sig. 0.003, sig. 0.009, sig. 0.009, sig. 0.03, sig. 0.007) with land use practices, irrigation system, soil moisturizing methods, responses or practices to cope with water unavailability and salinity, use of practices for trees or vines or plants, and applied farming practices to adapt water unavailability and salinity (IV 18, IV 19, IV 20, IV 22, IV 23 and IV 24). Therefore, Table 5 clearly indicated that climatic, economic, environmental and physical factors are controlling the farming

Table 5 Pearson Chi-square test between DVs and IVs for farming adaptation in Mangalkot union and Tala union

	Dependent variables (DV)—factors to consider farming adaptation			
	DV 1: Factors to Response for Climate Change Adaptation; Asymp. Sig. (2-sided)	DV 2: Barriers for Climate Change Adaptation Measures; Asymp. Sig. (2-sided)	DV 3: Factors for Climate Change; Asymp. Sig. (2-sided)	DV 4: Factors to Help to Develop Climate Change Adaptation Measures; Asymp. Sig. (2-sided)
	Chi-square value**	Chi-square value**	Chi-square value**	Chi-square value**
Independent variables (IV)—factors to consider farming adaptation				
Climatic factors				
IV 1: Annual precipitation change	**0.01**	0.05	**0.03**	0.86
IV 2: Annual temperature anomaly	**0.03**	0.09	0.05	0.95
IV 3: Unavailability of climatic data for farming (precipitation, temperature, evaporation, crop factor, crop coefficient data, averaged crop water requirements, sunshine hour and humidity)	0.05	0.06	0.10	0.97
Social factors				
IV 4: Social status of farmers	0.06	0.75	0.92	0.86
IV 5: Farming ages	0.25	0.05	0.42	0.29
IV 6: Types of farmers	0.05	0.58	0.75	0.66
IV 7: Farming education or education level of farmers	0.39	0.99	0.09	0.72
IV 8: Weather forecasting system	0.53	0.39	0.87	**0.02**
Economical Factors				

Table 5 (continued)

	Dependent variables (DV)—factors to consider farming adaptation			
	DV 1: Factors to Response for Climate Change Adaptation; Asymp. Sig. (2-sided)	DV 2: Barriers for Climate Change Adaptation Measures; Asymp. Sig. (2-sided)	DV 3: Factors for Climate Change; Asymp. Sig. (2-sided)	DV 4: Factors to Help to Develop Climate Change Adaptation Measures; Asymp. Sig. (2-sided)
	Chi-square value**	Chi-square value**	Chi-square value**	Chi-square value**
IV 9: Economical class of farmers	**0.01**	0.81	0.69	0.44
IV 10: Off-farm income	0.31	0.29	**0.03**	0.41
IV 11: Price of farming commodities	**0.01**	0.96	0.41	0.82
IV 12: Price of farming products	**0.02**	0.78	0.43	0.06
Environmental factors				
IV 13: Geological/Geographical place of farming	0.54	0.08	0.37	**0.001**
IV 14: Cropping sequence change	**0.03**	0.09	0.75	0.82
IV 15: Increase of water and soil salinity	**0.002**	0.28	0.16	0.75
IV 16: Reduce of farming productivity	0.06	0.75	0.48	0.95
Physical factors				
IV 17: Area of farmland	0.97	1.00	0.05	0.13
IV 18: Land use practices	0.37	0.95	**0.001**	**0.008**
IV 19: Irrigation system	0.11	**0.02**	0.21	**0.003**
IV 20: Method for soil moisturizing	0.18	0.43	0.27	**0.009**
IV 21: Amount of fertilizers used in farmland	0.29	0.38	0.55	0.72

Table 5 (continued)

	Dependent variables (DV)—factors to consider farming adaptation			
	DV 1: Factors to Response for Climate Change Adaptation; Asymp. Sig. (2-sided)	DV 2: Barriers for Climate Change Adaptation Measures; Asymp. Sig. (2-sided)	DV 3: Factors for Climate Change; Asymp. Sig. (2-sided)	DV 4: Factors to Help to Develop Climate Change Adaptation Measures; Asymp. Sig. (2-sided)
	Chi-square value**	Chi-square value**	Chi-square value**	Chi-square value**
IV 22: Responses or practices to cope with water unavailability and salinity	**0.01**	0.18	0.26	**0.009**
IV 23: Use of practices for trees/vines/plants	0.71	0.95	0.73	**0.03**
IV 24: Applied farming practices to adapt water unavailability and salinity	0.23	0.19	0.82	**0.007**

Bold numbers indicate significant values for analytical consideration

**Chi-square value shows the value of 'p.' $p < 0.05$ = Highly significant relationship

adaptation measures in the study areas, where the individual variables for different factors play significant role.

3.8 Traditional farming practices and farming adaptation measures

The traditional farming practices of coastal region are generally agriculture based, because agriculture is the most important options of livelihood in the coastal region of Bangladesh. 20 years back farmers were using compost as an organic fertilizer (household wastes turned into compost) for their agricultural purposes. Since then, the coastal agricultural practices are transforming dramatically and rapidly due to extreme climatic events, i.e., frequent cyclone and storm surge, prolongated waterlogging and saltwater intrusion. Consequently, farmers started freshwater fish farming and shrimp cultivation to mitigate the loss in their traditional agriculture. Besides, farmers are copping these extreme climate events by changing their traditional farming adaptation measures for their traditional agricultural activities, which are described below. Traditionally seeds are stored in earthen pots, bamboo baskets or similar containers made from natural materials rather than in sacks. The storage place must be free from moisture and have good air circulation and frequently checked for pests. Often ears heads and fruits of vegetables are tied and hung in a smoky area, in kitchen. Some materials like dried neem leaves, chillies, limestone dust and ash are effective in controlling storage pests. However, in early periods, seed conservation was a domestic duty and women and men both play a key role in that case.

However, this study considered 11 sustainable adaptation measures which are identified and named according to the farmer's observation (Fig. 9 and Table 6). Diversification of various crops is an important adaptation measure, and most of the farmers (84% in Mangalkot and 100% in Tala) are preferred to consider this in the study areas. In this case, saline-tolerant crop species are getting more acceptable rather than others. However, farmers are facing difficulties to effort saline tolerance corps' species due to the lack of proper economic status (Table 5). Majority of farmers (100% in Mangalkot and 100% in Tala) are changing their planting and harvesting time, and increasing fertilizers and pesticides application for high crop yield. Homestead gardening (41% in Mangalkot and 65% in Tala) is very common and feasible adaptation measure in the study areas. Only farmers (83% in Tala) of Tala union considered their plants in a heap for natural drainage and prevent root damage from decay, because heavy rainfall and waterlogging are typical scenario in this study area. Water hyacinth is an excellent example for low-lying areas that are found as the widely used mulching material due to its availability in study areas (17% in Mangalkot and 37% in Tala). Floating garden is only considered in Tala union (46% in Tala). Cucumber, bitter gourd, tomato, turmeric and potato are good example for crops that are practicing in study areas. Aquaculture (54% in Mangalkot and 88% in Tala) is another alternative income generation activities found in study areas and practiced by the farmers during the flood and waterlogging period in the recent years. Farmers (10% in Mangalkot and 94% in Tala) collected saline-tolerant rice seeds and crops seeds (i.e., maize and sunflower) from different regional NGOs and governmental agricultural extension offices. In addition, farmers (39% in Mangalkot and 67% in Tala) are cultivating watermelon and groundnut as drought-tolerant crops.

Fig. 9 Farming adaptation strategies in Mangalkot and Tala union. M, Mangalkot; T, Tala

3.8.1 Traditional varieties of crops and their conservation status

Rice (*Aus, Aman* and *Boro*), wheat, jute, rape, mustard, lentil, chuckling vetch, potato, sugarcane, chilli and others crops are the traditional crops in coastal region of Bangladesh. Now rice is the most climatic resilient crops where farmers are cultivating both local and HYV rice species. Besides, some other crops especially vegetables are climatic resilient nowadays. The Ministry of Agriculture including Bangladesh Rice Research Institute (BRRI), Bangladesh Agricultural Research Council (BARC) and Bangladesh Agricultural Research Institute (BARI) keep stocks of seeds, fertilizers and insecticides and are responsible for carrying out research on the development of different crop varieties resilient to different climate stresses in coastal region of Bangladesh.

Table 6 Adaptation strategies in Mangalkot union and Tala union. *Source*: Bangladesh Agricultural Department; Agricultural Extension Office Keshabpur and Tala Upazila; and Field survey, 2013

	Adaptation Strategies	Remarks	Respondents (%)				Total (N=200)
			0–25% VL	25–50% L	50–75% M	75–100% H	
1	Diversification of various crop	IA		43M	41M and 54T	46 T	84M and 100T
2	Change in planting and harvesting period	IA			33M and 17T	67M and 83T	100M and 100M
3	Increase of fertilizers application	IA and OBA			11M	89M and 100T	100M and 100T
4	Increase of pesticides application	IA and OBA			21M	42M and 83T	63M and 73T
5	Homestead gardening	IA and OBA		22M	19M and 40T	25T	41M and 65T
6	Plantation (heap)	IA			13T	70T	83T
7	Mulching	IA			7M and 16T	10M and 21T	17M and 37T
8	Floating garden	IA and OBA				46T	46T
9	Aquaculture	IA and OBA			8M and 12T	46M and 76T	54M and 88T
10	Cultivation saline-tolerant varieties	OBA	12M		10T	84T	10M and 94T
11	Cultivation drought-tolerant varieties	OBA	9M	30M and 26T	41T		39M and 67T

IA, Individual Adaptation; OBA, Organization Based Adaptation (GOs and NGOs); M, Mangalkot, T, Tala; VL, Very Low; L, Low; M, Medium; H, High; N, Number of respondents

4 Discussions

The southwest coastal region of Bangladesh is a very unique and dynamic region of the world. This region covers the Sundarbans Mangrove Forest and the downstream part of Ganges–Brahmaputra–Meghna River systems and connected to the Bay of Bengal. Agriculture is the main livelihood and land use practice in southwest and all coastal region of Bangladesh. During the last decades, southwest coastal region is facing a numerous climatic hazards which are responsible to change the coastal livelihoods and food security. In this circumstance, coastal farmers are changing their cropping pattern (Fig. 6), livelihood activities (Fig. 8) and choosing some adaptation measures (Table 6). In north and northwest Bangladesh, farmers are not facing salinity intrusion and waterlogging problem for their farming activities. For this, northwest farmers are avoiding some adaptation options like saline-tolerant rice and crop varieties, excavating the canals of surrounding field, digging drain, and excess water is withdrawn by pump from the field (Arfanuzzaman et al. 2016) which are common in the southwest region of Bangladesh and present in study areas (Table 6 and Fig. 9).

The study provided evidence that the farmers in study areas can identify subtle changes in climate and can distinguish between increased natural climatic variability with past scenarios. Farmers are considering that climatic variables are changing since the 1990s which are visible by climatic data analysis, and temperature and precipitation change models (Figs. 3, 4, 5a, b). 'Pearson Chi-square test' clearly explained the farming adaptation variables with factors that came from farmers' perception of climate changes on agriculture through the HHs and FGDs. Farmers' response for climate change adaptation is depending on annual precipitation and temperature change, as well as it also depends on the cropping sequence change, increasing water and soil salinity (Table 5). Depending on farmers' perception, some IVs could help to obtain climate change adaptation measures like as price of farming commodities and products, weather forecasting system, geological/geographical place of farmlands, land use practices and irrigation system (Table 5). However, farmers are considering some barriers to taking climate change adaptation measures, and irrigation system is one of them (Table 5).

Farmers are assuming these rapid changes are very harmful for the farming system. For this reason, farmers are now changing their cropping sequences (Fig. 6) and adaptation strategies (Table 6). Farmers are now adapting 11 different measures for their farming sectors in Mangalkot and Tala union (Fig. 9). Based on adaptation strategy, ~ 90% of farmers are cultivating high yield variety (HYV) rice for waterlogging and increasing soil and water salinity. Even most of the farmers are changing their planting and harvesting time to cope with the adverse effect of climate change such as excessive rainfall, seasonal floods, drought and storm surge. At present, farmers are depending on short duration rice variety which is also flood or high water level tolerance. For climate change, most of the farmers of the study areas are using chemical fertilizers and pesticides rather than organic for HYV. For this, local crop yield is decreasing in study areas.

5 Conclusions

Farmers' adaptation for agriculture owing to climate change depends on 24 IVs including five different factors' and four DVs in the study areas. The individual variables are depended on both natural and human induce drivers. Farmers' perception of climate change events is a contest with changes in climate variables. The mean annual deficit in precipitation is 548 mm from 1995 to 2015. The increase of atmospheric annual mean temperature is 1.06 °C from 1995 to 2015. The climatic analysis shows that climate change is mostly controlled by natural phenomena that are unpredictable precipitation and atmospheric temperature changes in study areas, so-called nature controlled acts, whereas farmer's perception reveals that human-induced activities, i.e., land use practices, may lead to damage agricultural production in coastal region of Bangladesh, so-called human-controlled act. Consequently, current farming adaptation measures are coped from farmers' individual adaptation and organized-based adaptation (governmental organizations and non-governmental organizations). However, local farmers are trying to implement their ideas and indigenous knowledge about 11 different farming adaptation measures which have been identified in the study areas. Farmers are considering that their adaptation strategies are time dependent, which can be more feasible depending on the impacts and changes of different factors and variables, which are mentioned and noted during the study. Considering farmers time-dependent adaptation measures, development of sustainable climate change adaptation strategies is possible; here it is worth to mention that farmers' perception on climate change, climate variables as precipitation and temperature changes are positively related, which has enlighten the predictability of farmers for adaptive farming activities.

Through the above findings and discussion, the following recommendations can be proposed for future improvement of sustainable agriculture planning to achieve SDG 2 for coastal areas in Bangladesh.

- Ensure the management of waterlogging, water salinity and soil salinity.
- Ensure economical and organizational supports to farmers to practice farming adaptation measures (i.e., for saline-tolerant crop seeds, drought-tolerant crop seeds)
- Manage the coastal land use practice (i.e., agriculture, shrimp farming and crab farming) considering regional climate and agricultural needs.

Compliance with ethical standards

Ethical declaration This research conducted interviews with farmers in different formats. The research ensures that there was no conflict or any unfriendliness against interviews, and every interview was conducted with the interview's truthful concern and understanding.

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