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Farmers' adaptation strategies to combat climate change in drought prone areas in Bangladesh

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Author has made corrections in ce:affiliation. Carry out the corrections in sa:affiliation also using the XML Editor.

Abstract

Drought introduces a different set of risks and adaptation strategies as compared to flood, river erosion and other natural hazards. This paper attempts to investigate farmers' adaptation strategies to combat climate change in drought prone areas and identify their determinants based on a survey of 480 farmers from northwestern Bangladesh. Farmers commonly practicing six technology-based strategies and one labour/family-based strategy with 80% adapting two or more adaptation strategies. Although synergy exists between selected strategies, competition also exist between rice- and non-rice based strategies. The likelihood of undertaking climate change adaptation strategies are significantly and positively influenced by education, subsistence pressure, income from livestock and poultry, extension services, involvement in organizations and the use of ICT in farming. Adaptation probability inversely related with increasing women participation in agricultural labour force. Recommendations include strengthening extension services and promoting use of ICT in farming, incorporation of climatic information in education, easing and facilitating farmers' access to institutions and promotion of livestock rearing to combat climate change induced challenges on farming in drought prone areas.

Keywords:

Climate change, Adaptation strategies, Agriculture, Multivariate probit model, Bangladesh

1 Introduction

While climate is changing and its associated anomalies are becoming more frequent, agriculture and livelihood of farm households, particularly in developing countries, are increasingly being threatened [1,2]. In the future, climate change induced losses in food production will lead to higher food prices, and ultimately the poor will experience more welfare and income losses [1,3].

Bangladesh is in the list of the extremely vulnerable countries to climatic anomalies [1,4], where agriculture contributes one-seventh of the total GDP and employs 40% of the total population [5]. It is predicted that by 2100, the country will experience 33% yield loss due to climate change [6]. The threat of crop loss is higher for small and marginal farmers constituting 84% of the country's total farm households [7] and are heavily dependent on agriculture for their livelihood as well as have lower adaptive capacity [8,9]. Different extreme climatic events, such as, flood, cyclone, storm and drought along with salinity intrusion and waterlogging are also common in Bangladesh [10].

The northwest is the driest region of the country, which is prone to drought [11] and the current study focuses on this region because of its importance as the breadbasket of the country. The groundwater depth level in the region has increased from 3.7 m in 1981 to 7.3 m in 2016 with an increasing trend [12]. Past droughts have affected 47% of the country's total area and 53% of the population [13]. During last five decades, the country experienced 19 severe drought episodes causing around 20% loss in major rice season output in a typical year [10]. Although water stress induced changes in agricultural production in the region is already evident, there are implications on food security, particularly for the landless and small labourers, because of food price increases and reduction in job availabilities [14].

Drought impacts are manifold and diverse in nature and can be broadly classified into economic, environmental and social impacts [15,16]. Drought causes abiotic stresses that are different from other climatic stresses [17]. The metabolic and morphologic process of plants in all stages of their lifecycle is affected from drought, while some growth stages are more sensitive to water stress [18]. Ultimately yield, yield components and quality traits are affected [19]. Consecutive years of water stress has threatened native species and ecosystem function in the arid and semiarid regions [20]. Ultimately the livelihood of the poor, particularly those dependent on farming become more vulnerable, and in extreme cases, they may leave farming [21] and might become displaced [22]. Though the situation in the northwestern Bangladesh is not so severe, the effects of water stress on farming, livelihood and on habitat in the region is already evident [e.g. 14, 23]. In addition, drought related heat and water stresses have negative health implications, particularly on the children, which the trend is increasing in the region and are projected to increase further [24].

Given such vulnerabilities, appropriate adaptation strategies are needed to combat climate change effects and sustain agricultural systems, particularly for the sake of vulnerable communities [23,25]. Burnham and Ma noted multiple competing definitions of adaptation in literature [26], whereas Harmer and Rahman observed that findings in the literature are largely inconclusive [27]. This is not surprising since the domain of this decision process is not limited to climate change alone, rather includes a wide range of complex and interconnected socio-political, social and environmental issues [28]. Moreover, adaptation is closely linked with farmers' perception about climate change and its associated severity and the extent to which farmers are certain about receiving returns from adaptation [29,30]. Farm level adaptation responses to climate change are context specific and localized, as the effects are time-variant in nature as well [31].

1.1 Farm level adaptation to climate change

Literature investigating adaptation strategies of the farming population is vast, though geographically majority focused on African countries [32]. In empirical literature, the notable and common adaptation strategies, particularly in water stressed situations, are changing and rotating crop and/or crop varieties; adjusting planting and harvesting dates; resource (soil and water) management and conservation; changing input (particularly fertilizer and irrigation) quantity, application method and practices; planting trees; diversifying towards livestock; etc. [16,33–37]. But with only few exceptions, strategies beyond farming are overlooked and strategies are also assumed to be mutually exclusive (i.e., independent of each other) [e.g. 38, 39]. Alauddin and Sarker classified the underlying adaptation factors noted in empirical literature into three broad categories, namely, household characteristics, institutional factors, and social capital [27]. Another category of explanatory variable includes household's vulnerability or exposure to different climatic shocks [35]. Some studies explored adaptation strategies of the farmers in the north-western region of Bangladesh as well [e.g. 14, 23, 32, 40, 41, 42, 43].

The following limitations can be identified from the existing literature. *First*, adaptation strategies to combat climate change were investigated without explicitly acknowledging underlying theories, except few exceptions [e.g. 44, 45, 46], but none were from Bangladesh. Furthermore, some studies used ‘adaptation’ and ‘coping’ strategies interchangeably. For example, Habiba et al. [14] and Selvaraju et al. [43] considered agronomic practices such as weeding, seedbed method, using manure and composting, etc. as adaptation strategies, whereas Al-Amin et al. [40] and Alauddin and Sarker [32] considered supplementary irrigation as an adaptation strategy, while it is a coping strategy when rainfall is inadequate or irregular. *Second*, the focus was to analyze farming strategies suitable for rice farmers in drought prone areas [e.g. 23, 32, 35, 40, 41, 43, 44, 47], while a farmer may adopt strategies beyond the domain of farming [21]. *Third*, studies based on qualitative research approach [e.g. 14, 43, 48, 49], which are helpful to understand the nature of the problem but cannot provide information about the direction and magnitude of the effect of strategies undertaken to inform policy decisions. *Fourth*, some studies analysed farmers' perception about adaptation strategies [e.g. 26, 32], which does not necessarily imply that actual actions were also undertaken based on those perceptions. *Fifth and final*, is a methodological one. The common approach was to use univariate and/or multinomial probit/logit models [e.g. 23, 32, 33, 41, 50, 51]. Such modelling exercises cannot accommodate multiple adaptation strategies simultaneously, which farmers normally do [35,47]. Furthermore, such univariate modelling approach assumes that farmers' individual adaptation decisions are mutually exclusive, and therefore, ignores any possible synergies amongst strategies [52].

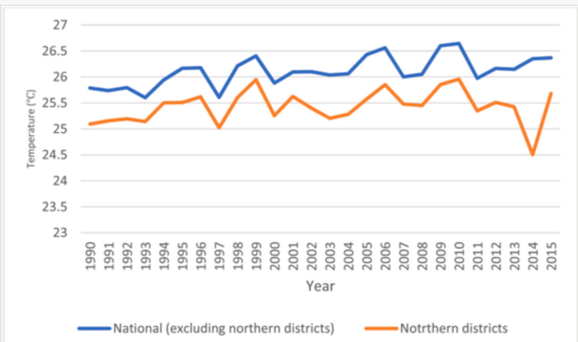
Therefore, taking account of these research gaps in the literature, the main objectives of this study are to: (a) examine various adaptation strategies farmers undertake to combat climate change effects under water-stress or drought situation; (b) identify the determinants of undertaking climate change adaptation strategies, while allowing farmers to undertake any one or multiple strategies simultaneously; and (c) explore whether synergy and/or competition exist between various strategies undertaken by the farmer to combat climate change effects.

2 Changing climatic pattern in the northern region and Bangladesh

Northern Bangladesh is one of the major crop producing regions supplying 45% of total rice produced in the country [53]. The proportion of households having agriculture as the main source of livelihood is five times higher and employment as agricultural wage labour is eight times higher than the national average in this region [54]. The two main climate indicators: temperature and rainfall, differ substantially between the northern region and overall Bangladesh.[1] The annual mean temperature and total rainfall covering a 25-year period shows that both temperature and rainfall in northern districts are typically lower than the national average (which exclude northern districts) with relatively sharp upward and downward peaks and the gaps are widening in recent years, particularly in case of temperature (Figs. 1 and 2). The annual average rainfall in the region is 24% lower than that of national average. In general, the hot season commences early in March and continues till the middle of July in all three study areas. The maximum mean temperature observed is about 32–36 °C during the months of April, May, June and July and the minimum temperature recorded in January is about 7–16 °C. Annual average maximum and minimum temperature are 37.8 °C and minimum 11.2 °C for Naogaon district whereas 30.3 and 20.3 for Bogra district respectively. 1448 mm, 1862 mm and 1762 mm mean rainfall have been observed in Rajshahi, Naogaon and Bogra districts respectively, which indicates that Rajshahi is drier than other two districts. Farming in the region is increasingly becoming dependent on supplementary irrigation, which raises concern about sustainability of the agricultural system as the groundwater depth in the region is deteriorating fast over time (Fig. 3).

alt-text: Fig. 1

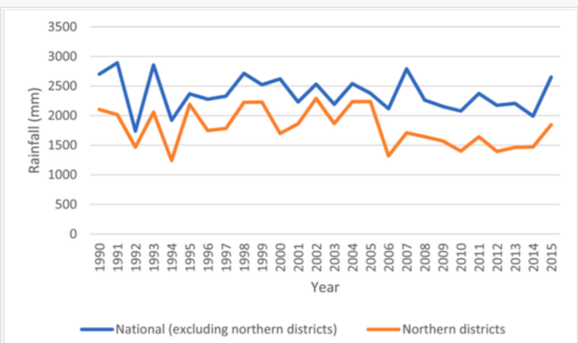
Fig. 1



Annual mean temperature (°C) in northern districts and Bangladesh (1990–2015).

alt-text: Fig. 2

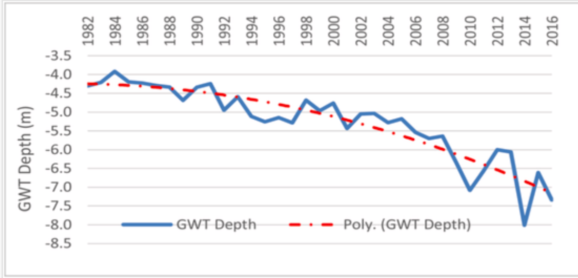
Fig. 2



Annual mean rainfall (mm) in northern districts and Bangladesh (1990–2015).

alt-text: Fig. 3

Fig. 3



Depletion in the depth of groundwater-table in the northern region, Source: FPMU (2017).

3 Methodology

3.1 Theoretical framework underpinning the research: The action theory premise

Adaptation is a farmer's spontaneous or planned response to changing climate to withstand production loss [45,46], where the outcome might be stressful or gainful livelihood strategies uptake within and/or beyond farming [55]. Farmers often do trade-offs amongst multiple objectives [56] as there are interdependency among his/her personal, family and farming objectives [e.g. 57, 58]. Differences in farmers' socio-economic and resource base can result in differences in their objective functions, while some are ‘utility’ and some are ‘profit’ maximisers [59,60].

In accordance with own objective function, a farmer adapts a technology when the perceived benefit from adapting is higher than non-adapting [e.g. 61, 62]. Though the underlying objective function, which drives a farmer's adaptation decision is unobserved, we can observe different farm and farmer specific socioeconomic, institutional, climatic and natural resource domains that influence adaptation decisions. To understand the dynamism in farmer's adaptation process, we utilize the action theory framework, originally developed by Eisenack and Stecker [45], where adaptation is defined as decisions and related actions required against vulnerability caused by environment or human induced changes, which is subject to one's adaptive capacity. We assume that the changing climatic factors works as a stimulus and whether a farmer (an actor, also known as operator) will respond to some of such stimulus in the pursuit of some intended benefits depends on several factors (different resources, e.g. natural, social networks, access to institutions and information, etc.) and conditions (i.e. constraints and resources that are beyond the control of the operator). In the adoption process, a farmer needs to collaborate with different social entities and non-human system.

3.2 Data and sampling procedure

The data for this study is from a farm-level survey where the respondent households were selected through a carefully designed multi-stage simple random sampling procedure. The survey was conducted during October 2018 and the respondents were asked for information covering three preceding crop growing seasons: dry summer 2017, monsoon 2018 and winter farming 2017–18. At first, the Herfindahl Index of crop diversification[2] for all the greater northern districts[3] of Bangladesh was estimated and three districts with highest level of diversification were selected. Then, all districts belonging to selected greater districts were ranked based on the cultivable land area. As result, the top three districts namely: Rajshahi, Naogaon and Bagura were selected. Next, from each of the selected districts, two sub-districts and two unions within each sub-district, the most and the least severely affected by climate change were selected. Since, information about climate change beyond district level is not available, the judgement of the district agriculture offices were used for selecting sub-districts and union. The officials were requested to make their qualitative judgement considering their last three years' experiences about temperature and rainfall variability and incidence of climatic hazard. Then, one village from each union was selected randomly. The sample size (n) of household units in the study area was determined by applying the following formula [63]:

$$n = \frac{Nz^2 p(1-p)}{Nd^2 + z^2 p(1-p)} \quad (1)$$

where.

N = total number of farm households in the selected three districts (11,65,049).

z = confidence level (at 95% level z = 1.96).

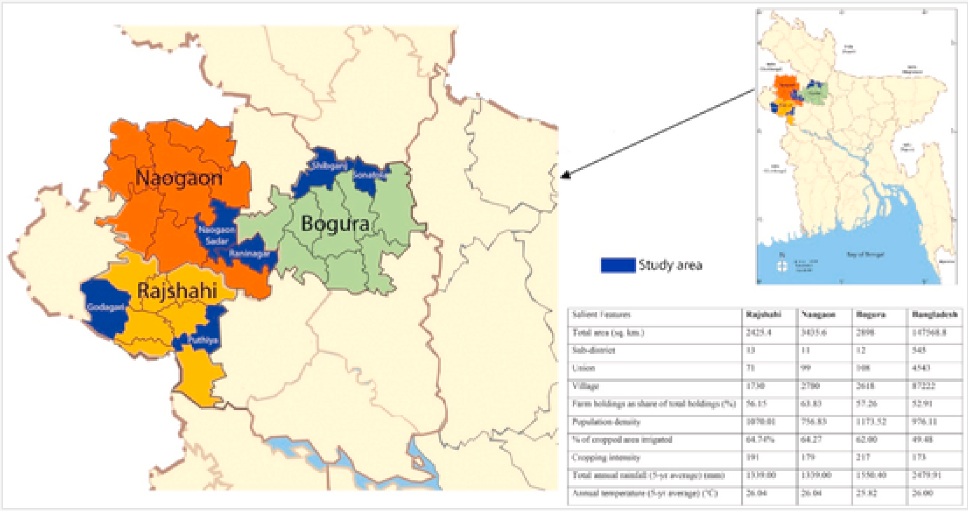
p = estimated population proportion (0.5, this maximizes the sample size).

d = error limit of 5% (0.05).

The above equation with the values specified resulted in a total required sample of 384. Including a reserve of 25%, the total sample requirement stands at 480, which was equally divided into selected villages, i.e. 40 farm households from each village were randomly selected using the list of farmers available with the local agriculture office. Thus, the survey interviewed 480 farmers belonging to 12 villages from 12 unions belonging to 6 sub-districts from 3 districts in northern Bangladesh. Fig. 4 presents the geographic location of the study areas and some salient features. In line with the earlier section (Section 2) comparing between some selected climatic features of the northern region and Bangladesh, the total rainfall in the selected districts is notably lower than the national average, but the difference in average temperature was not high. Compared to the national level, the selected districts have high population density and share of farmers in total population is also higher. The districts also have relatively high cropping intensity and area under irrigation.

alt-text: Fig. 4

Fig. 4



Map of the study area and some salient climate and socio-economic features, Source: http://maps-of-bangladesh.blogspot.com/2010/06/upazila-map-of-bangladesh.html.

Prior to the survey, participatory research approach was applied to develop the survey instrument, particularly to identify adaptation strategies and different means and conditions that may influence adaptation decisions. A series of six Focus Group Discussions (FGDs),[4] one in each of the selected sub-districts with 10–12 farmers from the selected villages were conducted. In addition, Key Informant Interviews (KIIs) were conducted with the local agriculture officials and other agriculture professionals. During FGDs and KIIs, a list of possible adaptation strategies extracted from the literature covering five typologies listed by Harmer and Rahman [27] were shared. Many of the strategies particularly those belonging to the categories of 'financial adaptations', 'help from others' and 'cultural/religious' strategies were discarded were not practiced by the farmer. Even though we kept some of these strategies in the questionnaire, their frequencies were not enough to be considered as a separate strategy and seven strategies appeared to be common amongst farmers in the survey. The FGD participants were also asked for factors, constraints and opportunities that may influence adaptation decisions. Besides, exploring relevant literature, a detailed list of factors that may affect a farmer's adaptation decision was developed.

During the survey, two special instructions were provided to the enumerators. *First*, both climatic and economic factors can influence the same adaptation decision [64]. For instance, water-stress and higher yield both might encourage a farmer to shift from rice to less water intensive vegetables. Enumerators were instructed to record strategies as adaptation only when climate change has some role. *Secondly*, some strategies (e.g. applying more irrigation and/or chemical inputs) might be part of both adaptation and coping strategies. These strategies were considered as 'technology-based' adaptation strategies when the motive was largely related to solve technology aspects related to production practices, not only for preventing loss.

3.3 Analytical framework: the multivariate probit model

We have applied a system of multiple equation probit model, i.e., multivariate probit model, to jointly identify the determinants of multiple adaptation strategies (i.e. actions) that a farmer (an actor) takes when exposed to certain changes in the climate (i.e. stimulus). The survey identified seven common adaptation strategies: drought tolerant variety cultivation, short duration variety cultivation, adjusting farming calendar, adjusting irrigation frequency and level, increasing intensity of chemical inputs, shifting towards non-rice crops and undertaking off-farm activities. Therefore, the system of multiple equation probit model contained seven equations, i.e., one probit equation for each option, where the value of the dependent variable is 1 if the farmer has undertaken that strategy or 0 otherwise (please see Table 1 for a list of the strategies and their definitions). Another major motivation for choosing multivariate probit model is to test potential inter-relatedness of the decision-making process among different adaptation decisions by providing an estimate of the correlation between the error terms of the individual univariate models (i.e. individual adaptation strategy uptake model), which are nested in the multivariate model.

alt-text: Table 1

Table 1

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Definition of different adaptation strategies and the proportion of farmers adopting those strategies along with the value of output produced.

Adaptation strategies	Definition	% of farmers adopting	Value of output (USD/ha)[a] Non-adopter	Adopter
Technology based strategies:				
Drought tolerant variety cultivation	Dummy; 1 for farmers cultivating drought tolerant rice variety, 0 otherwise	49.06	1476	1536
Short duration variety cultivation	Dummy; 1 for farmers cultivating short duration variety (mainly rice), 0 otherwise	41.09	1464	1572**
Adjusting farming calendar	Dummy; 1 for farmers adjusting farming calendar, 0 otherwise	44.23	1488	1536
Increasing intensity of chemical inputs	Dummy; 1 for farmers increasing intensity chemical inputs (e.g. fertilizer, pesticides, etc.), 0 otherwise	62.68	1536	1488
Adjusting irrigation frequency and level	Dummy; 1 for farmers adjusting irrigation frequency and level, 0 otherwise	64.57	1380	1584***
Shifting towards non-rice crops	Dummy; 1 for farmers replacing rice with other crops (e.g. vegetables), 0 otherwise	39.83	1512	1620***
Labour/family- based strategies				
Undertaking off-farm activities	Dummy; 1 for farmers replacing farming with off-farm income generating activities, 0 otherwise	6.92	1560	1500

Note: [a] Includes all field crops grown by a farmer during last one year. For non-marketed crops, price was calculated through opportunity cost principle.
*** and ** indicate that mean differences in value between the adapters and non-adapters are significant at 1% and 5% level of significance, respectively.

A multivariate probit model exploring farmers' M number of adaptation decisions can be written as [65]:

$$y_m^* = x_m'\beta_m + \varepsilon_m, y_m = 1 \; if \; y_m^* > 0, 0 \; otherwise, m = 1, \ldots, M$$

$$E\left[\varepsilon_m | x_1, \ldots, x_M\right] = 0$$

$$\text{Var}\left[\varepsilon_m | x_1, \ldots, x_M\right] = 1$$

$$\text{Cov}\left[\varepsilon_j, \varepsilon_m | x_1, \ldots, x_M\right] = \rho_{jm}$$

$$\left(\varepsilon_1, \ldots, \varepsilon_m\right) \sim N_M\left[0, R\right] \quad (1)$$

The joint probabilities of the observed events $\left[y_{i1}, y_{i2}, \ldots, y_{iM} | x_{i1}, x_{i2}, \ldots, x_{iM}\right],\ i = 1, \ldots, n,$ that form the basis for the likelihood function are the M -variate normal probabilities [65]:

$$L_i = \Phi_M\left(q_{i1}x'_{i1}\beta_1, \ldots, q_{iM}x'_{iM}\beta_M, R^*\right), \quad (2)$$

where,

$$q_{im} = 2y_{im} - 1$$

$$R^*_{jm} = q_{ij}q_{iM}\rho_{jm}$$

where ρ_{jm} is correlation between ε_j and ε_m. The distributions are independent if and only if $\rho_{jm} = 0$. Then equations for farmers facing m adaptation choices can be written as:

$$\begin{cases} y_1^* = x'\beta_1 + \varepsilon_1,\ y_1 = 1\ if\ y_1^* > 0,\ 0\ otherwise \\ y_2^* = x'\beta_2 + \varepsilon_2,\ y_2 = 1\ if\ y_2^* > 0,\ 0\ otherwise \\ \vdots \\ y_m^* = x'\beta_m + \varepsilon_m,\ y_m = 1\ if\ y_m^* > 0,\ 0\ otherwise \end{cases} \quad (3)$$

The stochastic component (ε_m) takes care of all the unobservable factors that may explain the marginal probability of deciding to adopt a strategy m. Each ε_m is drawn from an M -variate normal distribution with zero conditional mean and variance normalized to unity, where $\varepsilon_m \sim N\left(0, \sum\right)$, and the covariance matrix $\sum$ is given by Ref. [66]:

$$\sum = \begin{bmatrix} 1 & \rho_{12} & \cdot & \cdot & \cdot & \rho_{1m} \\ \rho_{21} & 1 & \cdot & \cdot & \cdot & \rho_{2m} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \rho_{m1} & \rho_{m2} & \cdot & \cdot & \cdot & 1 \end{bmatrix} \quad (4)$$

The off-diagonal elements of the covariance matrix (ρ_{jm}) are of our particular interest. The elements represent the unobserved correlation between the stochastic components of the j^{th} and m^{th} types of livelihood decisions [66]. Because of symmetry in covariances, that is $\rho_{jm} = \rho_{mj}$, the joint estimation of Eq. (4) is not only efficient but also allows us to estimate the joint probabilities of the various livelihood-based decisions. The marginal probability of observing m^{th} livelihood option adoption can be expressed as [66]:

$$\text{Prob}\left(y_m = 1\right) = \Phi\left(x'\beta_m\right)\ for\ all\ m = 1 \quad (5)$$

where $\Phi(.)$ is the cumulative density function (CDF) of the standard normal distribution. According to Young et al. [66], the joint probabilities of observing all possible types of livelihood options take-up comes from the M -variate standard normal distribution:

$$\text{Prob}\left(y_1 = 1, \ldots, y_m = 1\right) = \Phi_m\left(x'\beta_1, \ldots, x'\beta_m; \sum\right) \quad (6)$$

Based on the learning from the literature and FDGs, we identified several farm and farmer specific characteristics (e.g. age, education, subsistence pressure, income sources, information source and access) and conditions (e.g. fixed effect variables such as location, volumetric water pricing) and included those as explanatory variables in the analysis. The definitions of the variables included in the model are presented in Table 2.

alt-text: Table 2

Table 2

The table layout displayed in this section is not how it will appear in the final version. The representation below is solely purposed for providing corrections to the table. To preview the actual presentation of the table, please view the Proof.

Definition and summary statistics of explanatory variables used in the model.

Household and household head's characteristics	Description of the variables	Mean	S.D.
Age	Age of the household head (years)	46.42	11.70
Education of head (Base = illiterate or informally literate)			
Primary	Dummy for primary education (value is 1 if years of schooling >0 and ≤5, 0 otherwise)	0.25	0.43
Secondary	Dummy for secondary education (value is 1 if years of schooling >5 and ≤10, 0 otherwise)	0.35	0.48
Higher secondary & above	Dummy for secondary and above education (value is 1 if years of schooling >10, 0 otherwise)	0.09	0.28
Subsistence pressure, labour use and land resources			
Dependency ratio	Ratio of dependent (i.e. children, student, sick, aged and other members who do not participate in any economic activities) and total family member	0.56	0.18
Female labour share	Ratio of female family members working in agriculture to total household members in agriculture	0.23	0.25
Cultivated land	Log of gross cropped area (ha)	0.75	0.78
Income sources*			
Off-farm income	Dummy for off-farm income (value is 1 if the household had off-farm income, 0 otherwise)	0.59	0.49
Fisheries	Dummy for fisheries income (value is 1 if the household earned from fisheries, 0 otherwise)	0.41	0.49
Livestock and poultry	Dummy for income from poultry & livestock (value is 1 if the household had income from livestock and poultry, 0 otherwise)	0.68	0.47
Institutional factors and ICT			
Volumetric water pricing	Dummy for households paying volumetric water pricing (value is 1 if irrigation cost was volumetric; 0 if the household paid area-based irrigation charges)	0.62	0.49
Use of mobile phone in farming	Dummy for use of mobile phone in farming activities such as communicating buyers and sellers, seeking farming advices and weather forecast, etc. (value is 1 if the household used mobile phone for any of these purposes, 0 otherwise)	0.59	0.49
Involvement with organizations	During the survey, households were asked to mark their level of involvement with - cooperatives, market committee and NGOs, in a scale of 5 where higher score means more regular and active participation. The score mentioned against each organization was than divided by the maximum attainable score (i.e. 5) and the summation of scores were divided by three. This gives an index value between 0 and 1, where higher score indicates higher level of involvement.	0.05	0.10
Extension services	Dummy for extension service (value is 1 if the household received extension service during last year, 0 otherwise)	0.67	0.47
District fixed effects (Base = Naogaon)			
Rajshahi	Dummy for households living in Rajshahi (value is 1 if the household was from Rajshahi; 0 otherwise)	0.34	0.47
Bogura	Dummy for households living in Bogura (value is 1 if the household was from Bogura; 0 otherwise)	0.34	0.47
Climate change effect			
Affected area	Dummy for severely climate change affected areas, identified by the local agriculture office (value is 1 if the area was severely affected, 0 otherwise).	0.50	0.50

Note: * Spearman rank correlations of the three sources of income dummy variables were conducted which shows negatively significant correlation with very small correlation coefficient values between fisheries and livestock (−0.148) and between livestock and off-farm income (−0.224). Therefore, there is no issue of multi-collinearity.

4 Results

4.1 Socio-economic and demographic profile of the farmers

Table 1 presents summary statistics of the variables used in the econometric analysis, i.e. the resource base and conditions, which may shape a farmer's adaptation decisions. The average age of the respondent farmers was 46 years with 60% being educated up to primary level only. The dependency ratio of 0.6 implies that every four economically active persons need to support around six economically inactive individuals within the household. One in four family members involved in farming were women. Around two out of every three households reported to receive extension service, which is much higher compared to that reported in earlier literature [67]. Although mobile phone is the most common household asset and almost all households in Bangladesh have access to phone [68], 60% of the households use it specifically for farming purposes as well, which is substantial.

4.2 Climate change adaptation strategies at the farm-level

Seven different adaptation strategies or actions were identified of which six are 'technology-based' strategies and the rest was 'labour/family-based' strategy (Table 2). The most common strategy in the water-stressed region is 'adjusting irrigation frequency and level' (64.6%) closely followed by 'increasing intensity of chemical inputs' (62.7%). Water-stress led 49.1% and 39.8% of the farmers to adopt drought tolerant variety and less water intensive crops, mostly vegetables, respectively. Another 41.1% farmers adopted 'short duration variety cultivation'. Substituting farming with off-farm activities is the least frequently reported strategy (6.9%) (Table 2). Only 10.4% of the farmers did not follow any adaptation strategies whereas 30% and 21.3% have undertaken two and three strategies, respectively. Overall, at least 80% of the farmers have undertaken two to seven strategies (Fig. 5). Farmers who adopted adaptation strategies generated higher output as compared to those who did not, except the off-farm income strategy adapters (Table 2).

alt-text: Fig. 5

Fig. 5

Distribution of proportion of farmers based on number of strategies adopted (%).

4.3 Joint determination of farmers' climate change adaptation strategies

The marginal effects of the explanatory variables used to analyze farmers' adaptation decisions and the model diagnostics are presented in Table 3 .[5] One of the key hypotheses in the multivariate model is that the 'correlations of the error terms across seven equations are jointly zero'. The null hypothesis is strongly rejected at the 1% level of significance, thereby justifying superiority of our chosen approach as compared to those available in the literature.

alt-text: Table 3

Table 3

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Marginal effects from the joint estimation of the determinants of undertaking different adaptation strategies.

Variables	Drought tolerant variety cultivation	Short duration variety cultivation	Adjusting farming calendar	Increasing intensity of chemical inputs	Adjusting irrigation frequency and level	Shifting towards non-rice crops	Undertaking off-farm activities
Age	0.003* (0.001)	0.0004 (0.002)	0.002 (0.002)	0.002 (0.002)	0.002 (0.002)	0.001 (0.002)	−0.003*** (0.00
Primary education	−0.020 (0.047)	0.075 (0.054)	−0.012 (0.059)	0.007 (0.058)	0.178*** (0.058)	0.021 (0.057)	0.038 (0.029)
Secondary education	0.00002 (0.044)	0.085* (0.048)	0.037 (0.053)	−0.062 (0.053)	0.047 (0.054)	0.053 (0.051)	0.012 (0.029)
Higher secondary and above	0.038 (0.073)	0.011 (0.075)	0.229*** (0.083)	0.095 (0.089)	−0.032 (0.083)	0.009 (0.078)	−0.022 (0.043)
Dependency ratio	0.380*** (0.107)	0.254** (0.116)	0.115 (0.126)	0.398*** (0.122)	0.072 (0.129)	−0.131 (0.124)	0.155* (0.081)
Female labour	−0.386*** (0.105)	−0.389*** (0.112)	−0.313*** (0.133)	−0.463*** (0.135)	−0.052 (0.138)	0.125 (0.127)	−0.069 (0.064)
Cultivated land	0.088 (0.058)	0.199*** (0.064)	−0.010 (0.073)	0.033 (0.072)	−0.047 (0.072)	0.271*** (0.067)	−0.016 (0.040)
Off-farm income source	−0.027 (0.039)	−0.035 (0.042)	−0.017 (0.047)	−0.002 (0.048)	0.089* (0.048)	0.028 (0.046)	0.006 (0.024)
Fisheries income source	0.020 (0.041)	−0.010 (0.045)	0.025 (0.050)	−0.071 (0.050)	0.002 (0.051)	−0.065 (0.047)	0.020 (0.026)
Livestock income source	0.084** (0.042)**	0.135*** (0.045)	0.144*** (0.051)	0.167*** (0.048)	0.045 (0.051)	−0.005 (0.048)	0.059** (0.029)
Volumetric water pricing	0.060** (0.039)	0.006 (0.046)	0.113 (0.052)	−0.140 (0.048)	−0.014 (0.053)	0.153** (0.051)	−0.002 (0.030)
Extension services	0.072* (0.199)	0.056 (0.231)	0.141*** (0.248)	−0.080 (0.221)	0.088 (0.243)	−0.008 (0.246)	−0.034 (0.180)
Mobile phone use	0.163*** (0.073)	0.092** (0.080)	0.012 (0.092)	0.203*** (0.084)	−0.048 (0.086)	0.022 (0.076)	0.036 (0.042)
Involvement with organizations	0.472*** (0.044)	0.612*** (0.051)	−0.324 (0.056)	−0.027 (0.055)	0.090 (0.057)	1.218*** (0.054)	−0.086 (0.030)
Rajshahi	0.337 (0.046)***	0.428*** (0.050)	0.153*** (0.062)	0.172*** (0.063)	0.137** (0.061)	0.115* (0.059)	0.110*** (0.032)
Bogura	0.772*** (0.080)	0.708*** (0.088)	0.528*** (0.107)	0.294*** (0.107)	0.281*** (0.109)	−0.109 (0.101)	0.076 (0.058)
Affected area	0.016 (0.044)	0.133*** (0.047)	0.119** (0.053)	−0.043 (0.053)	0.118** (0.053)	−0.149*** (0.050)	0.056* (0.030)
Model diagnostic							
Wald χ^2	551.27***						
Log likelihood	−1575.18						
LR test $H_0: \rho_{SDDT} = \rho_{FCDT} = \rho_{AIDT} = \rho_{CIDT} = \rho_{NRDT} = \rho_{OFDT} = \rho_{FCSD} = \rho_{AISD} = \rho_{CISD} = \rho_{NRSD} = \rho_{OFSD} = \rho_{AIFC} = \rho_{CIFC} = \rho_{NRFC} = \rho_{OFFC} = \rho_{CIAI} = \rho_{NRAI} = \rho_{OFAI} = \rho_{NRCI} = \rho_{OFCI} = \rho_{OFNR} = 0$							
χ^2 (21)	112.137***						
Predicted marginal probability	0.498	0.416	0.439	0.642	0.625	0.395	0.068
Correlation between error terms							
Short duration variety cultivation	0.540*** (0.079)						

Adjusting farming calendar	0.319*** (0.079)	0.352*** (0.071)					
Increasing intensity of chemical inputs	0.104 (0.083)	0.130* (0.080)	0.017 (0.076)				
Adjusting irrigation frequency and level	0.045 (0.083)	0.093 (0.079)	0.064 (0.077)	0.045 (0.075)			
Shifting towards non-rice crops	−0.095 (0.083)	−0.115 (0.080)	−0.254*** (0.074)	−0.230*** (0.076)	−0.356*** (0.072)		
Undertaking off-farm activities	0.229* (0.130)	0.077** (0.033)	0.117 (0.139)	0.168 (0.124)	0.104 (0.129)	−0.196** (0.109)	

Note: Figures in parentheses are the standard errors. ***, ** and * represent a significant level of 1%, 5% and 10%, respectively.

4.4 Socio-economic and demographic characteristics and adaptation strategies

To represent a household's socio-economic and demographic profile we used five types of explanatory variables: head's age, head's education, dependency ratio, amount of cultivated land and dummy variables for different income sources. Head's age significantly increases the probability of adapting ‘drought tolerant variety cultivation’ but reduces the probability of ‘undertaking off-farm activities’. Different levels of educational attainment significantly increase the probability of undertaking different strategies with higher level of influence with an increase in the level of education. Subsistence pressure has a prominent influence on the probability of choosing four out of seven strategies namely, ‘drought tolerant variety cultivation’, ‘short duration variety cultivation’, ‘increasing intensity of chemical inputs’ and ‘undertaking off-farm activities’. The amount of land significantly increases the probability to undertake ‘short duration variety cultivation’ and ‘undertaking off-farm activities’. Income from poultry and livestock sources significantly increases the probability of undertaking ‘drought tolerant variety cultivation’, ‘short duration variety cultivation’, ‘adjusting farming calendar’, ‘increasing intensity of chemical inputs’, and undertaking off-farm activities. Share of female labour in farming significantly reduces the probability of undertaking four of the seven adaptation strategies, viz. ‘drought tolerant variety cultivation’, ‘short duration variety cultivation’, ‘adjusting farming calendar’, and increasing intensity of chemical inputs.

4.5 Institutions, ICT and adaptation strategies

A farmer paying volumetric water pricing has a significantly higher probability of adopting ‘drought tolerant variety cultivation’ and/or ‘shifting towards non-rice crops’ strategies than their counterparts who pay area based fixed changes.

Access to government extension services significantly increases the probability of adopting ‘drought tolerant variety cultivation’ and ‘adjusting farming calendar’ strategies. Similarly, use of mobile phone for farming purposes significantly increases the probability of choosing three adaptation strategies. Furthermore, households' involvement with different formal and informal organizations (e.g. cooperatives, market committee and NGOs) significantly increases the probability of choosing three of the seven adaptation strategies. Adaptation strategies varies significantly by location. Farmers in Rajshahi and Bogra districts have a significantly higher probability of undertaking several adaptation strategies.

The associated signs with the dummy variable for affected area across equations reveal that compared to the less-affected areas, farmer in the severely affected areas have a higher probability of adopting ‘short duration variety cultivation’, ‘adjusting farming calendar’, ‘adjusting irrigation frequency and level’ and ‘undertaking off-farm activities’. Similarly, farmers from the areas severely affected by climate adversities are more likely to undertake a number of adaptation strategies except choosing ‘shifting towards non-rice crops’.

4.6 Synergies in adaptation strategies

A unique feature of the multivariate probit model is that it enables testing correlations of the disturbance terms between any pair of equations $(i.e.\ \rho_{jk}=0)$, which enables us to determine whether there are synergies in farmers' adaptation strategies. The positive and negative correlation between the error terms of two equations implies that relationships between farmers’ chosen adaptation strategies are complementary and supplementary, respectively.

The lower part of Table 3 presents full-range of correlations across pair of equations. For example, the error terms of ‘drought tolerant variety cultivation’ has a significant positive correlation with ‘short duration variety cultivation’, ‘adjusting farming calendar’ and ‘undertaking off-farm activities’ strategies, implying that these strategies are complements to each other. Similarly, choice of ‘short duration variety cultivation’ has a complementary relationship with ‘adjusting farming calendar’, ‘increasing intensity of chemical inputs’ and ‘undertaking off-farm activities’ strategies. On the other hand, ‘shifting towards non-rice crops’ as a strategy has a substitution relationship with ‘adjusting farming calendar’, ‘increasing intensity of chemical inputs’, ‘adjusting irrigation frequency and level’ strategies and ‘undertaking off-farm activities’.

5 Discussions

Climate change in northwestern Bangladesh is not a sporadic event, rather taking place gradually. The region not only have low and skewed average temperature and rainfall compared to other regions, but also the ground water level is depleting (Figs. 1–4). These are regular stimulus driving farmers towards different adapting strategies and actions, particularly ‘technology-based’ adaptation strategies, which do not require any major adjustment and changes in farming practices and applicable for all crops across seasons. Rahman [69] noted significant influence of climatic factors and events on Bangladeshi farmers' crop choices. Adaptation of ‘undertaking off-farm activities’ by few farmers implies that climate stress as a push factor towards off-farm activities is less effective in the region. This may be due to households' lack of ‘means’ (human, physical and financial resource base) and/or outcome of high level of ‘constraints’ (limited opportunity available in the locality). Adaptation of multiple strategies established that synergies exist amongst some strategies (Fig. 5, Table 3).

Compared to the non-adapters, the adapters produce significantly higher value of output, which implies that choosing certain option not only enables farmers to cope with the problem of climate change but also do pay-off through higher output. Results from the synergy analysis show that patterns of adaptation by farmers choosing rice-based adaptation strategies is different than those who shifts away from rice altogether. For example, when a rice grower experiences inadequate monsoon rainfall, go on to choose drought tolerant variety, which is a common practice among the food crop growers across water stressed regions across globe [70]. Similarly, due to changing winter pattern where the duration of the winter season is shortening with very low temperatures (mainly during December, beginning of the winter rice season) and heavy fog, leading to cold injuries to rice seedlings, farmers are choosing to adjust farming calendar by shifting sowing period backward by a few days/weeks. Observing increasing incidences of early winter in the northern Bangladesh, Chowdhury and Hassan suggested early sowing of mustard seeds. The author also suggested early sowing of sesame in the summer season to achieve higher yield [71]. Similar practices are observed in the salinity stressed southern Bangladesh where farmers do early seedling transplantation to tackle salinity risk [72]. Only when this adjustment of calendar is followed-up by planting short duration variety in the summer season, the farmer can sow monsoon rice in due time. Choice of short duration variety also helps farmers when there is less rainfall during beginning of summer. Choice of short duration variety is likely to be associated with intensified chemical input use, probably from the fear of possible climatic affect, which has implications on human health, as noted by

Boxall et al. [73]. But a farmer may behave differently, for instance, when a water-stressed farmer undertakes water preservation measures by choosing non-rice crops over rice and/or drought tolerant rice variety.

The negative correlation of 'undertaking off-farm activities' with 'shifting towards non-rice crops' implies that farmers substitute between farming and non-farm enterprises. Furthermore, choice of 'shifting towards non-rice crops' makes a farmer less likely to 'adjusting farming calendar', 'adjusting irrigation frequency and level' and 'increasing intensity of chemical inputs', because those are mainly relevant for rice-based cropping system. In Bangladesh, though non-rice crops are mainly cultivated during dry winter, the concern of cold injuries are less likely since they are planted a couple of months prior to the winter season rice and the cold snap during December cannot do much harm to the matured plants. Besides, farmers try to fit non-rice crops between two seasons of rice, where farming calendar adjustment is difficult. Compared to rice, many of the non-rice crops require less irrigation and chemical inputs, particularly urea fertilizer. Hence, when a farmer shifts away from rice, farming is less likely to require more irrigation and chemical inputs. Crop diversification, particularly shifting away from food crops is a widely suggested climate smart technology, particularly in the water stressed areas. Such diversity in farmers' adaptation behaviour, though the stimuli are identical across farms, argue for differences in farmers' adaptive capacity, which can be explained by differences in their available resource base and other biophysical and agro-ecology specific factors that are beyond farmers' control.

Studies exploring relationship between age and technology adoption reports mixed results, which may not be linear at all levels of age. For instance, since age and experience are positively correlated, the aged farmers are more likely to perceive climate change and take necessary adaptive measured [74,75]. Experienced and older farmers are likely to accumulate assets and gain access to extension services or development projects [76] and hence are likely to undertake various adaptation strategies in a conducive adaptive environment. Also, since older farmers earn relatively higher portion of their total income from farming [77], they may be less reluctant to explore off-farming opportunities. Beyene argued that with age, the demand for leisure increases, which decreases the likelihood of choosing off-farm activities [78].

It is generally perceived and reported in the literature that education contributes to agricultural technology adoption [e.g. 79, 80], which was observed to work selectively in our analysis. The reason of relatively weaker influence of educational attainment may be due to disconnect between agriculture and the mainstream education system in Bangladesh. Very few agricultural institutions exist in Bangladesh at the tertiary level with even fewer focusing on the foundation level, thereby, hardly providing skills and knowledge required in farming.

Households with higher level of subsistence pressure indicate availability of fewer economically active members, thereby, may have increased need to adapt climate change strategies, which is consistent with the findings of Ojiako et al. [81]. The positive association between technology adoption and farm size is well documented in the literature [e.g. 82, 83]. The result is a concern for Bangladesh, since 84% of country's total farm households belong to the category of marginal and small farmers owning less than 1 ha of land [7]. For these land constrained farmers, ensuring food-security is paramount through cultivating rice in both monsoon and winter seasons. Therefore, 'shifting towards non-rice crops' may take place only with an increase in cultivated land.

Previous studies showed that, the relationship between income source and adoption is a complex one. For instance, farmers earning significant amount from off-farm activities are likely to adopt new agricultural technologies [e.g. 84, 85], particularly in areas where the capital market is poorly functioning and opportunities outside the farm is limited [86]. Alternatively, in areas where return from off-farm activities is higher than farming, a farmer may be reluctant in adopting farming technologies [87].

Addressing gender in climate change policy is important for ensuring sustainability of the system, though the issue is often overlooked in many policies and international treaties [88]. The negative association between female labour and adaptation of strategies are similar to that of Jost et al. for farming communities in Uganda, Ghana and Bangladesh [89]. The authors reported several constraints that are common to women: limited access to information and extension services, financial and resource constraints, social norms and security, individual characteristics like education, health and household responsibilities, etc. [89]. The negative relationship here is worth exploring as globally women's participation in agriculture is increasing [90] with empirically confirmed productivity and efficiency enhancing roles [91]. Bangladesh is no exception where compared to men, women have higher participation rate in the agricultural labour force [54], due to gradual increase over time [92].

There are several other factors that are beyond farmers' control (i.e. constraints) but can contribute to creating an enabling adaptation environment. For instance, volumetric water pricing enables a farmer to reduce irrigation cost through cultivating less water intensive crops such as drought tolerant variety and/or non-rice crops. However, in the predominant area-based water pricing system a farmer does not have any such incentive, which is the common practice in Bangladesh A large portion of the norther region irrigation market is different, where government organizations in severely water-stressed areas practice volumetric water pricing.

The dominant influence of location on adaptation strategies is consistent with the earlier literature on technology adoption, which argued for improved infrastructure [55,79, 93,94]. Among the three districts, Naogaon is an ordinary district which is notably less vibrant in terms of economic activities, whereas Rajshahi is the divisional headquarter of the three surveyed districts and Bogra is an important business hub and particularly famous for producing farm machinery.

The positive association between extension services and adaptation strategies is in line with the well-documented role of access to information on technology adaptation [47]. Similarly, farmers with higher level of involvement with different farming and marketing organizations are likely to have more exposure to information and facilities and hence they are more likely to explore potential technologies [95]. The importance of modern communication technologies in adoption is immense, particularly when the government extension service is increasingly being criticized for inefficiency [96]. Moreover, use of mobile phone in farming has implications on farm efficiency, as noted by Mwalupaso et al. [97] in case of Zambian maize producers.

Results also confirm that farmers located in the severely affected areas from climate change are more proactive in undertaking rice-based adaptation strategies than their counterparts located in less affected areas. However, adaptation of these strategies may be insufficient to mitigate the effects of climate change on rice production and hence farmers in these areas may not be able to release additional land for non-rice crops, indicated by less likelihood of adopting 'shifting towards non-rice crops'. The same reason also applies for farmers located in these areas to choose non-farm activities.

The contribution of our study to the existing literature on climate change adaptation strategies are as follows. First, our research findings have appeal beyond the study region since it is based on the well-established action theory. This is particularly true for the smallholder dominated drought prone areas since the explored adaptation strategies are not unique for Bangladesh. Moreover, though the frequency and severity and hence the associated effects of droughts may vary, there are similarities in constraints that are typical for the smallholders in the drought prone Sub-Saharan African and South Asian countries. Our research is helpful to understand how the available resources and factors that may or may not be within a farmer's control shape up his/her adaptive capacity, and ultimately different categories of farmers behave differently. Second, at the conceptual level we classified climate adaptation strategies undertaken by farmers within five typologies identified by Harmer and Rahman [27] by considering those which are purely 'adaptation' strategies and/or 'coping' strategies, hence addressed the issue of mixing up 'adaptation' and 'coping' strategies in the literature. Third, we have examined various strategies undertaken by each sampled farmer to gauge the level and extent of actions undertaken to combat climate change anomalies. Fourth, we have included a wide range of determinants including farm-level socio-economic characteristics as well as institutional and ICT factors, which is not commonly seen in any individual study in the literature. Fifth, is a methodological improvement where we specified a system of multiple equation probit models representing all adaptation strategies, which allowed us not only to jointly determine factors influencing each adaptation strategy, but also provided information on the existence of any synergy and/or competition between strategies.

6 Conclusions and policy recommendations

The study investigated various strategies undertaken by farmers in drought prone areas to combat climate change effects, identified the determinants of undertaking these multiple strategies jointly and examined whether synergy or competition exist between different adaptation strategies.

Results revealed that, in response to these climatic variations and increasing water stress, farmers in the region adapted one or more of the seven common strategies of which six were technology-based and the other was labour/family-based adaptation strategies. About 80% of the farmers undertook two or more climate change adaptation strategies mainly within the domain of technology-based solutions. Three of the seven adaptation strategies delivered significantly higher value of output per ha as compared to the non-adopter farmers, implying that undertaking adaptation strategies not only enable farmers to cope with the adverse effect of climatic variability but also makes farming relatively more profitable.

Among the wide range of determinants, education does not have a robust effect on adaptation decisions. Subsistence pressure is an important driver influencing adaptation of selected climate-change adaptation strategies, whereas the use of female labour has an opposite effect. The role of farmers' age varies depending on the strategy adapted. Income from livestock and poultry significantly increases the likelihood of undertaking several adaptation strategies. Institutions, ICT and geographic location also significantly increase the likelihood of undertaking multiple adaptation strategies. Synergy exists between some of the climate-change adaptation strategies, mainly rice-based technology solutions. On the other hand, competition exists between rice-based and non-rice crop based adaptation strategies.

The following policy interventions are suggested which could bring desired changes for the farmers by creating an enabling adaptation environment. First, strengthening extension services, particularly targeting women and areas with unfavorable geographic locations, which will enable farmers to adapt rice-based strategies (e.g. choosing drought tolerant varieties and adjusting farming calendar) to combat climate change effects. Second, promoting use of ICT in farming and extension services. Several ICT based farming tools, such as fertilizer recommendation guide, and different apps to get information on crop suitability and agricultural weather forecast are available in Bangladesh, but the extent of their actual use at the farm level is not known. Third, organizations (e.g. cooperatives, market committees and NGOs) should facilitate easy access of farmers to join, since such involvement encourage undertaking both rice and non-rice based adaptation strategies. Fourth, given weak relationship between education and adaptation strategies, incorporation of climate-focused information within the education system should be emphasized to enhance understanding of climate change effects. Fifth, given the significant role of livestock rearing on rice based and off-farm adaptation strategies, measures should be undertaken to reinvigorate livestock rearing practices. Finally, research is needed to explore underlying reasons behind women's low adaptation probability.

Our recommendations complement literatures arguing for strengthening extension services for the promotion of climate sensitive crop variety adoption [32] and importance of wider dissemination of climatic information at the farm level for promoting different adaptation strategies [16]. Role of different types of networking and community organizations were also reported in the literature as crucial for adaptation [98]. We have recommended ICT, based on our results, as a tool in promoting networking and access to institutions. The recommendation for promoting livestock rearing is for easing farm household's financial constraints for adoption, whereas literature suggested to overcome such constraints through access to credit facilities [32,35].

Climate change is a long-term concept and literature mainly considers changes in temperature, rainfall and natural hazard patterns. But long-term data on many of these changes and associated impacts at the farm level are largely non-existent. For instance, an individual can observe changes in rainfall and temperature and depleted soil and water quality but cannot quantify the extent of the problem. Therefore, a suitable alternative is to consider adaptation strategies undertaken in response to climate variability experienced by farmers, which we applied in our work. However, we acknowledge that this is a proxy measure and may not be able to capture the dynamics that exist between climate change and farmers' adaptation strategies over time. Therefore, there is need to develop long-term database that will allow examination of dynamic relationship between climate variabilities and farmers' adaptation strategies over time.

Declaration of competing interest

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

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Appendix Protocol followed in Focus Group Discussion

- Number of participants: Each FGD had 10-12 participants.
- Duration of FGDs: The time duration of the FGDs were between 60 and 90 min.
- Identifying participants: Participants were mainly leaders and proactive members of different farmers' groups and organizations, who were selected with the help of the local agricultural extension office. Attention was given so that all categories of farmers, gender balance, age groups are covered:
  - In accordance with national statistics, 80% of the participants were chosen to be marginal and small farmers (owner of less than 1 ha of land). The rest were medium and large farmers (owner >1 ha of land).
  - In each of the FGDs, at least three participants were female.
  - Representation of different age groups were ensured. Since, few of the younger farmers were in the leadership position of different organizations, their participation was ensured through selected of active members.
  - In addition to growing field crops, at least four participants in each FGD were involved with livestock and fisheries.
  - Similarly, some participations of farm households who have off-farm income sources were included.
  - The agricultural office was requested to suggest on the combination of owner-operator, owner-operator cum tenant and pure tenant in the selected villages, based on their knowledge of the study areas.
- One of the authors facilitated the FGD sessions, while a Research Assistant took the notes.
- After proper introduction and explanation of the goals and objectives of the discussion, the facilitator proceeded to the topic of interest. Rather than specific questions, the following broad topics were placed for discussion:
  - Climate change patterns in the locality
  - Impact of climate change on livelihood and particularly farming

- Farmers' adaptation strategies
- The drivers and barriers of adaptation

- A common meeting place, which was comfortable and does not bias informants, easily accessible, and where participants can see one another was chosen for the FGDs. In most of the instances, the yard of a school was chosen.

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The corrections made in this section will be reviewed and approved by a journal production editor. The newly added/removed references and its citations will be reordered and rearranged by the production team.

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Footnotes

Text Footnotes

[1] The paired *t*-test of mean-difference between northern region and rest of the country for both temperature and rainfall show that the differences between both the variables are significant at 1% level of significance.

[2] The Herfindal Index is defined as $\sum_{i=1}^{n} P_i^2$; where, $P_i = \sum_{i=1}^{n} \frac{a_i}{A}$, i.e. proportionate area of a crop to the gross cropped area. The index value lies between 0 and 1, where higher value indicates higher level of specialization.

[3] Earlier Bangladesh had 17 districts, which are known as greater districts. These districts were gradually split into 64 districts.

[4] The detailed protocol of the FGDs is presented in Appendix.

[5] The coefficients are not reported owing to space constraint but can be provided upon request.

Highlights

- Factors influencing seven climate change adaptation strategies jointly estimated.
- About 80% of the households adapted two to seven climate change strategies.
- Synergies exist between technology-based climate change adaptation strategies.
- Education, subsistence pressure and improved location positively influence adaptation strategies uptake decisions.
- Access to extension services, ICT and organizations also promote adaptation strategies.
- Diversification away from rice-farming and institutional strengthening suggested.

Queries and Answers

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