LOCAL ENVIRONMENT
2022, VOL. 27, NO. 6, 671–681
https://doi.org/10.1080/13549839.2022.2068139

Routledge
Taylor & Francis Group

RESEARCH ARTICLE

Farm level adaptation to climate change: insight from rice farmers in the coastal region of Bangladesh

Faijul Islam[a], G. M. Monirul Alam[b,c], Rokeya Begum[a], Md Nazirul Islam Sarker[d] and Humnath Bhandari[e]

[a]Department of Agricultural Economics, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh; [b]Faculty of Agricultural Economics and Rural Development, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh; [c]School of Commerce, University of Southern Queensland, Toowoomba, Australia; [d]School of Political Science and Public Administration, Neijiang Normal University, Neijiang, People's Republic of China; [e]International Rice Research Institute (IRRI), Dhaka, Bangladesh.

ABSTRACT

Coastal agriculture and livelihoods worldwide are highly vulnerable to changing climates, and Bangladesh is no exception due to its geophysical location. This paper examines rice farmers' vulnerability, adaptation strategies, and adaptation barriers to managing climate change impacts in the coastal region of Bangladesh. Survey data were collected from 220 randomly selected rice farmers located across two coastal districts of Bangladesh. A multinomial logit model was applied to analyze determinants of adaptation strategies of rice farmers. The results reveal that flood is the main risk to vulnerability, followed by cyclones and storms surges and saline intrusion. The main adaptation strategies are cultivating flood and salinity tolerant rice varieties, direct seeding of rice, supplementary irrigation, cultivation of non-rice crops that have shorter growth duration, and rearing of livestock, poultry, and duck. The econometric analysis shows that factors such as household head's education, household income, farm size, access to information, and extension services significantly influence the choice of adaptation strategies of the rice farmers. We recommend to increase investment in research, training of farmers, and targeted extension services to disseminate climate-smart technologies and information for minimising vulnerability of the farmers.

ARTICLE HISTORY
Received 2 March 2021
Accepted 16 April 2022

KEYWORDS
Bangladesh; rice farmer; climate change; vulnerability; adaptation; coastal region

1. Introduction

Farmers in developing countries are most adversely affected by climate change (IPCC 2014). Bangladesh, only 147,570 km^2 land area in South Asia and a population density of about 1,116 persons/km^2 (World Bank 2018), is regarded as one of the top vulnerable countries to climate change (Alam et al. 2020; IPCC 2014). Extreme climatic hazards such as floods, sea level increase, cyclonic storm surges, riverbank erosion, saline intrusion, and drought present significant risks to the life, livelihoods, and food security of 64% of the farm-dependent rural population (Alam et al. 2020, 2017; IPCC 2007). Particularly, farming in the southern coastal part of Bangladesh is very sensitive to climate change impacts. The region is more prone to sea-level rise (two metres above sea level), a big threat to our existence and coastal agriculture. The sea level at the Bay of Bengal rises slightly higher than the global average sea level (Nahar et al. 2018). The area faces constant inundation and increasing

CONTACT Md Nazirul Islam Sarker sarker.scu@yahoo.com School of Political Science and Public Administration, Neijiang Normal University, Neijiang, People's Republic of China

saline intrusion (Islam et al. 2021; Davis et al. 2018; IPCC 2014). The coastal region covers 28.9% of the country's total area and is home of 27.1% of the population who mainly depend on agriculture (BBS 2014).

Rice is one of the most important crops to feed the world's increasing population, including Bangladesh. Rice accounts for about 75% of the total cultivated area in the country (BBS 2014; Acharjee et al. 2017). Most coastal farmers cultivate rice that covers about 95% of the total coastal land (Islam et al. 2021; Kabir et al. 2019; Amin et al. 2018). They generally choose rice farming as their family subsistence and way of employment. But rice farming frequently faces various natural disasters such as flooding, salinity intrusion, extreme temperature and rainfall, and riverbank erosion. Any decrease in rice production due to climate change would seriously impair the country's food security. Appropriate adaptation strategies can help farmers lessen the impacts of climate change on their livelihood and food security.

In Bangladesh, the impacts of climate change are seen in the form of droughts, floods, cyclones, landslides, hurricanes, tornadoes, thunderstorms and diseases infestation occurrences (Alam et al. 2018). It is well known that every agro-ecological zone is unique in terms of its geography, topography, socio-economics, and climatic conditions, therefore making adaptation strategies unique to each locality or community (Alam 2016; Ayers et al. 2014). The existing adaptation policies focus on mitigation and adaptation to the overall adverse effects of climate change across the country. For developing context-specific adaptation policy, it is important to understand local and regional climate change scenarios and local adaptive strategies (Alam 2016; Alam, Alam, and Mushtaq 2017; IPCC 2007; Mertz et al. 2009). Adaptation is emerging as a key policy response for reducing the harmful effects of climate change and protecting poor farmers' livelihood and food security (Alam et al. 2018; IPCC 2014). Therefore, studies on adaptation are important for helping farmers to adapt to climate change (Sarker et al. 2021; Alam, Alam, and Mushtaq 2017).

Many previous studies have already focused on climate change perception (Kabir et al. 2020; Kabir et al. 2019; Asrat and Simane 2018; Deressa, Hassan, and Ringler 2011) and vulnerability issues of coastal dwellers (Ahmed et al. 2021; Kim, Song, and Chon 2021; Islam, Hossain, and Murshed 2015; Toufique and Yunus 2013). Understanding the factors that affect rice farmers' adaptation strategies is also important for policymaking and implementation. There are studies on adaptation strategies of the farmers covering different agro-ecological zones of Bangladesh, such as drought-prone areas (Hossain et al. 2019; Haque et al. 2017; Ayers et al. 2014; Ahmed et al. 2014; Anik and Khan 2012), coastal areas (Kabir et al. 2019; Amin et al. 2018), and riverbank erosion-prone areas (Sarker et al. 2020; Alam et al. 2018). However, studies on coastal farmers' adaptation strategies, particularly rice farmers' adaptation strategies and barriers to adaptation, are very limited, crucial to developing coastal adaptation policy in the country. So, this study has been designed to examine the following research questions: (i) what are the perceptions of coastal rice farmers about climate change vulnerability; (ii) what are the critical adaptation responses made by the farmers and barriers to adaptation, and (iii) what are the factors affecting the choice of adaptation strategies of the rice farmers? Therefore, this study aims to explore rice farmers' vulnerability, adaptation strategies, and barriers to adaptation for managing climate change impacts in the coastal region of Bangladesh.

The rest of the paper is arranged as follows: Section 2 describes the study area and its geographical features, data collection, and statistical analysis; Section 3 deals with the results and Section 4 presents a summary and policy recommendations.

2. Methodology

2.1. Selection of the study area

The study was conducted in Bangladesh's most vulnerable coastal regions (Betagi Upazila of Barguna and Galacipa Upazila of Patuakhali district), where the main problems are salinity, sea level rise, and cyclones. After a review of literature and newspaper reports, the study areas were selected purposively. The study followed a multi-stage purposive random method. Initially, two districts, one upazila from each district, and three villages from each upazila were selected purposively. Then, respondents were chosen randomly from the study villages. The study villages were Boro Char Kajol, Dokkhin Char Biswas, and Borosiba of Betagi Upazila, and Mayarhat, Uttorvora and Dokkhin-vora of Galacipa Upizala (Figure 1). All the villages are situated at the river bank and are affected by salinity, riverbank erosion, and other climatic hazards. The livelihood of the people mainly depends on agriculture.

2.2. Sampling, questionnaire, and data collection

A complete list of all rice farming households in the respective villages was collected from the Sub-Assistant Agricultural Officers (SAAOs) in the study areas. The sample size of this study was calculated by using the standard formula developed by Guilford and Fruchter (1977) as stated below-

$$n = \frac{z^2 pq}{d^2}$$

where, n = the expected sample size, z = setting standard normal deviate at 1.96, p = Calculated to be at 30% level, q = 1-p, d = degree of accurateness set at 6% and finally, 220 respondent was selected for this study.

To ensure representativeness of the population, 10% of households from each village were selected, giving a sample size of 220 households for the study. It is assumed that 5% of the population is representative of the total population's status and regarded as a sufficiently large sample size for survey research (Bartlett, Kotrlik, and Higgins 2001). The unit of analysis was the rural household, and the household head (either male or female) was the survey participant for the data collection. Data were collected from 220 rice farmers using a lottery system to ensure the randomness of the data.

Survey data were conducted using face-to-face interviews between January and February 2019 using a structured survey questionnaire. A pilot survey was conducted on 20 respondents to

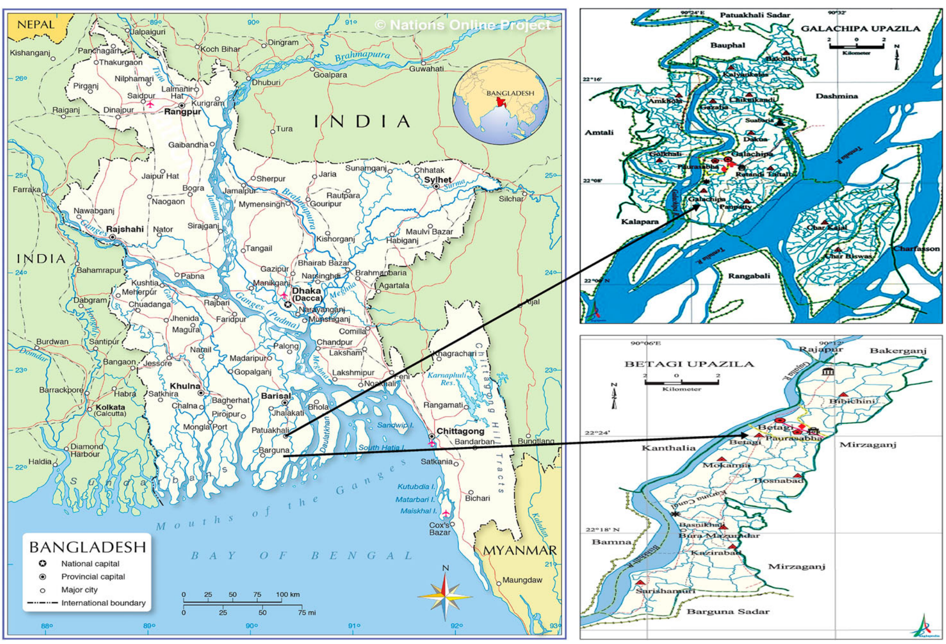

Figure 1. Study areas: Betagi and Galachipa upazila, Bangladesh.

avoid ambiguity and ensure the suitability for getting maximum available information before final data collection. Besides, in every village, one FGD (focus group discussion) comprised 8–10 household heads to cross-check individual interviews and socio-economic data. To fulfil the required number of respondents in each village, the next respondent was considered in case of non-response, which was relatively very low (less than 1%).

Descriptive and statistical analyses, such as the multinomial logit model (MNL), were used to analyze the data. Due to small landholdings, the study households were categorised as: large farm households (>7.49 acres of land) (12), medium farm households (>2.49–7.49 acres) (31), small farm households (>0.5–2.49 acres) (157) and landless (<0.5 acres land) (20).

2.3. Theoretical and empirical model

To assess the factors influencing the choice of adaptation strategies, Logit or Probit models can be used to explain categorical variables (Wooldridge 2009). The multinomial logit model (MNL) model simultaneously estimates all binary logit among categories or choices, performing all possible comparisons (Alam 2018; Alam, Alam, and Mushtaq 2016; Alauddin and Sarker 2014). MNL model was employed since the choice of adaptation was more than one. It was assumed that all the categories were mutually exclusive. The model for each category of the outcome variable is specified as:

$$\ln Y_{i(n|b)} = \ln \frac{\text{Prob } (Y = n|x)}{\text{Prob } (Y = \ b|x)}$$

Here, b is the reference category, and n is the number of categories. The model needs a base category to interpret the log-odds ratio. So, we can get n-1 (log-odds ratios). The probability (Y_i) of choosing one strategy j among a total of n alternatives conditional upon explanatory variables x_i takes the following form:

$$\text{Prob}_{(Yi|xi)} = \frac{e\ \beta jxi}{\Sigma nk = 1 \quad e\ \beta jxi}$$

This MNL model, as formulised in Green and Raygorodetsky (2010), estimates the utility from choosing one particular strategy (as shown in the numerator) relative to the sum of utilities from different choices (expressed in the denominator) (Alam, Alam, and Mushtaq 2016; Islam, Alauddin, and Rashid 2017). The choice of adaptation strategies is assumed to be influenced by socio-economic factors, institutional accessibility and livelihood status (Table 1).

An initial 15 adaptation strategies were identified through the focus group discussions. However, these failed to generate statistically significant parameters in the logit estimation. Based on the expert opinion, the close adoption strategies were grouped into six main outcomes for model analysis (Alam 2016; Alam, Alam, and Mushtaq 2016; Alauddin and Sarker 2014; Chen, Wang, and Huang 2014). There are six main adaptation strategies, such as the cultivation of High Yielding Varieties (HYVs), supplementary irrigation (Sen et al. 2017), direct-seeded rice, cultivation of non-rice crops, planting time adjustment, and diversification income sources (livestock, duck, and poultry rearing). Adjusting planting calendar and techniques are the effective and most common practices to avoid the adverse effect of climate change. Adjusting the planting calendar (planting and harvesting date) can help escape climate stresses at planting and harvesting time. The use of alternate planting techniques (e.g. direct seeding of rice, minimum tillage, sorjan method, etc) can reduce the impacts of climatic stresses. So, adjusting planting calendars and techniques has been chosen as the base category to assess factors influencing different strategies compared to adjusting planting calendars and techniques. The study also tested the collinearity using the correlation matrix with all the explanatory variables and multicollinearity through Variance inflation factor (VIF) (range of VIF is 1.05-2.60) and did not find any problem.

Table 1. Selection of the variables.

Explanatory variables	Description	Expected sign	Source
Age	Years	+/-	(Alam, Alam, and Mushtaq 2016; Deressa, Hassan, and Ringler 2011)
Education	Years of schooling	+	(Alam 2018; Alauddin and Sarker 2014)
Gender	Dummy, 1 = male, 0 = female	+/-	(Alam 2018; Alam 2016)
Average household income	Bangladeshi Taka (Continuous)		(Alam, Alam, and Mushtaq 2016; Alauddin and Sarker 2014)
Farm size	Decimal (Continuous)	+	(Alam 2016; Sarker, Alam, and Gow 2014)
Access to extension service	Dummy, 1 = if access to extension services; 0 otherwise	+	(Alam, Alam, and Mushtaq 2016; Alauddin and Sarker 2014)
Access to credit	Dummy, 1 = if access to credit; 0 otherwise	+	(Alam, Alam, and Mushtaq 2016; Sarker, Alam, and Gow 2014)
Access to information	Dummy, 1 = if access to information; 0 otherwise	+	(Alam 2015; Alauddin and Sarker 2014)

3. Results and discussion

The study results are presented in different phases: farmers' perception of vulnerabilities and factors affecting the adaptation strategies.

3.1. Socioeconomic characteristics of the rice farmers

About 15% of the respondents were female-headed. The majority of the respondents (62%) were 31–50 years old, indicating the most active age group to provide more physical efforts for farming. About 15% of the respondent had no education, and most of them (72%) had primary (one to five class) education level. The average family size was 4.56. The majority of the sample households were small farmers (owning 50–250 decimal lands), and about 20% of the sample households were virtually landless (owing to less than 50 decimal lands). Agriculture is the primary source of income. Many of them had no access to electricity (50%), no bank account (49%), not a member of any organisation (56%), no access to agricultural extension services (52%), and also no access to bank services for credit (63%). Many of them (74%) did not receive any training in their profession.

3.2. Rice farmers' perception about vulnerabilities to climate change

Climatic vulnerability is the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and adaptive capacity (IPCC 2007). Farmers in the study areas are exposed to many vulnerabilities such as floods, salinity intrusion, sea-level rise, and cyclones and storms. According to the respondents, flood is the main risk to vulnerability (93%), followed by cyclones and storms surges (74%) and saline intrusion (71%) (Figure 2). Farmers incur huge losses due to floods, cyclones, storm surges every year. Salinity intrusion, which is increasing over the years, is a major issue in the coastal zone (Nahar et al. 2018).

Riverbank erosion is a crucial vulnerability in the study area. Every year, many lands are eroded due to riverbank erosion, affecting farmers' livelihood and food security, particularly for small and landless farmers who depend intensely on agriculture.

3.3. Main adaptation strategies

Farmers in the study areas are found to adopt many adaptation strategies in response to climate change. The most common adaptation strategies include cultivation of HYV of rice, supplementary irrigation, direct seeding of rice, cultivation of non-rice crops, and diversifying income sources (Figure 3).

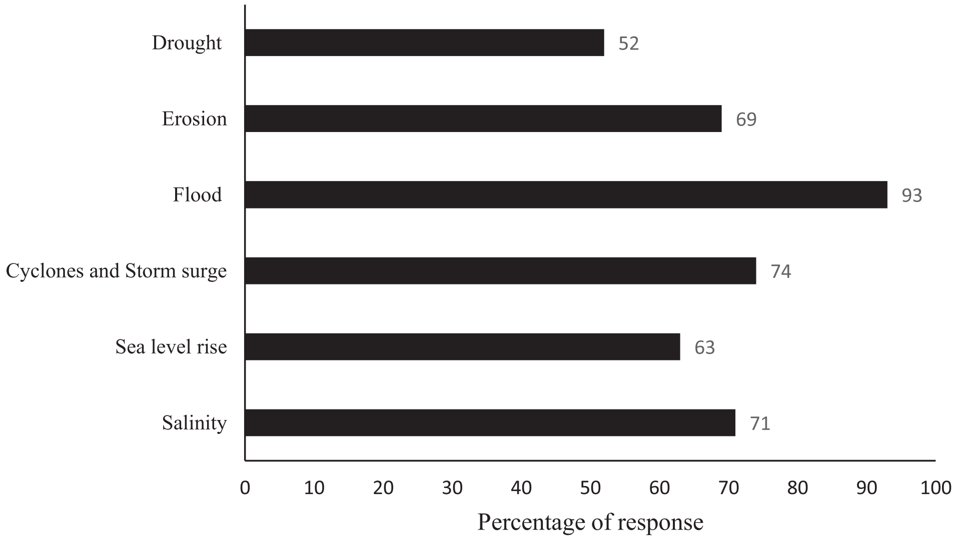

Figure 2. Farmers' perception about vulnerabilities.

Diversifying income and livelihood sources included livestock, poultry, duck rearing, small business, and off-farm employment. Cultivation of non-rice crops includes homestead gardening and horticultural crops such as pulses, watermelon, potato, chickpea, sweet gourd, and onion. Cultivation of HYV rice includes saline, flood, and drought-tolerant rice. They usually cultivate BRRI dhan 39, BRRI dhan 49 and Binadhan 7 rice varieties. However, many farmers are still cultivating local verities of rice and thus losing good economic return from rice cultivation. Due to limited rainfall, farmers use water from shallow tube-well known as supplemental irrigation. In the Aman rice season, coastal farmers face a shortage of water for their rice cultivation. Supplementary irrigation during Aman seasons is often required due to inadequate and delayed rainfall. Small and landless farmers used

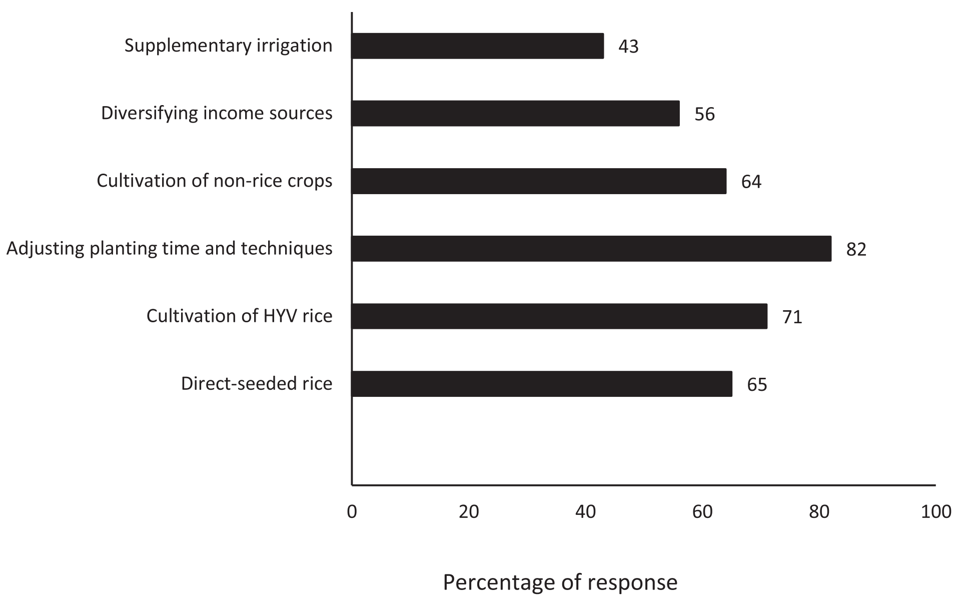

Figure 3. Main adaptation strategies.

supplementary irrigation more than large and medium farmers. Because small/landless farmers are very caring about the cropping because of less farming land. They take care of their rice farming more than middle and large farmers. They are trying to supply more water from shallow tube-well to get maximum yield from the small field. Adjusting planting dates and techniques, such as changing harvesting date, using water-saving technology (such as alternative wet and dry irrigation method and direct seeding of rice), and changing cropping patterns are preferred by large and medium farmers over small and landless farmers. In fact, small and medium farmers have less amount of land and practices subsistence farming. Large farmers, on the other hand, cultivate crops for profit. As a result, they use these technologies in their commercial farming. Moreover, medium and large farmers have better access to information and improved technologies on climate-smart agriculture.

3.4. Barriers to adaptation

Rice farmers were also asked to mention present barriers to climate change adaptation. In the study areas, farmers appear some barriers to adaptation which is presented in Figure 3. About 92% of respondents mentioned lack of financial resources in terms of credit, money, or saving as the main barrier to adaptation, followed by lack of knowledge concerning appropriate adaptation (89%). Similar constraints are also mentioned in previous studies (e.g. Shrestha, Chaweewan, and Arunyawat 2017; Alam 2016; Alam, Alam, and Mushtaq 2016; Sarker et al., 2019; Deressa, Hassan, and Ringler 2011). Previous studies indicate that information and knowledge are important to build perception, which further influences adaptation (Alam, Alam, and Mushtaq 2017; Asrat and Simane 2018). The other important barriers mentioned by the farmers are lack of education (72%), high cost of improved crop varieties (67%), lack of weather and potential climate change and weather forecast information (65%), and poor agricultural extension service (62%) (Figure 4). Due to inadequate road facilities, the farmers also face problems buying and selling their input and output.

3.5. Factors affecting the choice of adaptation strategies

The results of the MNL model for determining the factors affecting adaptation strategies are presented below:

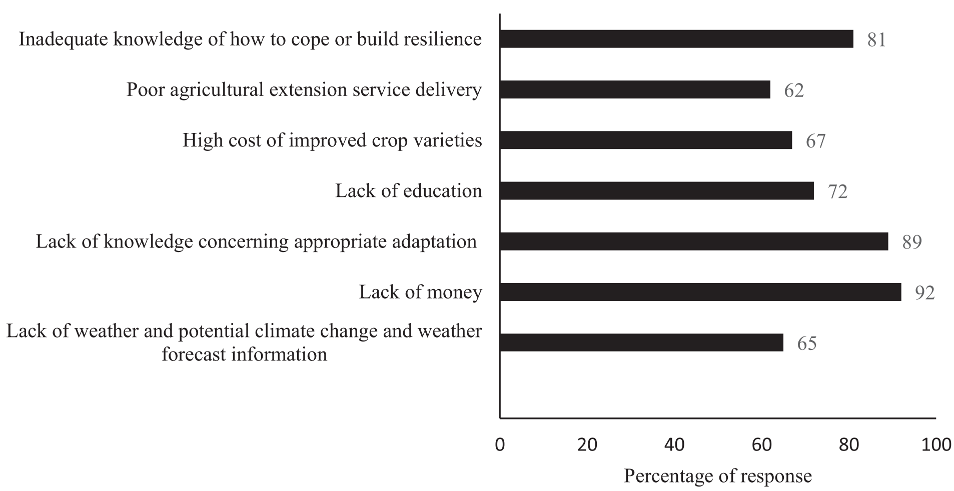

Figure 4. Major barriers to adaptation.

Overall, the model shows a good fit in terms of the statistical significance of key variables and the overall model. The chi-square statistics (LR–88.16) indicates a strong explanatory power of the model. The McFadden pseudo R^2 of 0.22 also reveals the reasonable explanatory power of the model. The majority of the explanatory variables were seen as statistically significant with an expected sign. The collinearity of the variables was tested using the correlation matrix with all the explanatory variables and multicollinearity through VIF and did not find any statistical problem.

The results show that education has a significant positive relationship on the adoption of cultivation of HYV (1.018, $p < 0.10$), supplementary irrigation (1.013, $p < 0.10$), cultivation of non-rice crops (1.020, $p < 0.05$) and diversifying income sources (0.992, $p < 0.001$) (Table 2). This indicates that a one-unit (year) increase in a respondent's level of education will increase the probability of adopting cultivation of HYV by 1.018 relatives to the base category while the effect on the remaining options is negligible. The same interpretation holds true for the other variables. These findings support the previous findings of Alam, Alam, and Mushtaq (2016) and Alauddin and Sarker (2014).

The adoption of direct-seeded rice method of crop establishment (1.182, $p < 0.05$) increased with male-headed households. On the other hand, non-rice crop cultivation (0.165, $p < 0.10$) increased with the increase of age (Table 2). This result is in accordance with the field experience. Age is a proxy of experience. The cultivation of non-rice crops such as vegetables is more profitable than rice cultivation. Therefore, experienced people adopt the cultivation of the non-rice crop to mitigate climate change impact in the area.

Access to credit and extension services also increases the probability of adopting adaptation strategies (Alam, Alam, and Mushtaq 2016; Bryan et al. 2009; Deressa, Hassan, and Ringler 2011). This study finds that access to credit and access to extension services have significant positive influence on the adoption of HYV (0.175, $p < 0.10$), supplementary irrigation (0.108, $p < 0.05$ and 1.010, $p < 0.10$), cultivation of non-rice crop (1.071, $p < 0.05$) and diversify income sources (0.207, $p < 0.05$) respectively (Table 2).

Farm size and household income play an important role in farmers' livelihood and choosing adaptation strategies (Alam 2018; Alauddin and Sarker 2014). The study reveals that farm size has significant positive impact on adoption of HYV rice (0.013, $p < 0.10$), direct-seeded rice (0.014, $p < 0.05$), and non-rice crop cultivation (0.008, $p < 0.05$). Whereas household income has a significant positive impact on HYV rice and non-rice crop cultivation (Table 2).

The study reveals that access to information has positive significant impact on the adoption of HYV rice (0.330, $p < 0.05$), use of supplementary irrigation (0.166, $p < 0.10$), direct-seeded rice (0.152, $p < 0.05$) cultivation of non-rice crops (0.125, $p < 0.05$) and diversifying income sources

Table 2. Results of the MNL model of estimated parameters (marginal effects).

	Adaptation strategies (co-efficient values)				
Explanatory variables	Cultivation of HYV	Supplementary irrigation	Direct seeded rice	Cultivation of non-rice crops	Diversifying income sources
Constant	−6.593 (5.56)	−0.736 (5.062)	1.211 (5.104)	15.141** (6.012)	−2.646 (5.945)
Age	−0.008 (0 .06)	−0.066 (0.059)	0.021 (0.060)	0.165* (0.103)	−0.075 (0.077)
Gender	2.393 (1.13)	1.068 (0.382)	1.182* (1.023)	−1.088 (1.177)	3.215 (1.406)
Education	1.018* (0.52)	1.013* (0.612)	0.089 (0.693)	1.020** (0.458)	0.992*** (0.357)
Household income	0.028** (0.011)	1.071 (7.40)	0.011 (0.021)	1.010** (0.387)	0.001 (9.67)
Farm size	0.013* (0.005)	0.007 (0.006)	0.014** (0.005)	0.008** (0.003)	0.004 (0.007)
Access to Extension service	1.021 (1.088)	1.010* (0.402)	0.644 (0.99)	1.071** (0.383)	1.456 (0.891)
Access to credit	0.175* (0.068)	0.108** (0.041)	1.036 (0.922)	0.769 (1.098)	0.207** (0.075)
Access to information	0.330** (0.124)	0.166* (0.065)	0.152** (0.054)	0.125** (0.048)	0.079* (0.029)

Log likelihood = −162.26939; Pseudo R^2 = 0.2136; LR (Chi-square) = 88.16.
N = 220. Adjusting planting time and techniques is used as base category. Standard errors are indicated in parentheses.
*$p < 0.10$, **$p < 0.05$, and ***$p < 0.001$.

(0.079, $p < 0.10$). Previous findings by Alam (2016) and Deressa, Hassan, and Ringler (2011) indicate that adopting adaptation strategies increases access to information. Below et al. (2012) argued that information related to climate change greatly influences creating awareness among farmers, which encourages farmers to adopt strategies.

5. Conclusion and policy implications

Bangladesh's agriculture sector and rural livelihoods, especially in the coastal zone, are highly vulnerable to the negative impacts of climate change. This paper investigated rice farmers' vulnerabilities to climatic hazards and their adaptations to climate change. The results reveal that coastal rice farmers are frequently exposed to floods, droughts, salinity intrusion, sea-level rise, cyclones and storms surges, coastal erosion, and riverbank erosion. Flood is the most common source of vulnerability, followed by cyclones and storm surges, and saline intrusion. Farmers tried to minimise the negative impacts of climate change by adopting various adaptation strategies such as the cultivation of climate-smart (e.g. flood and salinity tolerant) rice varieties, use of supplementary irrigation for non-rice crops, using direct-seeded rice method of crop establishment, shift from rice to non-rice crop cultivation, adjusting planting time and techniques, and diversification of income sources. These adaptation measures reduced rice production losses from climatic disasters and improved farmers' resilience to climate change. Model analysis showed that education has a significant positive relationship on the adoption of cultivation of HYV, supplementary irrigation, cultivation of non-rice crops and diversifying income sources . Majority of the respondents mentioned lack of financial resources in terms of credit, money, or saving as the main barrier to adaptation, followed by lack of knowledge concerning appropriate adaptation..

The use of digital tools in agriculture is rapidly increasing. Agricultural extension service providers can use a mobile phone-based technology transfer mechanism to supply their services since most farmers have mobile phones. The Department of Agricultural Extension and NGOs can give technical support to farmers at the local level through a call centre, community weather forecasting, and instant messaging. Promoting digital tools requires effective policies and programmes to supply context-specific digital services and develop farmers' knowledge and skills to use the technologies. Improving farmers' adaptations to climate change also requires strong research-extension linkages and training of extension workers for quick transfer and use of new climate-smart agricultural technologies such as flood and salinity tolerant rice varieties. Farmers' limited access to knowledge on appropriate adaptation technologies and cultivation practices is an important barrier to climate change adaptation. Farmers should be educated and trained on climate-smart agriculture technology and its applications through agricultural skill development training at the local level. The lack of irrigation facilities, especially supplemental irrigation, hinders rice farmers' production activities in the Aman season. Policymakers should emphasise Aus and Aman rice production in the coastal area by enabling supplementary irrigation to increase overall rice production and thus ensure household food security. Another important measure to reduce adverse impacts of climate change is the timely supply of weather forecast information to farmers. Effective implementation of these policies and programmes can substantially reduce the adverse effects of climate change on rice farmers.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

We acknowledge the partial funding support of the National Science and Technology (NST) Fellowship, Bangladesh, and Krishi Gobeshona Foundation (KGF) for this study.

References

Acharjee, Tapos Kumar, Fulco Ludwig, Gerardo van Halsema, Petra Hellegers, and Iwan Supit. 2017. "Future Changes in Water Requirements of Boro Rice in the Face of Climate Change in North-West Bangladesh." *Agricultural Water Management* 194: 172–183. doi:10.1016/j.agwat.2017.09.008.

Ahmed, Nesar, Stuart W. Bunting, Sanzidur Rahman, and Christopher J. Garforth. 2014. "Community-Based Climate Change Adaptation Strategies for Integrated Prawn-Fish-Rice Farming in Bangladesh to Promote Social-Ecological Resilience." *Reviews in Aquaculture* 6 (1): 20–35. doi:10.1111/raq.12022.

Ahmed, Naser, Newton Howlader, Muhammad Al Amin Hoque, and Biswajeet Pradhan. 2021. "Coastal Erosion Vulnerability Assessment Along the Eastern Coast of Bangladesh Using Geospatial Techniques." *Ocean and Coastal Management* 199 (September 2020), doi:10.1016/j.ocecoaman.2020.105408.

Alam, Khorshed. 2015. ""Farmers' Adaptation to Water Scarcity in Drought-Prone Environments: A Case Study of Rajshahi District, Bangladesh." *Agricultural Water Management* 148 (January 2015): 196–206. doi:10.1016/j.agwat.2014.10.011.

Alam, G M Monirul. 2016. "An Assessment of the Livelihood Vulnerability of the Riverbank Erosion Hazard and Its Impact on Food Security for Rural Households in Bangladesh." PhD Dissertation, University of Southern Queensland, Australia.

Alam, G M Monirul. 2018. "Determinants of and Barriers to Adaptation: Evidence from Hazard-Prone Rural Households in Bangladesh." *Bangladesh Journal of Political Economy* 34 (2): 307–330.

Alam, G M Monirul, Khorshed Alam, and Shahbaz Mushtaq. 2016. "Influence of Institutional Access and Social Capital on Adaptation Decision: Empirical Evidence from Hazard-Prone Rural Households in Bangladesh." *Ecological Economics* 130: 243–251. doi:10.1016/j.ecolecon.2016.07.012.

Alam, G.M. Monirul, Khorshed Alam, and Shahbaz Mushtaq. 2017. "Climate Change Perceptions and Local Adaptation Strategies of Hazard-Prone Rural Households in Bangladesh." *Climate Risk Management* 17: 52⍰⍰⍰63. doi:10.1016/j.crm.2017.06.006.

Alam, G M Monirul, Khorshed Alam, Shahbaz Mushtaq, and Walter Leal Filho. 2018. "How Do Climate Change and Associated Hazards Impact on the Resilience of Riparian Rural Communities in Bangladesh? Policy Implications for Livelihood Development." *Environmental Science & Policy* 84: 7–18. doi:10.1016/j.envsci.2018.02.012.

Alam, G M Monirul, Khorshed Alam, Shahbaz Mushtaq, Md Nazirul Islam Sarker, and Moazzem Hossain. 2020. "Hazards, Food Insecurity and Human Displacement in Rural Riverine Bangladesh: Implications for Policy." *International Journal of Disaster Risk Reduction* 43), doi:10.1016/j.ijdrr.2019.101364.

Alauddin, Mohammad, and Md Abdur Rashid Sarker. 2014. "Climate Change and Farm-Level Adaptation Decisions and Strategies in Drought-Prone and Groundwater-Depleted Areas of Bangladesh: An Empirical Investigation." *Ecological Economics* 106: 204–213. doi:10.1016/j.ecolecon.2014.07.025.

Amin, M. N., H. M. Solayman, S. S. Snigdha, and J. Sultana. 2018. "Climate Resilient Livelihood Activity in the South Central Coastal Region of Bangladesh." *Journal of Science Technology and Environment Informatics* 6 (1): 421–430. doi:10.18801/jstei.060118.45.

Anik, Sawon Istiak, and Mohammed Abu Sayed Arfin Khan. 2012. "Climate Change Adaptation Through Local Knowledge in the North Eastern Region of Bangladesh." *Mitigation and Adaptation Strategies for Global Change* 17 (8): 879–896. doi:10.1007/s11027-011-9350-6.

Asrat, P., and B. Simane. 2018. "Farmers'perception of Climate Change and Adaptation Strategies in the Dabus Watershed,North-West Ethiopia." *Ecological Processes* 7 (1): 1–13. doi:10.1186/s13717-018-0118-8.

Ayers, Jessica, Saleemul Huq, Helena Wright, Arif M. Faisal, and Syed Tanveer Hussain. 2014. "Mainstreaming Climate Change Adaptation Into Development in Bangladesh." *Climate and Development* 6 (4): 293–305. doi:10.1080/17565529.2014.977761.

Bartlett, James E., Joe W. Kotrlik, and Chadwick C. Higgins. 2001. "Organizational Research: Determining Appropriate Sample Size in Survey Research." *Information Technology, Learning, and Performance Journal* 19 (1): 43–50.

BBS. 2014. *Statistical Pocketbook. Bangladesh Bureau of Statistics (BBS)*. Dhaka, Bangladesh: Statistics and Informatics Division, Ministry of Planning, The Government of Bangladesh.

Below, Till B., Khamaldin D. Mutabazi, Dieter Kirschke, Christian Franke, Stefan Sieber, Rosemarie Siebert, and Karen Tscherning. 2012. "Can Farmers' Adaptation to Climate Change Be Explained by Socio-Economic Household-Level Variables?" *Global Environmental Change* 22 (1): 223–235. doi:10.1016/j.gloenvcha.2011.11.012.

Bryan, Elizabeth, Temesgen T. Deressa, Glwadys A. Gbetibouo, and Claudia Ringler. 2009. "Adaptation to Climate Change in Ethiopia and South Africa: Options and Constraints." *Environmental Science and Policy* 12 (4): 413–426. doi:10.1016/j.envsci.2008.11.002.

Chen, Huang, Jinxia Wang, and Jikun Huang. 2014. "Policy Support, Social Capital, and Farmers' Adaptation to Drought in China." *Global Environmental Change* 24 (1): 193–202. doi:10.1016/j.gloenvcha.2013.11.010.

Davis, Kyle Frankel, Abinash Bhattachan, Paolo D'Odorico, and Samir Suweis. 2018. "A Universal Model for Predicting Human Migration Under Climate Change: Examining Future Sea Level Rise in Bangladesh." *Environmental Research Letters* 13 (6): 1–10. doi:10.1088/1748-9326/aac4d4.

Deressa, T. T., R. M. Hassan, and C. Ringler. 2011. "Perception of and Adaptation to Climate Change by Farmers in the Nile Basin of Ethiopia." *Journal of Agricultural Science* 149 (1): 23–31. doi:10.1017/S0021859610000687.

Green, D., and G. Raygorodetsky. 2010. "Indigenous Knowledge of a Changing Climate." *Climatic Change* 100 (2): 239–242. doi:10.1007/s10584-010-9804-y.

Guilford, J. P., and Benjamin Fruchter. 1977. *Fundamental Statistics in Psychology and Education*. 6th ed. New York: McGraw-Hill Book Co. doi:10.1016/j.physleta.2009.09.042.

Haque, Mohammad Mahfujul, Scott Bremer, Saifullah Bin Aziz, and Jeroen P. van der Sluijs. 2017. "A Critical Assessment of Knowledge Quality for Climate Adaptation in Sylhet Division, Bangladesh." *Climate Risk Management* 16: 43–58. doi:10.1016/j.crm.2016.12.002.

Hossain, Mohammad Shakhawat, Muhammad Arshad, Lu Qian, Minjuan Zhao, Yasir Mehmood, and Harald Kächele. 2019. "Economic Impact of Climate Change on Crop Farming in Bangladesh: An Application of Ricardian Method." *Ecological Economics* 164: 106354. doi:10.1016/j.ecolecon.2019.106354.

IPCC. 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability*. New York, NY, USA: Cambridge University Press.

IPCC. 2014. *Climate Change 2014: Impacts, Adaptation and Vulnerability, Fifth Assessment Report. In: Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press. Accessed February 15, 2021. https://www.ipcc.ch/report/ar5/wg2/ on.

Islam, Zeenatul, Mohammad Alauddin, and Abdur Rashid. 2017. "Determinants and Implications of Crop Production Loss: An Empirical Exploration Using Ordered Probit Analysis." *Land Use Policy* 67: 527–536. doi:10.1016/j.landusepol.2017.06.021.

Islam, Md Ashraful, Md Shakhawat Hossain, and Sanzida Murshed. 2015. "Assessment of Coastal Vulnerability Due to Sea Level Change at Bhola Island, Bangladesh: Using Geospatial Techniques." *Journal of the Indian Society of Remote Sensing* 43 (3): 625–637. doi:10.1007/s12524-014-0426-0.

Islam, F., G. M. Monirul Alam, Rokeya Begum, Md Nazirul Islam Sarker, Humnath Bhandari, and 2021. "Vulnerability, Food Security and Adaptation to Climate Change of Coastal Rice Farmers in Bangladesh." In *Climate Vulnerability and Resilience in the Global South*, 187–197. Springer International Publishing. doi:10.1007/978-3-030-77259-8_9.

Kabir, Md Jahangir, Rob Cramb, Mohammad Alauddin, and Donald S. Gaydon. 2019. "Farmers' Perceptions and Management of Risk in Rice-Based Farming Systems of South-West Coastal Bangladesh." *Land Use Policy* 86: 177–188. doi:10.1016/j.landusepol.2019.04.040.

Kabir, Jahangir, Rob Cramb, Mohammad Alauddin, Donald S. Gaydon, and Christian H. Roth. 2020. "Farmers' Perceptions and Management of Risk in Rice/Shrimp Farming Systems in South-West Coastal Bangladesh." *Land Use Policy* 95: 104577. doi:10.1016/j.landusepol.2020.104577.

Kim, Min, Kihwan Song, and Jinhyung Chon. 2021. "Key Coastal Landscape Patterns for Reducing Flood Vulnerability." *Science of the Total Environment* 759: 143454. doi:10.1016/j.scitotenv.2020.143454.

Mertz, Ole, Kirsten Halsnæs, Jorgen E. Olesen, and Kjeld Rasmussen. 2009. "Adaptation to Climate Change in Developing Countries." *Environmental Management* 43 (5): 743–752. doi:10.1007/s00267-008-9259-3.

Nahar, Ashrafun, Jeff Luckstead, Eric J. Wailes, and Mohammad Jahangir Alam. 2018. "An Assessment of the Potential Impact of Climate Change on Rice Farmers and Markets in Bangladesh." *Climatic Change* 150 (3–4): 289–304. doi:10.1007/s10584-018-2267-2.

Sarker, Md Nazirul Islam, Yang Peng, Most. Nilufa Khatun, G. M. Monirul Alam, Roger C. Shouse, and Md Ruhul Amin. 2021. "Climate Finance Governance in Hazard Prone Riverine Islands in Bangladesh: Pathway for Promoting Climate Resilience." *Natural Hazards*, doi:10.1007/s11069-021-04983-4.

Sarker, Md Abdur, Khorshed Rashid, Jeff Alam. 2014. "Assessing the Effects of Climate Change on Rice Yields: An Econometric Investigation Using Bangladeshi Panel Data." *Economic Analysis and Policy* 44 (4): 405–416. doi:10.1016/j.eap.2014.11.004..

Sarker, Md Nazirul Islam, Min Wu, GM Monirul Alam, and Roger C. Shouse. 2019. "Livelihood Vulnerability of Riverine-Island Dwellers in the Face of Natural Disasters in Bangladesh." *Sustainability* 11 (6): 1623. doi:10.3390/su11061623..

Sarker, Md Nazirul Islam, Min Wu, G. M. Monirul Alam, and Roger C Shouse. 2020. "Life in Riverine Islands in Bangladesh: Local Adaptation Strategies of Climate Vulnerable Riverine Island Dwellers for Livelihood Resilience." *Land Use Policy* 94: 104574. doi:10.1016/j.landusepol.2020.104574.

Sen, R., N. N. Karim, M. T. Islam, and A. K. M. Adham. 2017. "Estimation of Supplemental Irrigation for Aman Rice Cultivation in Bogra and Dinajpur Districts of Bangladesh Estimation of Supplemental Irrigation for Aman Rice Cultivation in Bogra and Dinajpur Districts of Bangladesh." *Progressive Agriculture* 28 (1): 42–45.

Shrestha, Rajendra P., Nuanwan Chaweewan, and Sunsanee Arunyawat. 2017. "Adaptation to Climate Change by Rural Ethnic Communities of Northern Thailand." *Climate* 5 (3): 57. doi:10.3390/cli5030057.

Toufique, Kazi, and Mohammad Yunus. 2013. "Vulnerability of Livelihoods in the Coastal Districts of Bangladesh." *Bangladesh Development Studies* 36 (1): 95–120.

Wooldridge, Jeffrey M. 2009. *Introductory Econometrics: A Modern Approach*. 5th ed. Natorp Boulevard Mason, OH, USA: Cengage Learning. doi:10.4324/9781351140768-8.

World Bank. 2018. "Enhancing Opportunities for Clean and Resilient Growth in Urban Bangladesh." *Enhancing Opportunities for Clean and Resilient Growth in Urban Bangladesh*, no. i (September). World Bank, Washington, DC: 9–10. Accessed January 5, 2021. https://www.worldbank.org/content/dam/Worldbank/document/Full_Report_Vol_2_Turn_Down_The_Heat_%20Climate_Extremes_Regional_Impacts_Case_for_Resilience_Print%20version_FINAL.pdf doi:10.1596/30558.