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ORIGINAL ARTICLE

Changes in coastal farming systems in a changing climate in Bangladesh

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Abstract

Changes in farming systems are dominated by changes in global climate and local environment, apart from the non-climatic drivers. Given the challenges in partitioning the contribution of climatic and non-climatic factors to the changes in farming systems, this paper aims to assess the types and changes of coastal farming systems, the farmer perceptions of the causes of the changes in farming systems, and the relationship between the influencing factors and perceptions. A structured interview schedule was used to collect data from 381 randomly selected coastal households during September–October 2018. The random forest classification model was applied to estimate the relative importance of the farmers' characteristics on their perception of causes of changes in farming systems. This study reveals that the coastal farmers had mostly semi-subsistence type of mixed farming systems, which were going through dynamic changes in terms of their sizes and number of farmers. In general, the participation in rice, vegetables, and livestock farming was decreasing but increasing in fisheries, forestry, and fruit farming. Most (95.5%) of the farmers had to change at least one of the farming enterprises over the past decade (2009–2018) compared with the previous decade (1999–2008). About two-thirds of the farmers perceived that climate change had caused changes in their farming systems. Compared with the eastern coasts, the farmers in the western coasts tended to blame climate change to a higher extent for the effect on their agricultural activities. The random forest model outputs imply that the farmers who are younger in age and with less formal education, larger family, and smaller farmland should be supported with scientific knowledge on causes of changes in farming systems. This could help them more aware of climate change issues related to agriculture and increase their enthusiasm to take part in adaptive changes in farming systems.

Keywords Farmer perceptions · Coastal communities · Machine learning · Random forest · Climate change

Introduction

Farming activities are highly influenced by climate in an area (Howden et al. 2007; Kalra et al. 2007). Climate change and variability inevitably affect global crop yields (Lobell et al. 2011; Ray et al. 2015). Since mitigation activities in the short term could be beyond the farmers' capacity (Gopalakrishnan et al. 2019), adaption remains as a non-negotiable option for them. Thus, switching of farm enterprises aligned with climate resilience has become the main concern of the farmers. Existing dominant patterns of farm enterprises of a community, i.e., farming systems (Dixon et al. 2001) can be altered by means of altering the choice of farm types under climate change (Etwire 2020). However, agricultural practices are influenced not only by climate change but also by non-climatic drivers, such as soil fertility, input cost, market price, agricultural policy, and extension support (Bhatta et al. 2016). Farmers may change

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their farming enterprises when soil condition is not favorable, or input cost is higher compared with the market price of the outputs of a particular crop. Therefore, changes in farming systems are simultaneously caused by climatic and non-climatic factors.

The negative impacts of climate change on agriculture are now an established fact based on both modelling (Amin et al. 2015; Schlenker and Lobell 2010) and survey research (Hasnat et al. 2016; Olesen et al. 2011). Both coastal and non-coastal farming systems are susceptible to climatic and non-climatic stresses while coastal agriculture is particularly threatened by storm surges, cyclones, sea-level rise, floods, waterlogging, river bank erosion, coastal inundation, and seawater intrusion (Bernier et al. 2016; Filho et al. 2018; Gopalakrishnan et al. 2019). Climate change–induced soil salinity can make a piece of coastal-land completely unsuitable for crop cultivation, especially for rice (Gopalakrishnan et al. 2020). Infrastructural damage caused by tropical cyclones puts additional burden on the coastal people for the restoration of their livelihood activities (Mallick et al. 2011). Besides ecological and economic contributions, coastal areas of Bangladesh contain nearly one-third (29%) of the total area and 27.1% of the total population (CCC 2016; Hasan et al. 2020; Uddin and Kaudstaal 2003).

In the coastal farming systems of Bangladesh, farmers perform subsistence type of mixed farming with crop, fisheries, livestock, and forestry-related activities (Islam and Ahmed 2004; Warrick and Ahmad 2012). Average cropping intensity in the exposed coastal districts is 192% (Nasim et al. 2017). Coastal cropping patterns can be highly diverse even within a small geographical area (Shahidullah et al. 2006). Coastal farming systems can be seen as a mixture of coastal artisanal fish farming systems and rice farming systems (Dixon et al. 2001). Besides the dominant crop rice, more than 75% of shrimp culture takes place in the coastal areas. Mixed rice-livestock-fish farming and alternate rice-shrimp farming are also practiced in these areas (Ahmed 2013; Aravindakshan et al. 2020; Kabir et al. 2020; Warrick and Ahmad 2012). Similar to the mainland agriculture, the coastal areas also have three cropping seasons, which are pre-monsoon (kharif-I/aus rice, dry and hot summer extending from March to June), monsoon (kharif-II/aman rice, rainy and cooler summer extending from July to October), and winter (rabi/boro rice, dry season extending from November to February) (BBS 2017; Hofer and Messerli 2006; MOEF 2005). However, November–May is usually considered a dry season and July–September a wet season (Dasgupta et al. 2015).

In the coastal areas, average temperature and annual rainfall during 1988–2017 were 26.02 °C and 289 cm, respectively. Five-year running averages of 2013–2017 and 1998–2002 revealed that temperature had increased and rainfall had mostly decreased in the coastal part of Bangladesh (Hasan and Kumar 2020b). Salinity issues prevail in 62.5% of the coastal lands (SRDI 2010). Many of the coastal areas, particularly Khulna, Bagerhat, and Patuakhali districts, show soil salinity below 4 dS/m during wet months that exceeds 4 dS/m during dry months, hindering the growth and development of rice plants (Dasgupta et al. 2015; Lázár et al. 2015; Saleque et al. 2005). As an adaptive response, the coastal farmers practice brackish water shrimp farming during mid-February/March to mid-August and rice farming during mid-August to mid-January when freshwater becomes available through monsoon rainfall (Kabir et al. 2020). Freshwater flushes out salt from the soil, thus decreasing the salt concentration. One-millimeter increase in monthly rainfall can decrease soil salinity by 0.003 dS/m through dilution effect (Dasgupta et al. 2015). However, all farmers are not adequately adaptive. Only one-fifth of the coastal farmers showed a fair extent of resilience to environmental shocks and stresses (Roy et al. 2019). The better they can understand the factors affecting their farming systems, the easier will be their adaptive measures (Adger et al. 2003; Howe et al. 2014; Schlüter et al. 2017).

Coastal agroecology was reported to have a lower agricultural production efficiency compared with mainland agriculture in Bangladesh (Rahman and Anik 2020). Decreased biodiversity of aquatic system in a south-west coastal district (Satkhira) has been mentioned by Hossain et al. (2018). Unpredictable weather pattern and shortage of dry season irrigation water constitute the major production risks in the rice-based farming systems in Khulna (Kabir et al. 2019). Climate change–induced coastal inundation, flooding, and soil salinity had hampered their farm productivity over the past decade (Hasan and Kumar 2020c). Such environmental changes had largely influenced them to change their farm management practices, such as changes in crop varieties, livestock and fisheries breeds, planting and harvesting time, and intercultural operations (Hasan and Kumar 2020a).

Existing literature is much focused on adaptation; therefore, changes in farming systems under climate change are poorly understood (e.g. Aryal et al. 2020; Islam et al. 2019; Islam et al. 2020; Jordan 2020; Kabir et al. 2017). Aryal et al. (2020) found that climate variability had increased the risk of crop and livestock diseases. Farmers had to change farm management, use savings and borrowed funds, reduce food consumption, perform off-farm activities, and seek external assistance to overcome these risks. Increased vegetable cultivation with a decrease in food crop production is also a part of adaptation strategy in the coastal areas (Hasnat et al. 2016). Islam et al. (2019) described the shrimp farmers' adaptation strategies to climate change in Satkhira, Khulna, and Bagerhat districts. The strategies included increasing the pond depth, providing shade, strengthening the embankment, and fencing around the pond. Ahmed et al. (2017) looked at how shrimp cultivation deteriorates mangrove forests and triggers blue carbon emission. In the central coastal districts (Patuakhali and Barisal), Aravindakshan et al. (2020) examined the 20-year panel data on agricultural households to explore the trajectory of coastal farming systems. They found that the heterogenous mixture of rice-livestock-aquaculture farming systems had steadily transformed into more homogenous farming systems with decreased livestock and increased aquaculture, pulse crops, and off-farm activities.

A functional policy instrument to maintain agricultural sustainability in a changing climate requires information on how stakeholders perceive the causes of changes in farming systems. Farmers are the starting level stakeholders, and farming system level is the most critical platform to intervene. At this level, impacts of climate change are felt most severely, and much of the adaptation and mitigation activities are actively undertaken by the farmers (Hayman et al. 2012). Changes in individual crops due to climate change cannot provide sufficient understanding of the overall impacts of climate change on the farm as a system (Habtemariam et al. 2017). The practice of a farm enterprise, which can increase with a decrease in another enterprise by the farmers, is determined by its relative profitability influenced by climatic and non-climatic factors. Therefore, the whole-farm approach seems more useful to capture a holistic view of the causes of changes in coastal farming systems.

The aforementioned background demonstrates that changes in coastal farming systems (e.g., increasing or decreasing crops, livestock, fisheries, or forestry) driven by climatic and non-climatic factors along the entire coastal regions of Bangladesh are not clear. Therefore, the specific objectives of this study were to determine the coastal farming types, whether these were subsistence, semi-subsistence, or commercial; to examine the perceived changes in farming systems over the past 10 years compared with the previous decade; to describe the perceived causes of the changes in farming systems; and to highlight the relative importance of the factors that influence their perception of the causes of changes in their farming systems. The findings of this study would help development practitioners and researchers understand the existing farming systems, changes in the farming systems, and farmers' perceptions of causes of changes in their farming systems, to provide pragmatic policy instruments for coastal agricultural sustainability.

Methodology

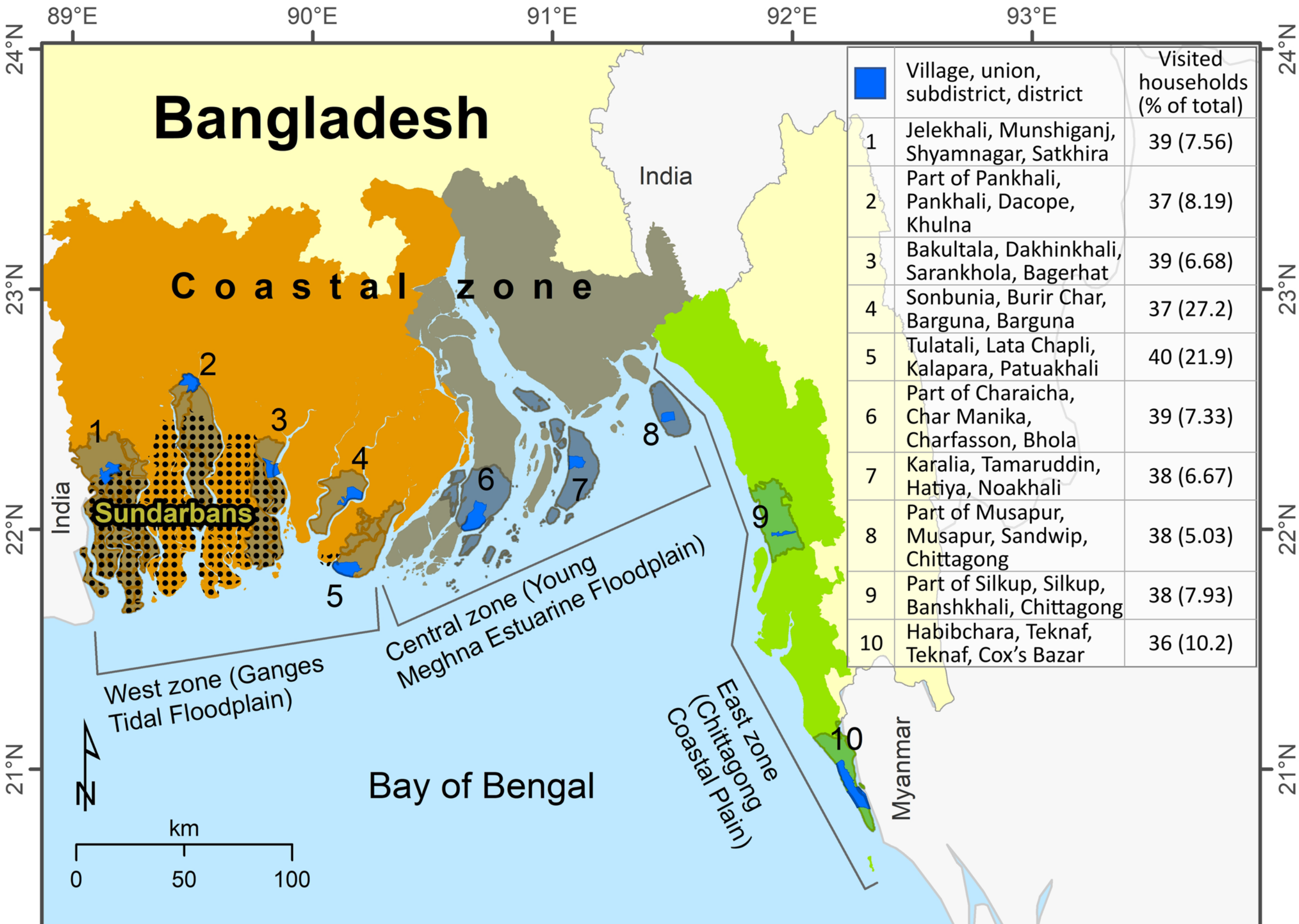
Study areas

The study area was spread along the entire coastal belt of Bangladesh (Fig. 1). The selected subdistricts are grouped into three distinct coastal agroecological zones, namely Ganges Tidal Floodplain (west zone), Young Meghna Estuarine Floodplain (central zone), and Chittagong Coastal Plain (east zone) (Ahmed and Hussain 2009). These three zones are ecologically different and have distinct land use patterns. The western zone has the world's largest mangrove forest, and rice is grown here mostly under rainfed conditions. Double and triple–cropped areas are commonly found in the eastern coastal areas. In Khulna (west coastal zone), rice crop is cultivated in rotation with shrimp, whereas in Cox's Bazar (east coastal zone), salt farming is practiced in a similar rotation with shrimp (Warrick and Ahmad 2012). Figure 1 shows that variations in average temperatures are small but the total rainfall generally decreases from the western to the eastern side. The western coast receives over 100 cm less annual rainfall than the eastern coast (Hasan and Kumar 2020b). This area has a higher number of polders (embanked lands) that promote soil salinity by discharging freshwater to the rivers and trapping saline water from the sea due to tidal surges and embankment failure. Consequently, the western subdistricts along the coastal belts have higher soil salinity than the eastern ones. However, the farmers can sometime bring saline water into the crop fields for saltwater shrimp culture (Dasgupta et al. 2014; Mainuddin et al. 2021; Tareq et al. 2018).

In the study areas, the recent (2013–2017) average temperature was found to be higher than that of the past (1998–2002) average with an annual warming of 0.013 °C. The temperature increase in the summer was higher than in the winter. However, rainfall had decreasing trends except in Hatiya and Banshkhali. The onset of rainfall had been delayed as opined by the farmers, which was consistent with the observed climate data (Hasan and Kumar 2020b). Therefore, climate change and variability were observed in the study areas.

Despite the variations in climatic and ecological conditions across the coastal areas, crop choices of the farmers are mostly determined by the soil salinity. Figure 2 shows a summary of 40 broad cropping patterns identified by SRDI (2010) in four coastal districts, namely Khulna, Patuakhali, Noakhali, and Chittagong. This illustrates that rice occupies a larger share of coastal agricultural lands. The monsoon season has a higher extent of rice cultivation than the dry winter and pre-monsoon. Rice cultivation is found in the lower land with higher level of soil salinity within each of the seasons. Rice cultivation in the rainy season is less affected by salinity because rainwater dilutes and reduces soil salinity to a tolerable limit for rice plant growth and development (Haque 2006). About 38% of the land is used for rice cultivation and an equivalent portion of the total cropped area is kept fallow. Fallow lands are usually found to a greater extent in areas where the salinity levels are higher.

Shrimp culture and salt farming are higher in the areas and seasons with higher salinity levels. However, the salt



	Village, union, subdistrict, district	Visited households (% of total)
1	Jelekhali, Munshiganj, Shyamnagar, Satkhira	39 (7.56)
2	Part of Pankhali, Pankhali, Dacope, Khulna	37 (8.19)
3	Bakultala, Dakhinkhali, Sarankhola, Bagerhat	39 (6.68)
4	Sonbunia, Burir Char, Barguna, Barguna	37 (27.2)
5	Tulatali, Lata Chapli, Kalapara, Patuakhali	40 (21.9)
6	Part of Charaicha, Char Manika, Charfasson, Bhola	39 (7.33)
7	Karalia, Tamaruddin, Hatiya, Noakhali	38 (6.67)
8	Part of Musapur, Musapur, Sandwip, Chittagong	38 (5.03)
9	Part of Silkup, Silkup, Banshkhali, Chittagong	38 (7.93)
10	Habibchara, Teknaf, Teknaf, Cox's Bazar	36 (10.2)

Map Labels	Location	Annual temperature (°C)	Summer temperature (°C)	Winter temperature (°C)	Annual rainfall (cm)	Areas with salinity (%)	Salinity level (dS/m)
1	Shyamnagar	26.16	29.23	23.08	182.3	80.93	>16
2	Dacope	26.17	29.19	23.15	185.4	79.70	>16
3	Sarankhola	26.19	29.00	23.37	220.9	61.80	4.1–8
4	Barguna	26.06	28.86	23.25	275.5	62.11	4.1–8
5	Kalapara	26.08	28.88	23.27	285.9	73.59	4.1–8
6	Charfasson	25.86	28.61	23.10	279.4	39.02	2.0–4
7	Hatiya	25.74	28.31	23.16	327.1	22.01	8.1–12
8	Sandwip	25.94	28.44	23.42	384.3	28.57	12.1–16
9	Banshkhali	25.94	28.17	23.70	314.0	31.12	2.0–4
10	Teknaf	26.06	27.96	24.14	438.0	16.70	12.1–16

Fig. 1 Map showing the study areas in the coastal zones of Bangladesh. A summary of the climatic and ecological indicators is provided in the legend table. Temperature and rainfall values were calculated based on 1988–2017 data collected from the Bangladesh Meteorological Department, and salinity values were based on SRDI (2010)

collection is a winter season farming, which is concentrated in the eastern coast (Cox's Bazar and Chittagong) of Bangladesh (MOI 2016). Vegetables and other non-rice crops (e.g., chickpea, chilli, felon, grass pea, groundnut, khesari, lentil, methi, mungbean, mustard, sesame, soybean, sunflower, sweet potato, til, watermelon, and wheat) are cultivated mostly in the winter. These are also found less in areas with greater levels of salinity. Major livelihood options in

Fig. 2 Seasonal use of coastal agricultural land with various salinity levels in Khulna, Patuakhali, Noakhali, and Chittagong districts based on the data obtained from SRDI (2010). Component-wise land use percentages are shown in the facet headings, and seasonal distribution of land use for each of the components is presented inside the panels

the coastal areas include fisheries activities, such as freshwater prawn, saltwater shrimp, and fish culture. However, the shrimp farming only occupies 8.7% of the total cropped areas. Other land use components include the natural and planted mangrove forest and other crops, such as jute, maize, and sugarcane.

Sampling and data collection

The total number of visited villages was ten (as mentioned in Fig. 1) and had a total of 4560 households (BBS 2011). Households in the selected villages were mostly involved in farming activities. The villages were selected according to the suggestions obtained from respective subdistrict agricultural officers who considered agricultural importance of the potential areas to be visited. For the larger villages that had more than 800 households, we selected only a part of each of those villages for household visits. The sample size was calculated using Eq. (1) provided by Krejcie and Morgan (1970), where n is the sample size, N is the population (4560), χ^2 is 3.841 (at 95% confidence interval with one degree of freedom), P is 0.50 (population proportion), which results in maximum variance and sample size, and d is 0.05 (margin of error) recommended by Bartlett II et al. (2001).

$$n = \frac{\chi^2 NP(1-P)}{d^2(N-1) + \chi^2 P(1-P)} \quad (1)$$

The calculated sample size (n) was 355. We visited randomly selected 40 households from each of the ten villages. For systematic randomization, every i^{th} household (i = number of total households in a visiting site ÷ 40) was selected for interview. Depending on the availability and willingness of the respondent farmers, we interviewed 36 to 40 farmers from the selected households from each of the villages. Thus, we interviewed 381 (8.36%) of the total households in the selected villages. The number of sampled farmers in each of the villages has been shown in Fig. 1. Household surveys were administered to collect both quantitative and qualitative information during September–October 2018 using a structured interview schedule (Appendix 2. Interview schedule).

All categories of farmers (small, medium, and large) were included in the sample to get the full picture about the causes of changes in farming systems in the study areas. However, at least 5 years of farming experience of the farmers after turning adult (18 years old) was a precondition to be selected for interviews. Thus, a minimum of 23 years was the age limit of the farmer respondents. Some of the perception-related questions sought information on the changes in farming systems and climatic variables during 2009–2018 compared to 1999–1998. For this time span, a respondent farmers should have at least 20 years of farming experience (38 years of age). The time frame of the previous decade could not be recalled by many of the respondents. In the sample, 28% of the farmers were below 38 years of age. Exclusion of this young segment of farmers would result in a loss of valuable information on the young farmers' perception of farming systems and climate change. Therefore, we interviewed these farmers together with older family members during the household visits to obtain more valid information on the changes.

In this study, the dependent variable was whether climate change had caused any changes in the farming systems as perceived by the farmers. We asked the farmers to select what farming enterprises (out of seven items, namely rice, non-rice crops, vegetables, fruits, livestock, fisheries, and forestry) they had operated in their farms. Major examples of rice crops included aus, aman, and boro rice; non-rice crops included wheat, maize, legumes, potato, sunflower, and watermelon; vegetables included spinach, okra, eggplant, gourds, beans, and radish; fruits included mango, jackfruit, coconut, banana, lychee, guava, and papaya; livestock included cows, ox, buffalo, goat, sheep, ducks, and chickens; fisheries included tilapia, pangasius (basa), China puti, carps, rohu, koi, and shrimps; and forestry included raintree, acacia, and mahogany.

The change in farming systems was measured by the number of the farm enterprises that had been changed over the past 10 years compared with the previous decade. The respondent farmers mentioned whether their households had recently started any of these enterprises or had been cultivating for more than 10 years; whether they had increased, decreased, or kept unchanged the size of farming enterprises; and whether they had operated these farming practices for consumption, sale, or both purposes. The farmers indicated why they had changed their farming enterprises (if any). We presented three possible answers to this query — "yes" (due to climatic reasons, such as changes in rainfall, temperature, salinity and cyclone), "no" (due to non-climatic reasons, such as market demand and input availability), and "not sure" (due to unknown reasons). These three responses were combined into a dummy variable with two categories "yes" and "no" ("no" and "not sure") to facilitate the application of different machine learning algorithms.

As the causes of changes in coastal farming systems were studied based on the farmers' perception, which is a psychological variable (Kalat 2016) and influenced by individuals' geographical and social locations, experience and availability heuristic (Foguesatto et al. 2018; Hasan and Kumar 2019; Kais and Islam 2019). Furthermore, socioeconomic and personal characteristics of people determine their social locations (Henslin 2017). Therefore, the interviews were conducted to seek information on the sampled farmers' age (years), education (years of formal schooling), family size (number of household members living and eating together), farmland (cultivated area in hectares), house roof (whether the roof was made of concrete, tin or leaves/straw), credit received (whether any agricultural loans were received), climate change awareness (whether the farmers had heard of climate change before the interview), and perception of temperature, rainfall, and cyclone (increased, decreased, or unchanged).

Statistical analysis

We used descriptive statistics (e.g., mean, standard deviation, and frequency distribution) to summarize the farmers' attributes. To conclude the relationship between the socioeconomic characteristics of the farmers (influencing factors) and their perception of the causes of changes in farming systems, we had to select an appropriate statistical analysis that can better explain the data. While linear regression is not suitable for qualitative response, there exists a wide range of statistical techniques for this task of classification, such as logistic regressions and machine learning algorithms (James et al. 2013). Machine learning techniques are being increasingly used in social science for their better predictive accuracy (Hofman et al. 2017). Therefore, to select the best model to characterize the farmers of the two categories (who perceived climate change had caused changes in farming systems and who did not), we tested logistic regression (GLM), k-nearest neighbors (KNN), linear discriminant analysis (LDA), quadratic discriminant analysis (QDA), random forest (RF), gradient boosting machine (GBM), support vector machine with the polynomial kernel (SVMpol) and radial kernel (SVMrad), and neural network (NNET) (Hastie et al. 2009; James et al. 2013). As shown in Appendix Table 4, the best performing model was selected based on the test error rates, sensitivity, specificity, precision, negative predictive value, accuracy, and Kappa statistics (Altman and Bland 1994a, b; Kuhn 2008, 2020). For data analysis and visualization, we used R (version 3.6.3) statistical software (R Core Team 2019) in RStudio (version

1.2.5033) with the help of several additional packages, such as *tidyverse* (Wickham et al. 2019), *caret* (Kuhn 2020), *randomForestSRC* (Ishwaran and Kogalur 2019; Ishwaran and Kogalur 2007; Ishwaran et al. 2008), *ggpubr* (Kassambara 2020), and *gridExtra* (Auguie 2017).

Results

Types and purposes of farming in the coastal areas

Farmers in the study areas performed mixed farming systems that comprised of multiple components of crops, livestock, fisheries, and forestry. Along with the farming activities, one or more non-farm activities were also found among 69% of the farmers (Hasan and Kumar 2020b). The major purposes of their farming practices were consumption, sale, or both consumption and sale. Information contained in Fig. 3 reveals that a great majority (92%) of the farmers cultivated rice during 1999–2018 mainly for consumption, and consumption and sale. Compared with other farming enterprises, rice had the highest fraction (96%) of the farmers practicing its cultivation. The respondent farmers produced non-rice crops, such as legumes, maize, potato, sunflower, and watermelon, mainly for consumption and sale. Vegetables and fruits were cultivated in the homestead areas mainly for consumption rather than selling. A similar trend of practicing fisheries and forestry was observed in the study areas. However, shrimp culture was an exception that was practiced mainly for commercial purposes. Among the farmers, 30% raised livestock and cattle for selling, 13% for consumption, and 36% for both consumption and sale.

Perceived changes in farming systems

The farmers in the study areas were farming-dominated as shown in Table 1. Their participation was not uniform across various farming enterprises. An overwhelming majority (95.54%) of the farmers were previously involved in rice cultivation, which had decreased to 93.44% in recent years. Participation in fish farming was the lowest (67.98%) compared with other farming enterprises in the previous decade.

Table 1 Percentages of farmers (n = 381) practicing different farm enterprises

Farm enterprises	Previously practiced (1999–2008)	Currently practicing (2009–2018)
Rice	95.54	93.44
Non-rice	70.08	70.08
Vegetables	83.73	83.46
Fruits	82.15	84.78
Livestock	74.80	70.34
Fisheries	67.98	69.29
Forestry	76.90	78.22

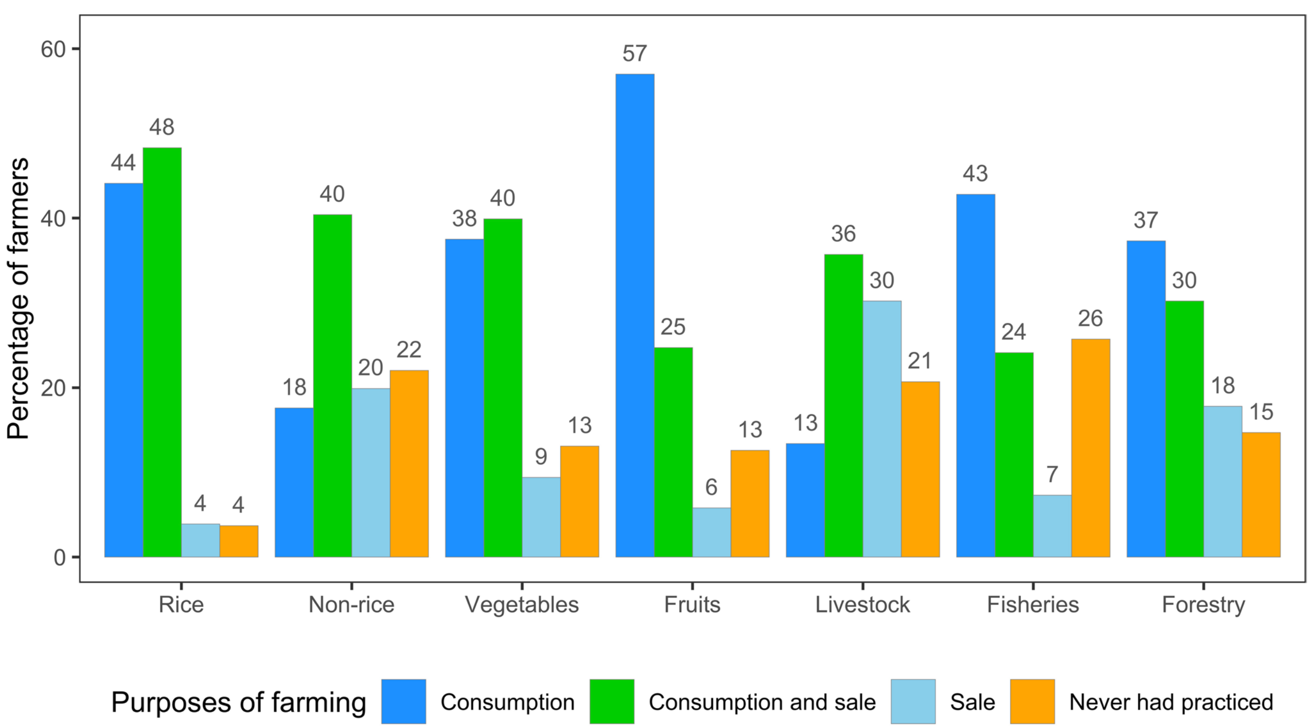


Fig. 3 Major purposes of farming activities practiced by the sampled farmers

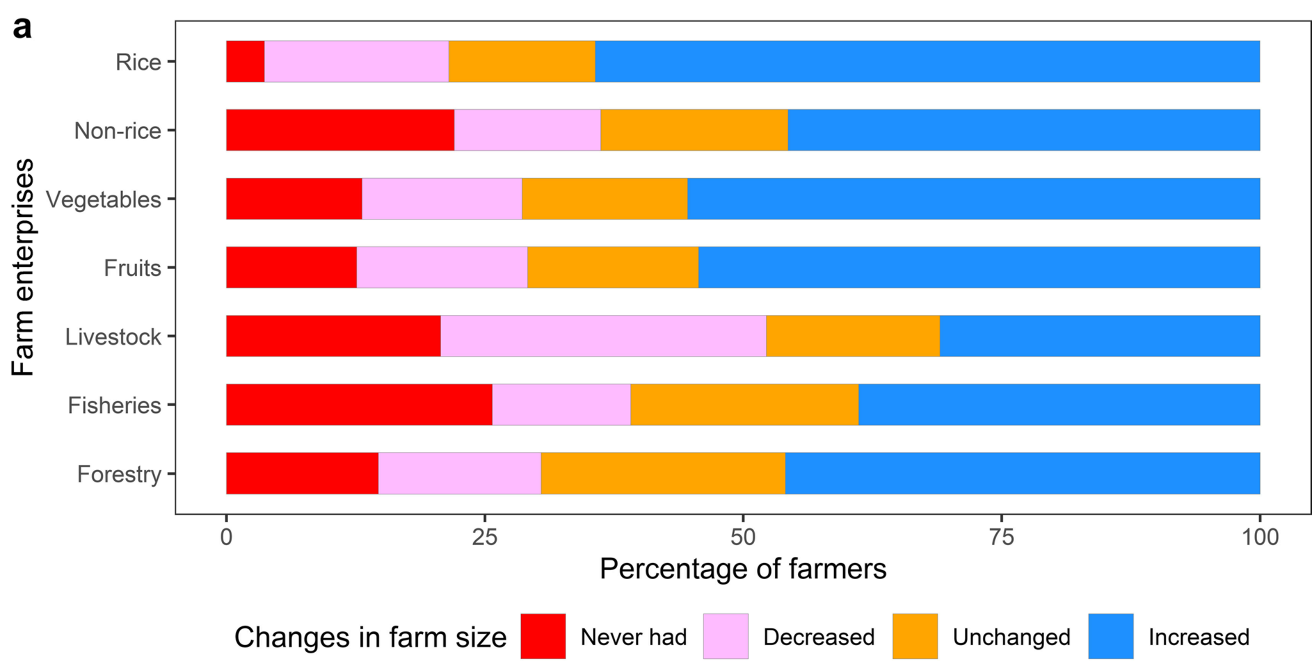
In the recent decade, the lowest participation (70.08%) was found in the cultivation of non-rice crops. Compared to the past, higher proportions of the farmers were involved in fruits, forestry, and fish farming. On the contrary, decreases in the number of farmers were found in rice, vegetables, and livestock farming. Rice farming was always in the top position based on the number of farmers engaged with the farming activities. Figure 4a shows that 64% of the farmers had increased rice farm size compared with the last 10 years, whereas such an increase was only among 31% for livestock rearing. On average, about half (48%) of the farmers had increased their farm size while 18% of them had kept their farming systems unchanged compared with the previous decade. Most (82%) of the farmers had changed between five and seven farming enterprises in their farming systems (Fig. 4b). We found only 2 out of 381 farmers who had not changed any of their farm components over the last 10 years.

Perceived causes of the changes in farming systems

The interviewed farmers mentioned why they had changed their farming systems, and their responses were classified into three categories, namely climate change (e.g., changes in temperature, rainfall, flood, drought, cyclone, or salinity), non-climatic factors (e.g., changes in market demand, price, or input unavailability), and unsure (when they could not decide on any of the climatic and non-climatic causes). Among the farmers, 64% perceived that climate change was responsible for their changes in farming systems (Fig. 5). There were 29% of the farmers who thought that they had changed their farming systems due to non-climatic factors. There were distinct spatial variations in the proportions of the farmers who claimed climate change to be responsible for their changes in farming systems. On average, higher percentages ($M = 73\%$) of the farmers in the western coast, compared with 63% in the central coast and 41% in the eastern coast, believed that climate change had forced them to change their farming systems. The highest level of consensus of the causes of changes in farming systems was observed in Sarankhola (85%) while the lowest was in Teknaf (36%).

Factors influencing farmers' perception of causes of changes in farming systems

Eleven socioeconomic characteristics were used as responsible factors to classify the farmers into two groups, namely



b

Number of changed enterprises	0	1	2	3	4	5	6	7
Frequency of farmers	2	1	9	20	36	69	94	150

Fig. 4 Changes in farming systems in terms (**a**) farm size and (**b**) number of changed enterprises over the last decade (2009–2018) compared with the previous decade (1999–2008)

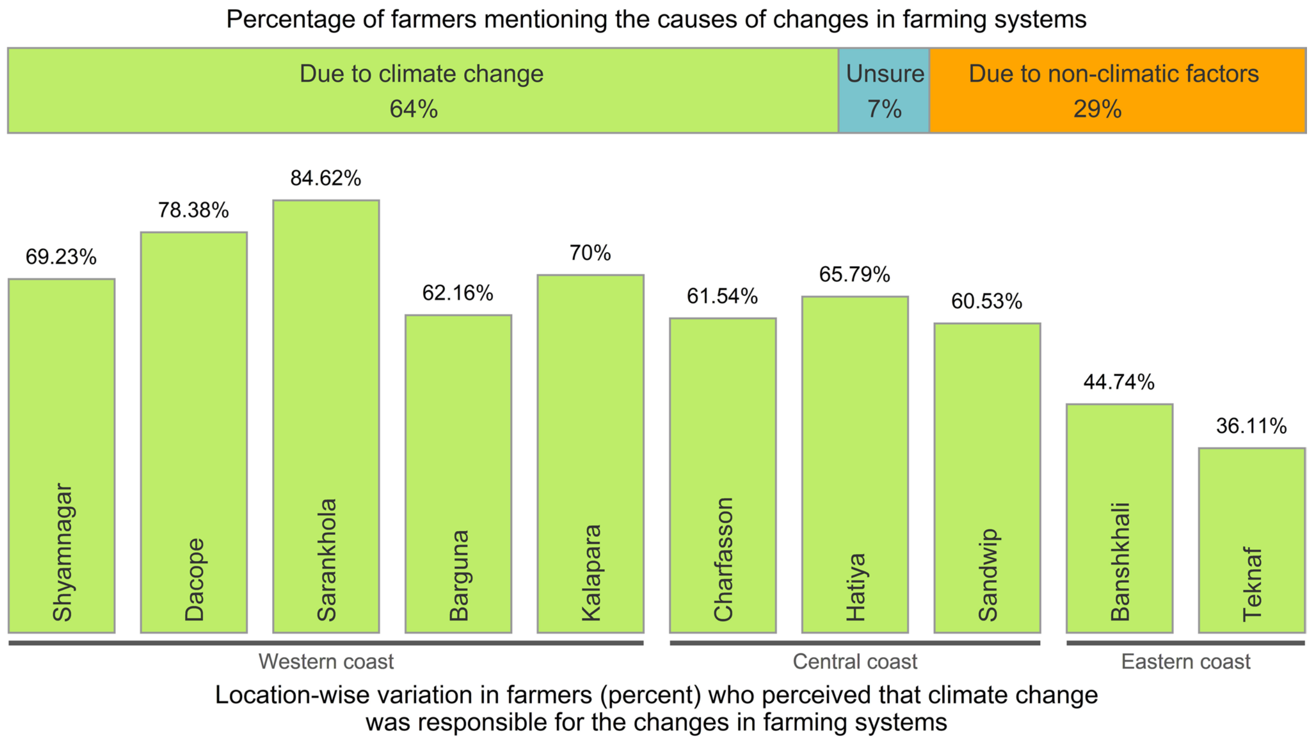


Fig. 5 Perceived causes of the changes in farming systems and their spatial variation

"yes" (who perceived that climate change was responsible for changes in farming systems) and "no" (who perceived that they had changed their farming systems due to non-climatic or unknown factors). Descriptive statistics of these predictors in Table 2 show that the average age of the farmers in the "yes" group of perception was 1.5 years higher than that of the "no" group. Years of formal education of the farmers varied from 0 to 18 years and they had, on average, a primary level (5 years of schooling) of education. A broad range (2 to 17) of family size was observed among the interviewed farmers with an average of 5.88 family members. A small area of land ($M = 0.70$ ha) was cultivated by the farmers with a range between 0 and 17 ha. We asked the farmers what farming enterprises they had changed over the past 10 years compared with the previous decade. There were seven main categories of farming enterprises, namely rice, non-rice crops, vegetables, fruits, livestock, fisheries, and forestry, for which we sought information. The farmers had changed between 0 and 7 of these farming enterprises in terms of farm size for at least 1 year over the last decade.

Most of the farmers (87.5%) had tin-made house roofs, about 1 in 10 was very poor with house roofs made of leaves/straw, and a very small fraction (2.36%) of them was rich having concrete houses. Awareness of climate change was substantially higher (49.1% compared with 21.8%) among the farmers who perceived that climate change had caused changes in their farming systems. Among the farmers in the "yes" perception group, 61.7% thought that temperature had increased, 52.5% stated that rainfall had not increased, and 39.6% mentioned that the frequency of cyclones had increased over the past 10 years compared with the decade before. The percentages of the farmers in the "no" perception group were lower in these cases.

To understand the relative influence of these factors on the perception of causes of the changes in farming systems, we used the random forest (RF) classification model because of its best classification performance (Table 3 and details in Appendix Fig. 7). The random forest model outperformed other models, with the lowest test error rate (0.37) and the highest kappa statistic (0.76) compared with GLM, KNN, LDA, QDA, GBM, SVMpol, SVMrad, and NNET. According to Denisko and Hoffman (2018), random forest algorithm minimizes heterogeneity of the training data classes and sets a decision rule to classify new data with a high predictive performance. In addition, this machine learning technique provides relative feature importance to classify the subjects. Therefore, we selected the random forest classification technique to classify the farmers into two groups — who mentioned that their farming systems had changed due to climate change and who mentioned that non-climatic factors were responsible for changes in their farming systems.

The random forest model classified the farmers into the perception groups with 89.8% accuracy with 95% *CI* of [86.2%, 92.6%]. Variance importance plot (Fig. 6a) shows

Table 2 Summary of farmers' characteristics

Characteristics	Range or categories	Mean ± SD for continuous or percentage of farmers for categorical variables	
		"Yes" perception*	"No" perception*
Age (years)	24–90	47.3 ± 12.9	45.8 ± 13.5
Education (years)	0–18	5.38 ± 4.11	4.12 ± 4.20
Family size (number)	2–17	5.62 ± 2.14	6.13 ± 2.47
Cultivated land (hectares)	0–5.34	0.76 ± 0.73	0.63 ± 0.61
Changes in farming systems (number of farm enterprises)	0–7	5.80 ± 1.38	5.60 ± 1.46
House roof materials	Leaves/straw	4.99	5.25
	Tin	57.0	30.5
	Concrete	1.57	0.79
Credit received	No	52.8	32.6
	Yes	10.8	3.94
Climate change awareness	No and unsure	14.4	14.7
	Yes	49.1	21.8
Temperature perception	Not increased	1.84	2.62
	Increased	61.7	33.9
Rainfall perception	Not increased	52.5	27.6
	Increased	11.0	8.92
Cyclone perception	Not increased	23.9	17.9
	Increased	39.6	18.6

*Perception groups: "yes" indicates the group of farmers who mentioned that climate change had caused changes in their farming systems and "no" represents the group of farmers who either perceived climate change had not caused any changes in their farming systems or were unsure of any of the causes

Table 3 Cross-validated error statistics of different models

Models	Test error	Sensitivity	Specificity	Precision	NPV	Accuracy	Kappa
GLM	0.40	0.87	0.32	0.69	0.60	0.67	0.22
KNN	0.41	0.95	0.20	0.67	0.70	0.68	0.18
LDA	0.40	0.87	0.33	0.69	0.59	0.67	0.22
QDA	0.38	0.87	0.42	0.73	0.66	0.71	0.32
RF	0.37	1.00	0.72	0.86	1.00	0.90	0.76
GBM	0.39	0.87	0.60	0.79	0.73	0.77	0.49
SVMpol	0.39	0.96	0.40	0.74	0.85	0.76	0.40
SVMrad	0.40	0.96	0.37	0.73	0.85	0.75	0.38
NNET	0.37	0.91	0.27	0.69	0.63	0.68	0.21

that six variables, namely cultivated land, age, education, family size, changes in farming systems, and climate change awareness could influence the overall predicted classification accuracy by 83%. The remaining variables influenced the overall accuracy by 17%. Partial dependency plots (Fig. 6b–f) illustrate the non-linear nature of the effects of the predictor variables on the perception that climate change had induced changes in the farming systems. Age of the farmers was positively correlated with the perception of causes of changes in the farming systems. Though the effect of age was more distinct among farmers below 50 years old, it had slightly declined for the farmers over 60 years old. A similar positive effect was found in the case of education, which reached a peak at 10 years of formal education.

Family size of the farmers negatively affected their perception almost in a linear fashion. For a small family with only two members, the probability of accepting the claim of climate change which had caused changes in farming systems was 68.6%, which decreased to 57.6% for a larger family of size 17. Area of cultivated land showed an exponential increasing effect on the probability of "yes" up to a certain level (< 1 ha) after which the probability remained almost constant at 67%. Three distinct phases of influence of actual changes in farming systems on the perception of causes of changes in the farming systems are depicted in Fig. 6f. In the first phase (0 to 2), the probability was increasing; in the

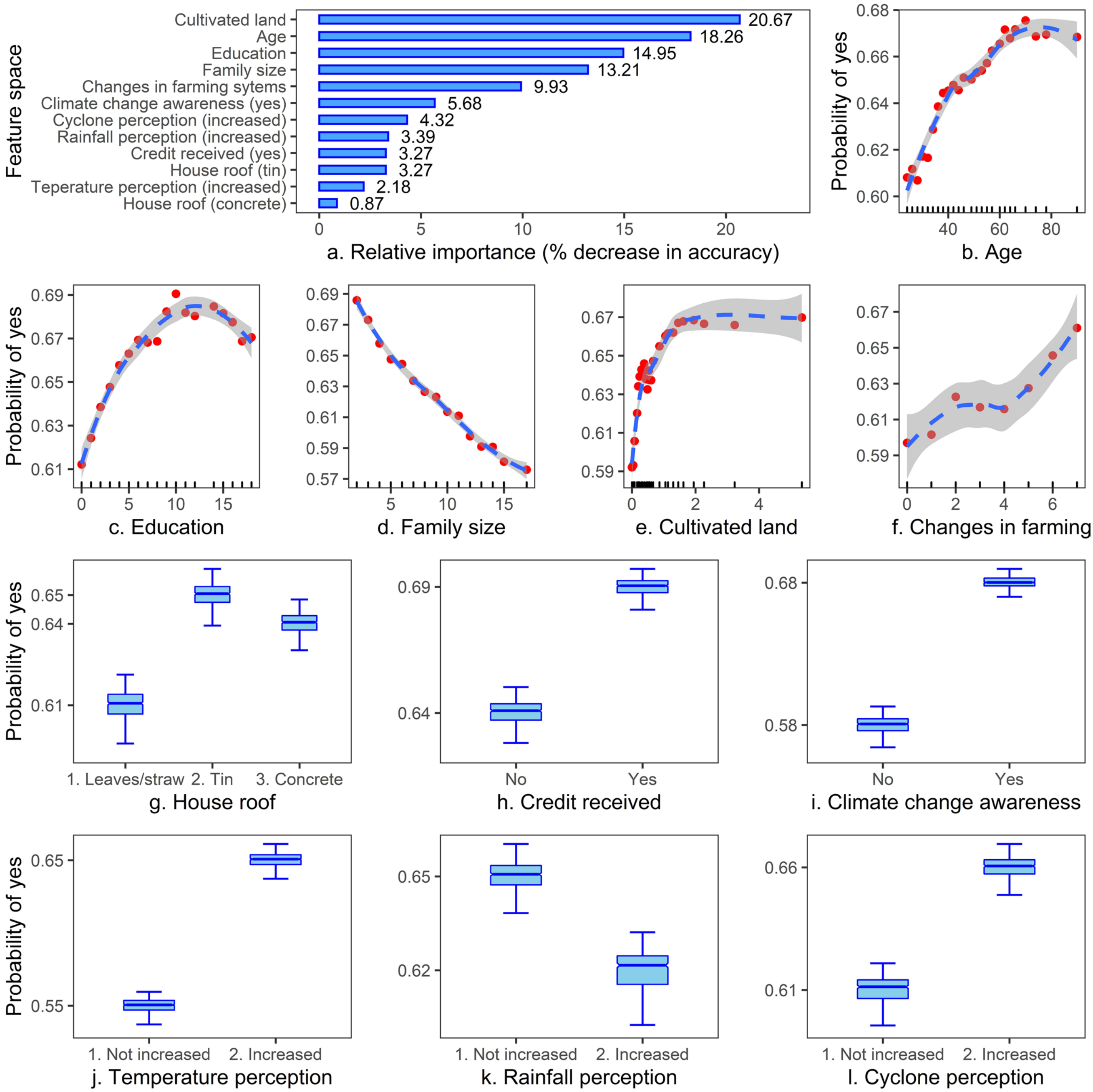


Fig. 6 Factors affecting perception of causes of changes in farming systems. **a** Random forest classification model based relative importance of the predictors of farmer perceptions of causes of changes in farming systems. **b–l** Partial dependency plots of individual predictors illustrating the effects of different levels (unique values) of the respective variables on the probability of perception that climate change had caused changes in farming systems. Gray bands **b–f** for continuous variables (and error bars **g–l** for categorical variables) in the partial dependency plots show 95% confidence intervals of the probabilities. **b–f** Rug lines along x-axes show sample distributions. **g–l** Group means appear along *y*-axes

second phase (3 to 4), it remained around 62%; and in the third phase (5 to 7), it had increased again up to 66%.

The probability of agreeing that climate change had induced changes in the farming systems was 4% higher among the farmers having tin-made house roofs than that of the farmers having house roofs made of leaves/straw. The farmers who received credit for agricultural activities had 5% higher probability of perception that climate change had caused changes in their farming systems. Climate change awareness had a positive influence on the probability in a way that the farmers who had heard of climate change before the interview had 68% probability of accepting the claim of climate change had caused changes in their farming systems compared with 58% probability of their counterparts. The farmers who thought that temperature and cyclone had increased had a greater probability of perception that climate change had changed their farming systems. However, the perception of increasing rainfall was negatively correlated with the probability of claiming climate change as a cause of changes in the farming systems.

Discussion

Findings of this study suggest that the farmers had been operating mainly semi-subsistence type of mixed farming activities. The share of consumption dominated over the share of selling of the farm products. However, purposes of non-rice crop cultivation and livestock rearing were more prevalent for the sale than the consumption. Such patterns of farming activities imply that the commercialization of farming among the farmers was very rare. They received income from the amount of farm products that was left after being consumed. The choice of their farming activities was mostly determined by their household necessities conditioned by climatic suitability. Over the past 10 years (2009–2018), the number of farmers practicing rice, vegetables, and livestock farming had decreased, while their participation in fisheries, forestry, and fruit farming had increased. Switching from rice and vegetables to shrimp culture in saline water is an indication that increased soil salinity had influenced this transition. Orchard and forestry-related activities do not need intensive daily care. This gives them extra time to take part in non-farm income generating activities. Two things we should keep in mind – rice is the staple food for Bangladeshi people and livestock is considered savings for the poor people (Hasan et al. 2018).

It may sound optimistic that the farmers were found to be moving towards greater commercialization (decreasing rice and vegetable while increasing forestry and orchard). This does not seem to be their deliberate choice, rather they are being forced to accept this transition due to climatic and non-climatic factors. Farmlands and grazing lands are decreasing in the coastal areas due to salinity intrusion (Roy et al. 2020). On the contrary, rice cultivation is losing its profitability due to unstable market price, especially during harvest (Sayeed and Yunus 2018). Nearly one-third of the farmers that indicated non-climatic factors were responsible for changing their farming systems. This has important implications for appropriate management of the non-climatic factors, such as market stability, input prices, farm labor, and land tenure. However, changes in farming practices were mostly influenced by climatic factors as perceived by a greater proportion (64%) of the farmers. Previous studies also reported that 64% of the farmers claimed that climate change had impacted their farm productivity (Hasan and Kumar 2020c) and 67% of them had to alter their farm management practices to cope with climate change (Hasan and Kumar 2020a). This mimics the assertion that farming systems are configured by climate (Hayman et al. 2012) that directly leads to the changes in coastal agricultural systems (Hasnat et al. 2016).

Farmers' perception of the causes of the changes in their farming systems varied depending on their geographical locations and socio-economic characteristics. The trajectory of cyclones and intensity of soil salinity are different in the eastern and western parts of the coast. South-western Bangladesh was hit by three devastating cyclones, namely *Sidr* in 2007 (GoB 2008), *Aila* in 2009 (IFRC 2009), and *Mahasen* in 2013 (Reliefweb 2013). Three other major cyclones (*Komen* in 2015, *Roanu* in 2016, and *Mora* in 2017) mainly impacted south and south-eastern coastal areas of Bangladesh (EM-DAT 2021). The cyclonic storm surges hamper agricultural production by bringing saline water into the crop fields through breaching the polder embankments, which are mostly located in the western coasts (Brammer 2016; Dasgupta et al. 2014). These recent experiences and availability heuristic (Foguesatto et al. 2018; Kalat 2016) could be the reason why farmers in the western coasts had agreed to a greater extent that climate change had impacted their farming choices compared to the eastern coasts.

Socio-economic characteristics of the farmers represent their livelihood capitals (Messer and Townsley 2003). This study reveals that the farming activities were operated by relatively older-aged farmers with primary level of education. Although quite a high number of active manpower could be expected from their larger families, many young family members had not assumed farming responsibilities yet. Small area of cultivated land and low level of affiliation with agricultural association could make their adaptation efforts difficult. Besides, their weak housing infrastructures were prone to be damaged by cyclone and tidal surges. However, the use of mobile phone is common for communicating farming information and early warning system. In addition to farming, diversified income sources were utilized by more than two-thirds of the farmers. Hasan and Kumar (2020b, c) noted that a majority (64%) of the coastal farmers had contacts with extension agents to get advice on farming activities. Thus, agricultural and livelihood adaptation initiatives would be easier to apply for the coastal farm households.

This study directly supports the theories of perception and behavior (Henslin 2017; Kais and Islam 2019) that the socioeconomic attributes of the farmers had influenced their perception of the causes of changes in the farming systems. The random forest classification model shows that cultivated land, age, education, family size, changes in farming systems, and climate change awareness of the farmers were the most influential factors to shape their perception. All these characteristics, except the family size, had increased the probability of accepting the view that climate change had caused changes in the farming systems. The positively influencing factors have one thing in common, which is the opportunity to learn climatic impacts on farming activities. Such opportunity was better for those farmers who were older in age and had larger cultivated areas, higher level of education, longer involvement with farming, undertaken more changes in farming systems, and greater extent of climate change awareness. The older-aged farmers had longer experience of monitoring weather, rainfall, soil conditions, and input availability on a regular basis for farming decisions. Larger farmlands, greater changes in farming enterprises, and greater formal schooling had motivated and helped them to understand the link between climate change and farming systems.

The family size of the farmers had a negative effect on their perception of the causes of changes in their farming systems. The larger families were usually involved in multiple income sources, such as farming, business, jobs, and day laborers, rather than only agriculture. This could be why their extent of blaming climate change for the changes in their farming practices was less than that of the smaller farm families. Climate change awareness was also an important indicator to explain farmers' perception of the causes of changes in their farming systems. The farmers who had previously heard of climate change had more accurate perception of changes in climatic variables, such as temperature, rainfall, cyclones, and salinity (Hasan and Kumar 2020b). Thus, the findings of this study highlight that the farmers who had a more consistent perception of changes in climatic variables with observed meteorological records had a greater tendency to claim that climate change had motivated them to change their farming systems.

Conclusion

The coastal farmers in the study areas were involved in semi-subsistence type of mixed farming practices, which had been changing in terms of number of farmers and farm size. Their diverse livelihood options were evident from their participation in both farm and non-farm activities. Such adaptive nature of the coastal farmers could be promising for further adaptation planning. The coastal farmers showed a substantial level of perception that climate change had driven them to change their farming systems. The socio-economic factors, geographical variations, and recent experiences of the farmers affected their differentiated perception of the causes of changes in their farming systems. The Department of Agricultural Extension under the Ministry of Agriculture in Bangladesh should target the farmers who are particularly younger and less educated and have larger families and smaller farmlands to provide updated knowledge on climatic impacts on their farming systems. Although the farmers had already started changing their farming systems, co-benefits and trade-offs of these adaptations need to be studied through sustainability and livelihood frameworks. Extension agents should facilitate adaptation actions so that the farmers do not need to reduce or discard any essential enterprises (e.g., rice and livestock) from their farming systems to support their livelihoods. Besides, adverse effects of non-climatic factors, such as input availability and market stability, should be kept to a minimum possible level by government interventions.

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Author contribution MKH and LK: conceptualization; funding acquisition; MKH: Data curation; formal analysis; investigation; methodology; software; visualization; writing – original draft; LK: project administration; resources; supervision; MKH and LK: writing – review & editing.

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Data availability Research data is submitted as a supplementary material.

Code availability We used standard codes from R and its packages as mentioned in the manuscript.

Declarations

Ethics approval Ethical approval of data collection (approval number HE18-216) was obtained from the Human Research Ethics Committee of the Ethics Office, Research Development & Integrity, Research Division, University of New England, Armidale, New South Wales 2351, Australia before data collection from the participants.

Data anonymization and statement of informed consent Interviews and focus group discussions were used to collect data from the farmers. Data has been completely anonymized, and none of the participants are identifiable. Information sheet for the participants were read aloud to inform the participants about research topic, type of questions to be asked, estimated time of interview (20-30 minutes), freedom to withdraw or stop interview anytime and data anonymization. Informed consent was obtained from all participants before starting the interviews and discussions. However, illiterate participants were requested to keep one literate family member or neighbour with each of them during interviews to help the informed consent process. We did not collect informed consents from any legally authorized representatives of participants because the participants were adult, the questions were not physically, religiously, culturally or politically sensitive, and none of them was with a cognitive impairment, an intellectual disability or a mental illness.

Conflict of interest The authors declare no competing interests.

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