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# Farmers' adaptation to water scarcity in drought-prone environments: A case study of Rajshahi District, Bangladesh

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**Abstract**

Water scarcity and droughts pose serious threats to the livelihood of farming communities and the economy in many parts of the world. Using a survey of 546 farming households and employing multinomial logit regression, this study investigates rice farmers' adaptation to water scarcity in a semi-arid climate in Bangladesh. It identified factors determining farmers' adaptation responses to addressing water scarcity. The analysis shows that farmers with more experience of farming, better schooling, more secure tenure rights, better access to electricity and institutional facilities, and an awareness of climatic effects are more likely to adopt alternative adaptation strategies. Farmers' alternative adaptation choices are examined in comparison to the traditional approach of groundwater irrigation. This study raises issues of sustainability of agricultural adaptation practices in the context of an increasing dependence on groundwater irrigation. The results provide an insight to sustainable irrigation practices and an understanding of the characteristics of farms and farming households to frame better strategies to cope with water-stressed regimes in drought-prone environments.

**Key words:** Adaptation, Bangladesh, Climate change, Drought, Rice farming, Multinomial logit model, Water scarcity

## 1.0 Introduction

With its 156 million people and small land area, Bangladesh is one of the world's most densely populated nations. It is also one of the most vulnerable to the adverse impacts of climate change (World Bank, 2013; Rashid et al., 2012; IPCC, 2007). Floods dominate the number of disaster events and amount of damage in Bangladesh. However, droughts have become a recurrent phenomenon in the country in recent years, particularly in the northwest region because of its high variability and uncertain rainfall (Habiba et al., 2011; Shahid and Behrawan, 2008). Shahid (2010) predicted an increased severity of droughts in the near future in Bangladesh. Over 100 million people (64.1%) live in rural areas and their livelihood and overall food production are vulnerable to extreme climate events. Droughts affect rice crops in all three cropping seasons in Bangladesh – about 0.45, 0.40 and 0.34 million ha of land are affected by severe droughts each year during *Rabi*, *Pre-kharif* and *Kharif* seasons[1], respectively (Habiba et al., 2011). Aman[2] accounts for 38% of Bangladesh's annual rice production of 34 million tons (BBS, 2012). As much as 17% of the Aman crops are lost in a typical year due to drought (DMB, 2010).

Mitigating drought and water scarcity is time consuming, difficult to implement and often requires huge investment. Farming practices should, therefore, adapt to the changing environment. Farmers' decision-making processes on adopting improved technology and irrigation management systems have been extensively studied in the literature (Gebrehiwot and van der Veen, 2013; Mertz et al., 2009; Pereira et al., 2002;). The majority of the adaptation studies to date focus on climate change and variability in general (Gobrehiwot and

[1] There are three cropping seasons based on the time of sowing and harvesting, namely Rabi (16 October–15 March), Pre-Kharif (16 March–30 June) and Kharif (1 July–15 October), during a year in Bangladesh.

[2] All rice varieties cultivated in the country are grouped into three distinct ecotypes, namely Aus, Aman and Boro. The Boro crop is grown completely under the irrigated ecosystem during the dry period (November–July) while Aman (July–December) and Aus (April–August) are grown under the rain-fed ecosystem.

van der Veen, 2013; Tessema et al., 2013; Bryan et al., 2009; Deressa et al., 2009). Studies specifically focusing on adaptation to drought and water scarcity are scarce.

Most climate adaptation studies are African focused (see, e.g., Juana et al., 2013 for a review of the studies), where agro-ecological, socio-economic and climatic conditions are distinctly different to other regions. There is no single approach to drought adaptation, nor does one solution fit all regions or countries. Rashid et al. (2013) also found that climate variability affected different climate zones differently in Bangladesh which warranted the need for more location-focused adaptation strategies. Each region (e.g., 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. Mertz et al. (2009) emphasised developing a better understanding of local and regional climate change scenarios as well as local adaptive strategies and capabilities for developing adaptation solutions.

Most studies focus on farmers' perceived or anticipated adaptation behaviours and there is little focus on actual or current behaviour and best management practices at farm level. In addition, adaptation research does not take into account sustainability issues in designing and implementing adaptation measures. Wall and Smit (2005) pointed out that despite the established nexus between climate change adaptation and sustainable agricultural practices, such linkages are rarely explored in the literature, nor are issues of sustainability integrated into the planning and implementation of adaptation policies and strategies in public and private initiatives.

Climate change adaptation strategies and sustainable agricultural practices need to be mutually supportive (complementary). For instance, farmers' current practices of adopting groundwater irrigation to cope with the growing water scarcity in the north-west region of Bangladesh resulted in the drawdown of groundwater tables, land subsidence and tube wells failing during dry seasons (Adhikary et al., 2013; Zahid and Ahmed, 2006; Dey et al., 2011).

These excessive withdrawals affect the sustainability of agricultural farming as groundwater supplies are being depleted to the potential detriment of future users.

Gebrehiwot and van der Veen (2013) noted serious consequences of drought for agriculture and food security and, consequently, the livelihood of rain-fed agriculture-dependent farming communities. Bangladesh has benefited from a long history of designing and implementing various adaptation strategies in the form of policies and capital investment, especially as they pertain to floods and cyclones (World Bank, 2010; Sarker et al., 2013). However, little has been done to design drought-resilient adaptation strategies for the agriculture sector. Drought-resilient strategies are important for rural livelihoods and the rural economy. Studies are required in different agro-ecological and climatic conditions to have a better understanding of farmers' adaptation behaviours and best management practices. Using Rajshahi, a drought-prone northwestern district in Bangladesh, as a case study, this research aims to provide adaptation practitioners with new insights on the factors affecting farmers' choice of adaptation in the study area. The following research questions are framed to achieve these aims: (i) what are the perceptions of farmers about climate change and variability, (ii) what are the key adaptation responses made by farmers and what are the factors affecting the adoption of adaptation strategies at the farm level, and (iii) what are the long-term sustainability implications of the current adaptation practices in the study area.

A better understanding of adaptation choices to address increasing water stress is of great importance to policy makers if the past phenomenal agricultural growth is to be sustained and to ensure food security for the country in the changing global environment. This research contributes to the literature by identifying rice farmer's responses to climatic variation in drought-prone environments. Clearly, understanding factors that influence farmers' choice of adaptation strategies and how these choices link with the sustainability of the agricultural practices is not only an academic challenge, but is also critical for policy making and implementation.

The rest of the paper is structured as follows: the next section reviews briefly the literature on adaptation and coping strategies and their determinants. Section 2 describes the geographic setting of the study area, data collection and sample selection procedures and the empirical model employed in this research. The results of the farmers' choices for different adaptation measures are presented in Section 3 with a discussion of the factors that influence their choices and the perceived barriers to adaptation. The conclusion in Section 4 presents policy implications.

### 1.1 Literature Review

This section briefly elaborates on the classification of adaptation strategies and factors influencing adaptation at the farm level to cope with extreme events. Agricultural adaptation to climate change refers to adjustments to farming systems in response to actual and/or anticipated climatic and non-climatic stimuli and conditions in order to avoid or to alleviate related risks or to realise potential opportunities (Smit et al., 2000; IPCC, 2001). Water scarce farms require innovative and sustainable adaptation strategies in order to maintain the productive capacity of the resource base. Adaptation may occur at different levels ranging from local to national to global. Agricultural farming practices are changing continually in terms of mechanisation, the adoption of high-yielding varieties and technological advancements.

Adaptation to extreme climate events has been a topic for recent research, chiefly focused on African developing economies and to a lesser extent in the developed countries (e.g., Wheeler et al., 2013; Nicholas and Durham, 2012). Climate change and extreme events will have negative and positive consequences in the agricultural sector in developed countries; however, in developing countries the consequences will be mostly negative. Additionally, the poor will be the most disadvantaged and marginalised and thus may be displaced (IPCC, 2014; Cannon, 2002). In the United States of America the impact of changes in climate variability are predicted to benefit crop productivity, although there will be strong regional differences (Reilly et al., 2003). Bindi and Olesen (2011) found that predicted warmer temperatures would affect European agriculture both positively and negatively depending on the crops and varieties and the adaptation measures undertaken. But studies indicate that African agriculture would be mostly negatively affected by climate change (Tessema et al., 2013; Bryan et al., 2009; Deressa et al., 2009). Farmers have traditionally been considered highly adaptable to extreme weather conditions, but climate variability poses new unpredictable risks for future farming practices.

Maddison (2007) noted perception and adoption of adaptation strategies were two key components of adaptation. This means that farmers first need to perceive a change in the climatic conditions and then implement a set of strategies to address them. Agricultural adaptation can vary depending on the agro-ecological and climatic conditions, farm types and socio-political and institutional arrangements. These include a wide range of forms, scales, timing and agents. Table 1 shows classifications commonly used in the adaptation literature.

**Table 1**
Classification of agricultural adaptations to climate change

| **Concept or attribute** | **Types** | **Key measures or examples** |
|---|---|---|
| Purposefulness/intent | Autonomous/spontaneous | Independently implemented by private actors, e.g., an adjustment to agricultural practices through crop diversification. |
| | Planned | Deliberate policy intervention by public sector agencies, e.g., setting of regulations, standards and policies. |
| Time scales | Anticipatory/proactive | Undertaken before impacts are observed, e.g., purchase of insurance, early-warning system. |
| | Responsive/reactive | After initial impacts are manifested, e.g., changes in farm practices. |
| | *Ex ante* | Measures to prevent or hinder climate damage. |
| | *Ex post* | Measures to regulate responsibility and compensation when damage happens. |
| Temporal scope | Short term | Can be implemented through a change in variable inputs to production. |
| | Long term | An adjustment to capital stock may be required. |

| | | |
|---|---|---|
| Spatial scope | Scales | Adaptation measures at farm, plant, community, region, sector, national and international scales |
| Level of strategies | On-farm measures | Diversification of crop varieties, species change, shifting planting seasons, changing crop management practices etc. |
| | Off-farm measures | Diversifying into off-farm employment, investing in non-farm assets, migrating to new industries etc. |
| Form | Hard adaptation | Use of specific technologies and actions involving capital goods. |
| | Soft adaptation | Focuses on information, capacity building, policy and strategy development, and institutional arrangements. |
| Agents | Players | Farmers, industries, governments and non-government organisations. |

Sources: Smit & Pilifosova (2001); Bryant et al., 2000; IPCC, 2001, 2007.

Various forms of adaptation strategies can be classified, including anticipatory (planned), reactive (autonomous), demand and supply management, structural and non-structural, and hard and soft (IPCC, 2001). Adaptation can take place both on-farm and off-farm. Planned adaptation requires government intervention, whereas autonomous adaptation occurs through private agents (Seo, 2011). A planned approach is seen as more efficient and more effective than a reactive approach for addressing climate variability (IPCC, 2001). In the case of reactive adaptation, farmers react to the climate event once the impact is observed. An anticipatory adaptation, however, needs good forecasting and, often, government incentives. In developing countries most adaptation measures are reactive. Pereira et al. (2002) assessed on-farm irrigation management, including the use of treated wastewater and saline waters. Other farm level adaptation practices include crop diversification, and land and water management (Wall and Smit, 2005). Jones and Boyd (2011) defined adaptation as *ex post* and *ex ante* strategies in coping with drought in times of shock and stress. *Ex post* strategies include wild food harvesting, reduction in food intake, trade of livestock, temporary migration and seeking aid assistance (both food and finance). Additionally, on-farm strategies include changes in the timing of planting, use of new crop varieties and working as agricultural labourers. *Ex ante* measures include the storage of food stocks and dissemination of drought-related early warning information. Mwinjaka et al. (2010) identified generic adaptation strategies for the agricultural sector to cope with climate variability in drought-prone Gujarat, India. These include *ex post* strategies (e.g., crop diversification, changing cropping intensity, crop mix, crop type and location) and *ex ante* strategies (e.g., crop insurance, pricing reform, opening up of trade and investment, extension services, income diversification, food reserve and storage, migration, improving weather forecasting, land-use change, and the development and adoption of new technologies). Mwinjaka et al. (2010) noted that both *ex ante* and *ex post* adaptation measures can be implemented at the local level through to the global level and can be assessed and incorporated into micro-level strategies.

Supply management strategies include the use of wastewater and inferior quality water for irrigation, increased storage capacity, improved conveyance and distribution systems, enhanced operation and maintenance, and the development of new sources of water supplies such as treated wastewater and saline groundwater (Pereira et al., 2002). Trinh et al. (2013) found the recovery and reuse of wastewater as an option to cope with water scarcity for 16% of rice-cultivated area for three rice seasons in Can Tho City, Vietnam.

Demand management strategies to reduce irrigation at the farm level include supplemental irrigation, deficit irrigation, improved irrigation methods and performance, distribution uniformity, and various soil and water conservation practices (Pereira et al., 2002). Pereira et al. (2002) defined demand management for irrigation to be practices and management decisions of a multiple nature, including agronomic, economic and technical.

Belay et al. (2005) investigated coping strategies focusing on offsetting the negative effects of droughts after their occurrence among pastoral and agro-pastoral communities in eastern Ethiopia. As Deressa et al. (2009) noted, studies on Africa attempted to investigate climate change impacts and the determinants of adaptation strategies in crop, livestock and mixed crop-livestock production systems and the results are highly aggregated. Consequently, the parameter estimates have little importance in identifying location-specific policies and strategies. Reilly et al. (2003) identified several measures as means of adjusting to drought, including shifting of varieties and planting dates, changes in types of crops, irrigation and input use.

Most of the literature found the use of new crop varieties and livestock species, crop and livelihood diversification, changing planting dates, planting trees, irrigation, soil and water conservation, and migration are the most common adaptation measures in agriculture for addressing climate change and variability (Hisali et al., 2011; Deressa et al., 2009; Mertz et al., 2009; Kurukulasuriya and Mendelsohn, 2008). For Ethiopian highland rain-fed crop agriculture, Gebrehiwot and van der Veen (2013) considered crop diversification, changing planting dates, soil conservation, increasing rainwater capture and planting trees as key adaptation measures. Adaptation measures can be implemented in isolation or in combination with other policies or strategies. Knowler and Bradshaw (2007) reviewed and synthesised research to identify factors that influence the adaptation of conservation in agricultural practices. They emphasised efforts to promote conservation in agriculture need to be tailored to reflect the particular conditions of individual locales. Adaptation is location specific and depends on many socio-economic and agro-ecological factors, and climate and weather conditions. Nhemachena and Hassan (2007) found the use of different crop varieties, crop diversification, changing planting dates, switching from farm to non-farm activities, the increased use of irrigation, and increased soil and water conservation practices are the most common adaptation measures in Africa.

The ability and capacity of a system (e.g., agro-ecological) to adapt to extreme events is influenced by certain system characteristics that are called ‘determinants of adaptation’ (Smit et al., 2000). Gebrehiwot and van der Veen (2013) found age, sex and education of the participants (head of the household), household and farm size, income, livestock ownership, access to extension services, credit, climate information, and temperature and precipitation influenced adaptation to climate change in the Ethiopian highlands. Using a pooled dataset for South Africa and Ethiopia, Bryan et al. (2009) identified factors affecting the decision to adapt to perceived climate change and found that farmers were more likely to adapt if they had access to extension services, credit and land.

Key determinants of adaptation strategies are modelled by an aggregate behaviour by many farming households over the medium to long term at the farm level (Gebrehiwot and van der Veen, 2013; Deressa et al., 2009; Nhemachena and Hassan, 2007). These can be driven by a suite of factors which can be broadly categorised as:

- climatic variables (e.g., rainfall and temperature);
- socio-demographic variables (e.g., age, education, gender, income and farming experience);
- farm characteristics (e.g., farm size and tenure status); and
- institutional variables (e.g., access to extension services, credit and markets).

Ascertaining the exact factors that influence adaptation choices, whether environmentally, climatically or socio-economically driven, is extremely difficult (Adger et al., 2005). Dealing with water scarcity requires a complementary approach of supply and demand management as well as on-farm and off-farm measures. Importantly, adaptation strategies can be framed and implemented not only at temporal scales, but can also have a range of spatial scales, from local to regional and to national (Bonsal et al., 2011 ). Appropriate adaptations foster resilience and decrease vulnerability to multiple threats.

Despite a large volume of literature on the impact of climate change on agriculture, most studies are at regional and national levels, and from a sectoral perspective, and are not specific to any particular crops nor are they farm or household specific. Although such studies are important to design mitigation strategies, these are 'less relevant in terms of providing critical insights for effective adaptation strategies at the household level' (Di Falco et al., 2011: 459). Agro-ecological and meteorological conditions vary substantially across regions, therefore household or farm level understanding remains relatively rudimentary. Clearly, there remains a gap in the understanding of location and crop specific adaptation capacities in drought-prone environments.

## 2. Materials and Methods

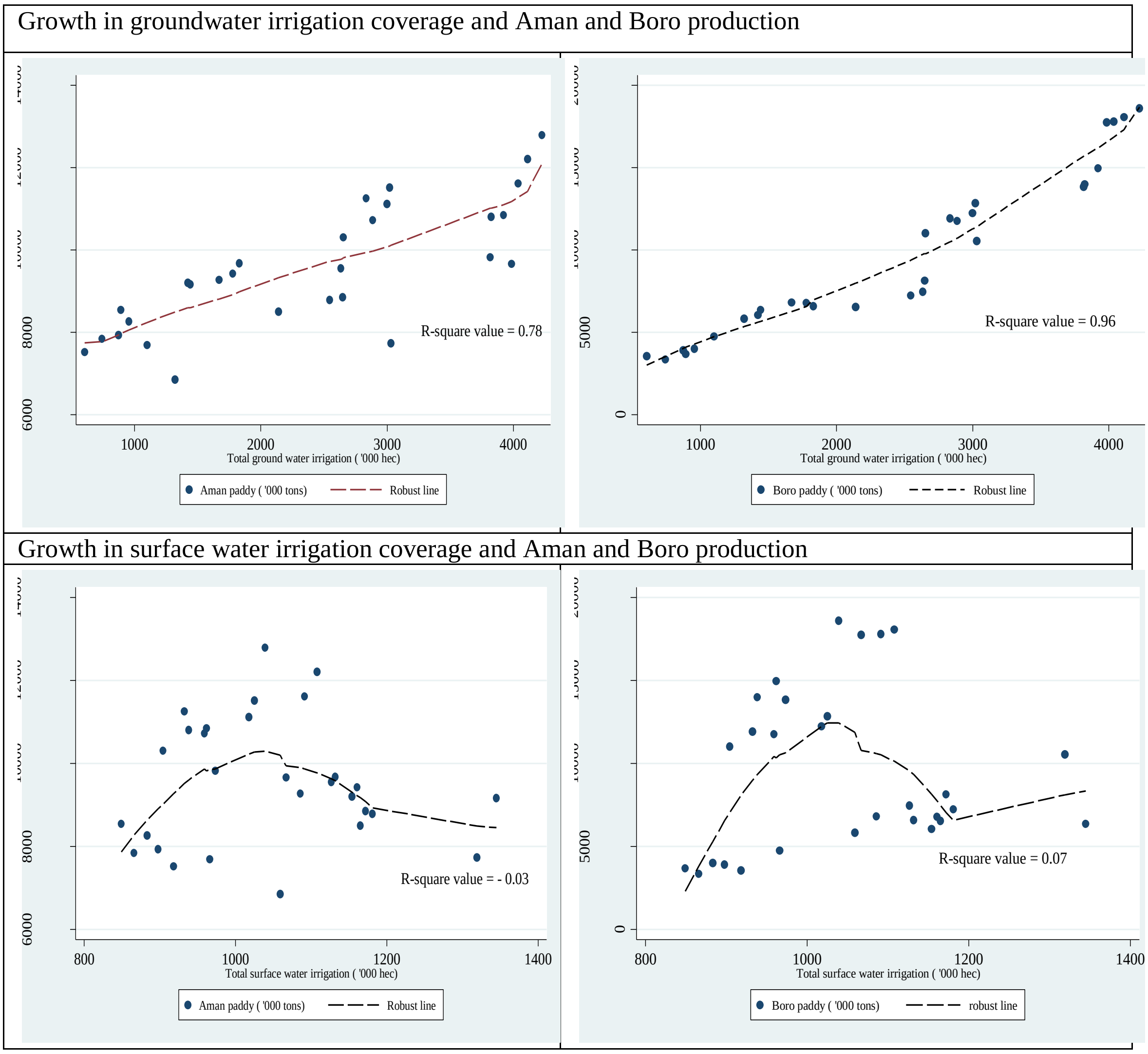
### 2.1 *Sustainability of the Adaptation Strategies*

Water is essential for agricultural farming, and the increasing use of irrigation water, especially groundwater, has contributed significantly to crop productivity in Bangladesh. Rice yield, for example, increased from 1 MT/ha in 1971/72 to 2.88 MT/ha in 2010/11. Much of this increase in yield was due to an increase in the share of irrigated rice, especially during the dry season: Boro rice farming increased from 11% in 1972/73 to over 65% in 2010/11 (BBS, 2012). The contribution of surface and groundwater sources to the total irrigated agriculture has changed significantly over the years – groundwater has increased from 41% in 1982/83 to 68.5% in 1996/97 to over 80% in 2010/11, while surface water declined from 59% to less than 20% over the same period (BADC, 2011; Planning Commission, 1997). Groundwater usage has increased over the years due to an increase in the farming intensity, the government's massive investment in irrigation development and the shrinking of surface water resources. Delayed monsoons and less and/or an uneven distribution of rainfall under the impact of climate change have aggravated water availability and increased water scarcity.

Over the last three decades the area under irrigation has expanded significantly throughout the country in order to increase food production, mainly through a rise in the number of shallow tube wells (STWs). The area under surface water irrigation has declined since the 1980s, while the area under STW irrigation has increased by a factor of ten (Fig. 1) (BADC, 2011). The shallow aquifer has become highly contaminated by arsenic in many parts of

Bangladesh, including in the study area. This situation poses a serious threat to human health and livelihood.

**Figure 1**
Growth of irrigated agriculture and rice production in Bangladesh, 1982–2011



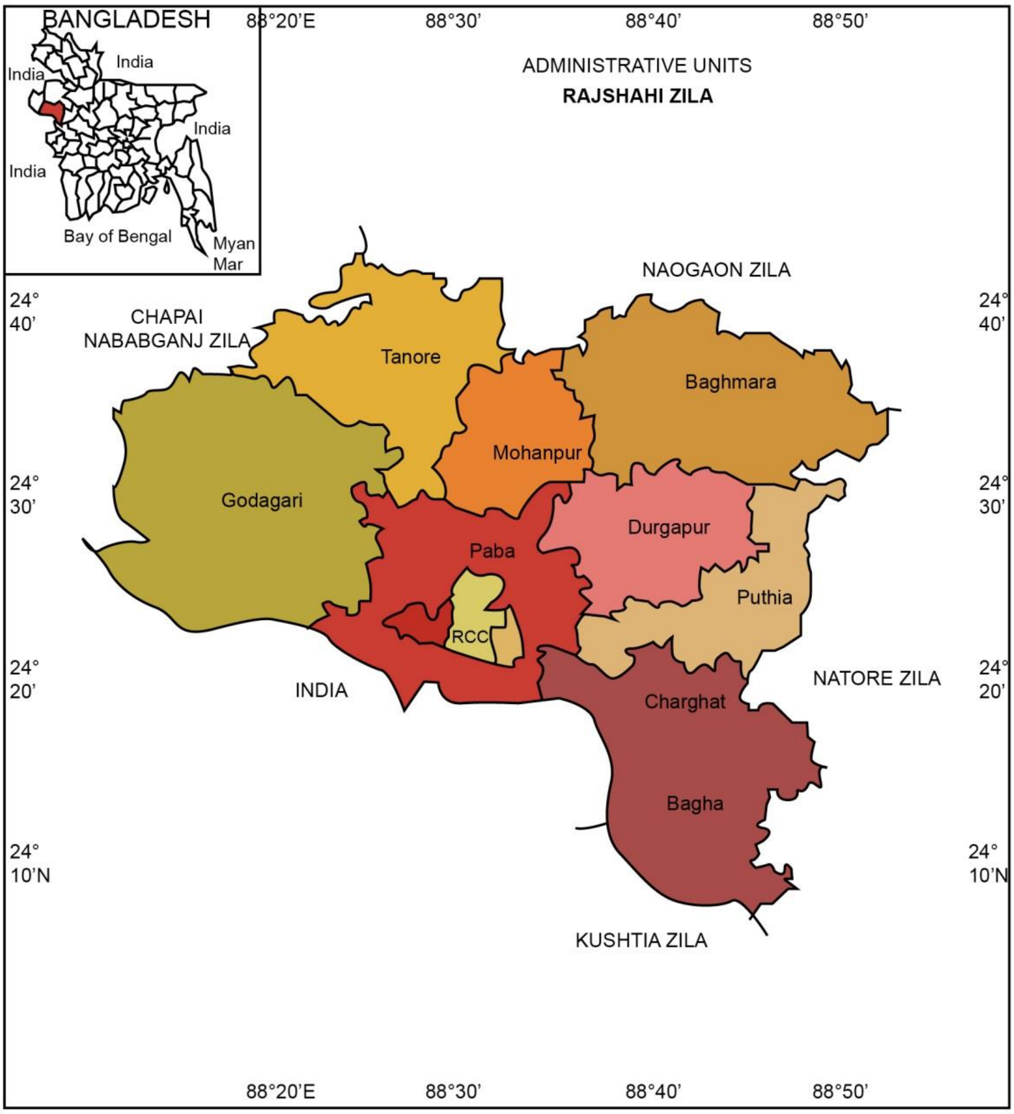

Source: Author's estimation from BADC (2011) and BBS (2012).

During 1982–2011 the total area under irrigation increased by 3.45 times: from 1.52 million ha in 1982/83 to 5.23 million ha in 2010/11. The growth in Boro production and the growth in the area covered under groundwater irrigation are strongly related with a correlation coefficient of 0.96 (Fig. 1). Currently, the agriculture sector withdrew 88% of the 35 870 million m$^3$ of freshwater resources in Bangladesh (FAO, 2014). With declining and more erratic rainfall predicted by the World Bank (2013), droughts and water scarcity are expected to be more frequent, particularly in southwest Bangladesh. As a result, both rain-fed Aman and dry-season Boro rice farming will be affected severely which will ultimately affect the agricultural economy and rural livelihoods, and threaten hard-earned food security.

### 2.2 Study Area and Data Sources

Rajshahi is in the heart of the drought-prone northwestern region of Bangladesh (24.40°N 88.50°E) (Fig. 1). The district has an area of 2407 $km^2$ with a population of 2.4 million people (population density of 997/$km^2$), making it the largest district of the Barind Tract (33% of the region). Because of its predominant dependence on crop agriculture, the district is referred to as the ‘bread basket’ of the country. Rice farming is very sensitive to changes in weather and climatic conditions. The climate of the region is semi-arid and is characterised by low rainfall and high fluctuation of the precipitation. The annual rainfall is about 1400–1600 mm, while most parts of the country receive at least 2000 mm of rain per year. However, seasonal and inter-annual variability of rainfall is high in the district where a disproportionate amount of rain (90%) falls during short spells (June–October), even though the total amount of rain does not change much (BMD, 2013; Rashid et al., 2013; Shahid, 2011). As a result, agricultural production is constantly threatened due to the high likelihood of drought and recurring water shortages. Traditionally, the rural economy and livelihood depend heavily on rain-fed agriculture. However, over the years the share of the irrigated rice farming area to the net cultivated area in the region has increased considerably. Water scarcity is expected to exacerbate this vulnerability through changes in precipitation patterns, including heavier and more erratic rainfall during monsoons (June–October) and a lack of rainfall in some areas during the winter season (October–March).

**Figure 2**
Map of the study area




A cross-sectional survey to collect data from farming households in the Rajshahi District was adopted for this study. Household data were collected from 12 randomly selected villages in the district during October–December 2013. A multi-stage random sampling technique was employed to select the Upazillas (sub-districts), villages and households. At the first stage, random sampling was used to select two Upazillas. At the second stage, six villages were selected from each of the selected Upazillas, making a total of 12 villages.

As the number of farming households within each village varies considerably, a pre-determined number of 15% households from each village were selected for the survey which gives a sample size of 550 for the 12 villages surveyed. This is considered to be sufficient: Bartlett et al. (2001) considered 5% to be adequate for cross-sectional household surveys. Furthermore, rural farming communities in the study area make up a mostly homogeneous group which also validates the use of a small sample (Blaikie, 2010).

The unit of analysis was the farm households, and these were selected by simple random sampling using the list of farming households collected from the Department of Agricultural Extension. Households were approached until the required number of surveys for a particular village was completed. Finally, heads of the households were selected as survey participants because they usually have the decision-making power for farming and the household's resources. Interviews were conducted by trained interviewers under the supervision of the researcher, either at participants' homes or a suitable place agreed upon (e.g., farms and community meeting places). Four observations were dropped due to data inconsistencies (e.g., interviewees were found not to be the head of households) which resulted in 546 observations for data analysis. Additionally, focus group discussions, key informant interviews and secondary sources of data augmented the survey to get a holistic view of the drought adaptation strategies practiced by the participating communities.

A structured questionnaire was administered in-person to elicit data regarding several aspects of adaptation strategies practiced by farming households and their socio-economic characteristics, institutional access, farm characteristics and perception of climate change.

### 2.3 Theoretical and Empirical Model

A model based on the theory of random utility is used to capture the determinants of adaptation to drought and water scarcity. There is no natural ordering in the preferred alternatives and a monotonic relationship between one underlying latent or unobservable variable and the observed outcome is not realistic, therefore a random utility framework model is justified (Verbeek, 2004).

Farmers make choices based on their perceived utility of different adaptation measures in response to climate variability. These decisions are derived from farmers' utility (or profit) maximization behaviour. Assume that $u_m$ and $u_j$ denote the utility of farmer *i*, who chooses between any two alternatives, then the linear random utility model can be presented as:

$$u_{im} = v_{im} + \varepsilon_{im} \tag{1}$$

where $u_{im}$ is individual *i*'s utility of choosing option *m*, $v_{im}$ is the deterministic (observable or explainable) component of a utility that individual *i* has for option *m* and $\varepsilon_{ij}$ is a stochastic element (random or unexplainable) that represents unobservable influences on individual choices, and measurement error. This random component or error term of the utility function is assumed to be independently and identically distributed (Greene, 2012). Here, the utility $v_{im}$ depends on an attribute vector *x* (e.g., socio-economic characteristics), i.e., $v_{im} = x'_{im}\beta$ is a function of observable attributes of alternatives.

Furthermore, farmers are assumed to select the alternative that has the highest utility. However, utility $v_{im}$ is not directly observed. Rather what can be observed are the choices farmers make in adapting to the water scarcity. When there are multiple choices, the likelihood of an individual choosing the alternative *i* among a set of alternative adaptations can be expressed as the probability:

$$\begin{aligned} P_{im} &= \Pr(u_{im} > u_{ij}) \ \forall m \neq j \\ &= \Pr(u_{im} + \varepsilon_{im} > u_{ij} + \varepsilon_{ij}) \ \forall m \neq j \\ &= \mathrm{r}(u_{im} - u_{ij} > +\varepsilon_{ij} + \varepsilon_{im}) \ \forall m \neq j \end{aligned} \tag{2}$$

Different choice models can be constructed based upon different assumptions, specifically the assumed distribution of the random disturbance terms. An application of the multinomial logit (MNL) model is justified for this study as we have multiple categories that are not ordered in terms of significance or importance. MNL is widely used in the adaptation research (Rashid et al., 2013; Tessema et al., 2013; Deressa et al., 2009). Let $y = (y_1, ..., y_M)$ represent the dependant variable having $M$ outcome variables (i.e., adaptation strategies) and $x = (x_1, ..., x_k)$ denote a vector of $K$ independent variables (e.g., household and farm characteristics).

$$\text{where, y} = \begin{cases} 1 = \text{Increased use of surface water} \\ 2 = \text{Increased use of ground water} \\ 3 = \text{Crop diversification and calendar adjustment} \\ 4 = \text{Land use change} \end{cases}$$

Any *ceteris paribus* change in a set of exogenous factors will affect the response probabilities $\text{P}(y = m \mid x),\ m = 1,\ 2, ...,\ M$. For a given $x$, the probability of observing $j$-th outcome is

$$\Pr(y = j \mid x) = \frac{\exp(x\beta_j)}{1 + \sum_{m=1}^{M} \exp(x\beta_m)} \qquad (3)$$

Where, $\beta_j = (\beta_{0j}, ..., \beta_{kj}, ..., \beta_{Kj})'$.

Equation (3) can be estimated by means of a MNL regression which assumes that choices are consistent with the Independence of Irrelevant Alternatives (IIA) property. This property requires that the probability of an option being chosen by a farmer should be unaffected by the inclusion or omission of other alternative options.

The estimated parameters of the MNL model only give an idea of direction of effects of explanatory variables and do not provide a direct interpretation (in terms of probabilities or direct magnitude change). In order to compute the marginal effects of different exogenous factors, we differentiate (3) with respect to *k*-th explanatory variable as:

$$\frac{\partial P_m}{\partial x_k} = P_m(\beta_{mk} - \sum_{m=1}^{M-1} P_m \beta_{mk}) \tag{4}$$

Marginal effects measure the likely change in the probability of the adaptation of a particular choice with respect to a unit change in an explanatory variable (Greene, 2012). The model was estimated using STATA Version 12.

The final MNL model of factors determining farmers' adaptation behaviour is specified as:

$Y_t = \beta_0 + \beta_1 X_1 + \beta_2 X_2 \ldots\ldots\ldots \beta_n X_n$

Where the X(s) are the explanatory variables and $\beta$(s) denote parameter estimates.

**2.4 Specification of Variables**

A set of five key constructs are hypothesised to influence farmers' adaptation choices: institutional access, climate awareness, farm and households' demographic characteristics, and infrastructural access (electricity for irrigation). Explanatory variables and their rationale are discussed here. The explanatory variables were selected by means of a review of the literature, the availability of data and through focus group discussions. Institutional arrangements facilitate farmers' adaptation within and across levels. An institutional access index was constructed based on households' access to various institutional facilities. Seven components were included in the index: (i) input market, (ii) output market, (iii) credit/loan facilities, (iv) agriculture extension services, (v) information on climate and weather conditions through government and non-government organisations, (vi) farmer-to-farmer knowledge sharing through community group or cooperative societies, and (vii) off-farm employment opportunities. Respondents were asked to respond either 'yes' or 'no' to the list of these questions. These responses were summarised and were scaled into three categories such as no, medium and high institutional access. Access to none of these facilities indicates no access, between one and three indicates medium and more than three indicates high access. High index value refers to high access to institutional facilities. Wheeler et al. (2013) noted that weightings could be inherently biased, so in order to treat all seven facilities equally no weighting was used. Farm characteristics include farm size (large, medium and small), tenure status and farming experience. Farm size is based on total cultivable acres operated, owned and rented. Farm size is included in the model as a categorical variable when large farm was used as the reference category. Participants' demographic characteristics include education, age, income and gender. Infrastructural accessibility is measured in terms of households' access to electricity for irrigation. Climate awareness indicates farmers' perception about the changing patterns of precipitation and its variability over the last 20 years in the region.

## 3.0 Model Specification and Testing

### *3.1 Farmers' Socio-economic and Demographic Characteristics*

The descriptive statistics of farmers' socio-economic and demographic characteristics are provided in Table 2. The respondents are all heads of their households. The majority of the surveyed farms (81%) in the study area are small and marginal owning less than one ha of farming land on average. Only 15% are classified as medium farmers (1.01–3.03 ha) and the remaining 4% are large farmers having more than 3.03 ha of land per household. About 95% of the farms have access to at least one form of irrigation. Regarding household size, 62% of the farming households have five or fewer members, 34% have 6–10 and 4% have more than ten members.

**Table 2**
Summary statistics

| Exogenous variables | Measure | Mean | Std |
|---|---|---|---|
| Education | Years of schooling | 5.36 | 4.45 |
| Age | Years | 47.11 | 12.56 |
| Gender | 1= male, 2= female | 1.01 | 0.17 |
| Average household income | BDT[1] | 38 110 | 40 506.15 |
| Tenure status | = 1 if farmer has secure access to land; 0 otherwise | 0.66 | 0.47 |
| Farming experience | Years | 23.95 | 12.87 |
| Farm size | Acre | 1.74 | 2.71 |
| Access to electricity | = 1 if farmer has access to electricity; 0 otherwise | 0.74 | 0.436 |
| Low institutional access | = 1 if low institutional access; 0 otherwise | 0.11 | 0.317 |
| Moderate institutional access | = 1 if moderate institutional access; 0 otherwise | 0.644 | 0.479 |
| High institutional access | = 1 if high institutional access; 0 otherwise | 0.241 | 0.428 |
| Climatic awareness | 1= Very adversely affected<br>2= Adversely affected<br>3= Moderately affected<br>4 = Slightly affected | 1.92 | 40.78 |

Notes: [1]Exchange rate; 1 US$= Taka 877.45 (BDT) in January 2014.

### *3.2 MNL Model for Adaptation Choices*

Almost all of the surveyed participants (99%) in the study area perceived a decline in average yearly rainfall over the years and experienced partial or complete crop losses due to droughts and water scarcity over the last 20 years. Farmers' perceptions of an average decrease in rainfall are consistent with the macro-level evidence of climate change and vulnerability in Bangladesh (World Bank, 2013). Farmers were asked whether they had undertaken any adaptation measures to address these adverse effects: 98% responded positively which was in line with expectations and observations during field visits in the study area. However, this is contrary to the findings in the African context where despite having perceived changes in rainfall and temperature, a large percentage of farmers did not make any adjustments to their farming practices (Bryan et al., 2009). Farmers were found to be adopting different strategies to adapt to drought-prone environments in the study area: seven adaptation responses were identified. Farmers adopted at least one form of adaptation, otherwise they could not sustain their farming and livelihood. They were asked to identify their most commonly used measure from a range of options which are currently being adopted, namely increased use of groundwater irrigation (56.04% of the total surveyed farmers), crop diversification and farming calendar adjustments (23.81%), land use change (9.71%), increased use of surface water irrigation (4.21%) and others (6.23%, which included water conservation and conservation tillage). The wide variation in the percentages of the adaptation choices made it difficult to model because the frequency was too low for some particular measures. Following Gbetibouo (2009) and Rashid et al. (2013), the model was reorganised by categorising closely related choices into the same category. For instance, water conservation measures were merged with the surface water irrigation choice. 'Water conservation' refers to the use and transport of water more effectively to increase overall water use efficiency. 'Surface water irrigation' refers to water drawn from rivers, lakes, canals, ponds and small dams. Farmers mainly use traditional methods and low lift pumps for extracting water from these surface water sources. This re-categorisation resulted in four outcomes (Table 3): increased use of groundwater irrigation, increased use of surface water, crop diversification and farming calendar adjustments, and land use change. Crop diversification includes inter-cropping, switching to alternative crops (plant crops other than rice), and using high yielding heat and drought-tolerant seed varieties. Farming calendar adjustments include changes in planting dates or replanting. Land use change includes changes in the land allocation among different crops and fallowing land in an extreme case. These measures are aimed at improving farming practices and, consequently, are mutually exclusive and exhaustive, i.e., the farmer should nominate one and only one of the choices as their most used.

**Table 3**
Multinomial logit model estimates

| | Increased use of surface water | | Crop diversification | | Land use change | |
|---|---|---|---|---|---|---|
| Variables | Coefficient | Marginal effect | Coefficient | Marginal effect | Coefficient | Marginal effect |
| Constant | -2.28 | – | -4.50 | | -2.97 | |
| | (0.97)* | | (0.96)* | – | (0.99)* | – |
| Education | 0.057 | 0.003 | 0.05 | 0.00 | 0.05 | 0.00 |
| | (0.033)*** | (0.00) | (0.03)*** | (0.00) | (0.03) | (0.00) |
| Age | -0.002 | -0.00 | 0.00 | 0.00 | 0.019 | 0.00 |
| | (0.012) | (0.00) | (0.010) | (0.00) | (0.012) | (0.00) |
| Gender | 0.004 | 0.011 | | -0.47 | -0.14 | -0.00 |
| | (0.84) | (0.077) | -0.42 (0.83) | (0.09) | (1.087) | (0.085) |
| Household income | $1.37e^{-06}$ | $1.66^{e-07}$ | $-1.96e^{-06}$ | $-2.53e^{-07}$ | $-7.81e^{-07}$ | $-4.23e^{-08}$ |
| | ($8.25e^{-07}$) | (2.57)** | ($8.82e^{-07}$)** | ($1.00e^{-07}$)* | ($1.17\ e^{-06}$) | (0.00) |
| Tenure status | - 0.63 | -0.053 | -0.08 | 0.014 | -0.38 | -0.03 |
| | (0.34)*** | (0.03)*** | (0.31) | (0.04) | (0.36) | (0.03) |
| Farming experience | 0.137 | -0.001 | 0.44 | 0.05 | 0.19 | 0.007 |
| | (0.22) | (0.02) | (0.21)** | (0.02)** | (0.23) | (0.02) |
| Farm size | -2.28 | -0.00 | 0.05 | 0.00 | -0.060 | -0.00 |
| | (2.36)* | (0.00) | (0.12) | (0.00) | (0.07) | (0.00) |
| Electricity | 0.59 | 0.02 | 0.90 | 0.09 | 0.48 | 0.02 |
| | (0.39) | (0.03) | (0.39)** | (0.05)** | (0.39) | (0.03) |
| High institutional access | -0.56 | -0.05 | 2.28 | 0.27 | -1.06 | 0.03 |
| | (0.54) | (0.04) | (0.58)* | (0.07)* | (0.43)*** | (0.03) |
| Moderate institutional | -0.15 | -0.08 | 1.73 | 0.22 | -0.92 | -0.04 |
| access | (0.34) | (0.03)* | (0.47)* | (0.05)* | (0.36) | (0.03) |
| Climate awareness | | | | | | |
| Adversely affected | -0.52 | -0.06 | 1.78 | 0.14 | 0.86 | 0.07 |
| | (0.39) | (0.031)** | (0.46)* | (0.03)* | (0.35)* | (0.03)** |
| Moderately affected | 1.21 | 0.04 | 3.72 | 0.46 | 0.31 | -0.04 |
| | (0.40)* | (0.04) | (0.48)* | (0.04)* | (0.58) | (0.02) |
| Slightly affected | -11.74 | -0.12 | -8.99 | -0.04 | -10.63 | -0.08 |
| | (1368.41) | (0.03)* | (622.73) | (0.02)* | (975.29) | (0.02)* |
| Log likelihood | -500.85 | | | | | |
| Pseudo $R^2$ | 0.19 | | | | | |
| LR (chi-square) | 234.59 ($p<0.0$) | | | | | |
| N | 546 | | | | | |

Notes: *, ** and *** are significant at 1%, 5% and 10% significant level, respectively. Increased use of groundwater is used as the base category. Standard errors are in the parenthesis.

The most common adaptation measure in the study region was groundwater irrigation. Therefore, it was used as the base, or reference, category. The probability of alternative choices is compared to the probability of choice in the reference category. Table 3 contains the MNL results where each column represents a different MNL model. Parameter estimates (coefficient) represent the likelihood of adoption of one of the three alternatives stated above compared to the reference category. The control variables remain the same in all models.

At the outset of the estimation an ordinary least square regression and post-estimate variance inflation factor (VIF) were run to check for possible mullticollinerity of the explanatory variables. Our estimated VIF results range from 1.02 to 2.46. As these values for the explanatory variables are less than 10, it can be concluded that multicollinerity is not an issue in our model (Kleinbaum et al., 2014). In the next stage parameter coefficients and the marginal effects of the MNL model are estimated (Table 3). The likelihood ratio statistics (chi-square = 234.59) indicate that the model has a strong explanatory power. In other words, the joint null hypothesis that all coefficients of exogenous variables in the model are zero is rejected at less than 1%. Another indicator of the model's overall fit is the estimated value of McFadden pseudo $R^2$ of 0.19 which, considering the cross-sectional nature of the study design, indicates the model's reasonable predictive power.

Finally, the validity of the independence of the IIA assumptions is tested by applying the Hausman test. The test results are as follows: chi-square values range from 1.28 to 77.04 and the p-value is 1.00. Therefore, the test results fail to reject the null hypothesis of independence of the adaptation strategies. This suggests that MNL specification is appropriate to model adaptation strategies among the rural farming communities in the Rajshahi district.

Model specifications may suffer from an endogeneity problem due to issues related to omitted variable bias, measurement error and simultaneity between the variables of interest (reverse causation) (Greene, 2003). The presence of endogeneity creates bias in the coefficient estimates of the explanatory variables and reduces the ability to make inferences about the characteristics (Wooldridge 2006). Randomization is one answer to determine causal relationships (Angrist and Krueger, 2001), although it is not always applicable as is the case in this study.

Issues of endogeneity have received very little attention in the climate change adaptation literature (notable exceptions are Wheeler et al., 2013; Di Falco et al., 2012). Wheeler et al. (2013) in their study on irrigators' planned and actual adaptation strategies to a water scarce future in Australia found that farmers' climate change beliefs and past actions are important factors in driving their adaptation behaviour. However, behaviour could also influence belief. Without addressing such causal influence, designing appropriate strategies will be a challenging task.

In this study the variable 'education' could be a potential endogenous variable due to the influences of some external confounding factors, namely the government's current education policy in Bangladesh (Compulsory Primary Education Policy) which mandates parents to send their children to the school. Using an augmented Durbin-Wu-Hausman test, this paper examines the endogeneity problem of the education variable in the model. The total number of educated members in the family is used as a proxy for the government policy intervention in the study. The test result of $F(1,\ 414) = 1.42$; $Prob > 0.12$ rejects the null hypothesis that the education variable is endogenous.

### 3.3 Results and Discussion

This section presents the empirical results of the MNL adaptation model. The marginal effects along with the level of significance of the explanatory variables are reported and discussed. In Table 3 it is observed that several factors do increase the likelihood of farmers' adaptation to extreme weather events. In general, education attainment, average household income, farming experience, tenure status, availability of electricity, institutional access and climate awareness are statistically significant predictors. A positive coefficient means the odd ratio is positive that is associated with the increased probability of choices relative to the reference category.

*Level of Education*

Education is one of the key determinants in adopting adaptation strategies. Results from Table 3 indicate that education appears to have a positive effect on the adoption of surface water irrigation. For instance, a one unit (year) increase of schooling would lead to a 0.3% increase in the probability of it being adopted compared with the base category while the effect on the remaining options is negligible. However, education is positively correlated with all of the alternative measures suggesting that as education level rises individuals become aware of different alternatives and thus opt for more land and water conservation measures.

*Household Income*

Increase in household income raises the probability of the adoption of increased surface water irrigation and decreases the probability of crop diversification and land use change, albeit a lesser extent. Table 3 shows the marginal effect of household income on adapting alternative strategies. For example, a unit increase in household income significantly increases the probability of surface water irrigation adaptation, although not at a greater extent.

*Tenure Status*

Tenure status in an agriculture-based rural economy is an important factor in the decision to adapt as land is a primary means and instrument of production and rural livelihood. Ownership of land gives farmers a sense of exclusive rights to the property and they therefore take responsibility to improve land and water management practices in irrigated and rain-fed systems. Previous studies found that farmers having secure land tenure were likely to take up adaptation strategies, particularly when they pertain to long-term investment (capital and maintenance) (Hisali et al., 2011; Deressa et al., 2009). Table 3 shows that households with tenure rights are more likely to undertake crop diversification compared to the base option. However, they are less likely to adopt surface water irrigation and land-use change strategies.

*Farming Experience*

Studies show that the greater the experiences in agricultural farming, the more likely farmers are to have good knowledge about the weather and climatic conditions and thus adapt to these risk factors. Hisali et al. (2011) pointed to the importance of farming experience in adaptation decision making. Farm experience has varying effects on different adaptation measures. For instance, a one unit increase in farm experience results in a 5% higher likelihood of adapting crop diversification.

*Electricity*

Access to electricity often represents household wealth which influences farmers' adaptation decisions (Bryan et al., 2013). During the field visit it was observed that the rural economy and livelihood were rapidly transforming due to massive electrification being undertaken in the region. Results in Table 3 indicate a positive and significant correlation between farmers' access to electricity for irrigation and the likelihood of adapting increased use of surface water irrigation to cope with water scarcity. The marginal effects indicate that compared to the base case, the likelihood of adopting crop diversification and land use change with greater access to electricity increases by 9% and 2%, respectively. The positive effect of electricity on adaptation is consistent with other studies in developing countries (Kurukulasuriya and Mendelsohn, 2008; Nhemachena and Hassan, 2007).

*Institutional Access*

Households with better access to institutional facilities are generally more likely to adapt to climate change. For example, households with high access to various institutional facilities are 27% more likely to adopt crop diversification as a coping strategy. However, moderate institutional access increases the probability of adopting crop diversification by 22% and reduces the probability of the increased use of surface water by 8% viz.-a-viz. an increased amount of groundwater. This finding is in concordance with other similar research that there is a strong positive relationship between access to institution and the farmers' adoption behaviour.

Hassan and Nhemachena (2008) noted that the availability of improved climate and agricultural information helped farmers make comparative decisions for alternative strategies. Some of the variables in the institutional index in this study are pertinent for enhancing financial, social and human capital. For instance, access to credit increases financial resources of farm households and the ability to purchase inputs such as drought-tolerant varieties and irrigation. Similarly, access to markets (selling or purchasing) serves as a platform for exchanging information (Gebrehiwot and van der Veen, 2013). Agricultural extension services – farmer-to-farmer or provided by government and/or non-government organisations – are vital sources of information on agronomic practices and climate change adaptation strategies. Access to information on climate change is believed to create awareness and increase the probability of adaptation (Maddison 2007).

*Climate Awareness*

The level of perceived risk associated with the capacity to adapt to climate change determines the likelihood of adopting adaptation measures (Hisali et al., 2011). Climate perception appears to determine the adaptation of various strategies to cope with water stress issues. In this study, farm households were asked about their perceptions on how did average precipitation and temperature and their variability over the past 20 years affect their rice farming. Farmers' awareness about climate change effects are classified as very adversely, adversely, moderately and slightly or not affected. Compared to very adversely affected households, those who perceive they are adversely affected are 14% more likely to adopt crop diversification, 7% more likely to adopt land use change and 6% less likely to adopt an increased use of surface water as their coping mechanisms. Compared to very adversely affected households, those who are affected moderately are 46% more likely to adopt crop diversification, 4% more likely to adopt an increased use of surface water and 4% less likely to adopt land use change as the coping strategy. Compared to very adversely affected households, those slightly affected were found to be less likely to adopt any of the adaptation strategies. These results reinforce the findings in other studies such that farmers' perception of climate change shapes their adaptation strategies (Mertz et al., 2009; Nhemachena and Hassan, 2007).

In summary, the estimation of the model in this section shows that the probability of adaptation to extreme weather conditions through increased use of surface water, crop diversification and land use change rises with increased schooling and household income, access to electricity, tenure status, high institutional access and a better awareness of climate conditions. The rest of the explanatory variables (i.e., farmers' age and gender and farm size) did not exert any statistically significant influence on adaptation choices although some were positively related while others were negatively related. These results are, in general, similar to the findings in the adaptation literature (Gebrehiwot and van der Veen, 2013; Hisali et al., 2011; Deressa et al., 2009; Nhemachena and Hassan, 2007), although there are some variations in terms of sign and magnitude which are expected.

Farmers are inherently resilient to a changing climate. However, current adaptation practices of groundwater dependence in the study area do not take into account long-term sustainability of the natural systems. Increasing dependence on irrigation as the most commonly used adaptation choice by farmers as evident in this study is also common in other regions (Gebrehiwot and van der Veen, 2013; Seo, 2011). This study raises the issue of sustainable agricultural farming under changing weather and climatic conditions where groundwater resources are becoming stressed due to their overuse and the non-consideration of the ecological needs of water.

For poor and marginal farmers whose livelihoods depend on crop farming, the socio-economic costs of extended droughts are huge. Adaptation to drought is essential to minimise these losses. Government policies regarding adaptation strategies in Bangladesh are centralised and often do not take into account local circumstances. Successive governments have promoted agricultural productivity (Planning Commission, 2008). To achieve this, the unilateral focus was on groundwater development and extraction. The National Water Policy of 1999 and the National Water Management Plan of 2004 emphasised the extraction of groundwater for dry season irrigation. Significantly, no specific strategies were adopted for the balanced use of surface and groundwater irrigation and the environmental needs of water. Goals of sustainable water resource developments are in such policies only, rather than being translated into action or strategies. For instance, the activities of the Barind Multi-purpose Development Authority, a key government agency for irrigation development in the study area, are purely limited to the development and extraction of groundwater for irrigation. The key function is focused on the irrigation cost recovery from selling water coupons[3], and not on sustainable irrigation or surface water development. Maintaining the balance between water withdrawal and recharge should be at the core of the sustainable groundwater resource planning. Adequate awareness about sustainable practices of water resources management has not built up among farmers through appropriate extension services.

[3] Farmers purchase coupons of different values from the Barind Multi-purpose Development Authority, and use them to receive water from their local water pump stations. The administrators of these stations control the measurement of water supply and billing.

## 4.0 Conclusion and Policy Implications

The objectives of this study were to understand rice growers' perceptions about climate change and variability and to identify determinants of actual adaptation decisions at the farm household level in drought-prone and water-scare regions in Bangladesh by means of an econometric analysis. The results of the study reveal that farmers made their adaptation decisions in the context of their household's socio-economic and farm characteristics, the institutional setting under which they are farming, infrastructural access, and perceptions about climatic extreme events. The multinomial logit analysis of adaptation reveals that institutional and infrastructural access, education, tenure status and an awareness of climate variability are the keys to enhancing farmers' adaptive capacity. This necessitates a coordinated intervention on the part of government, private and non-government organisations to improve farmers' access to these factors and to raise their status in order to adapt to changing climate and water-stress regimes.

A second objective of this study was to assess the factors potentially explaining adaptation in the context of their ability to attain sustainability in water resources management. This study reveals that the current practice of increasing reliance on groundwater as a potential source for irrigation to adapt to water scarcity and droughts cannot be a sustainable solution.

The findings of this study have several macro and regional level policy implications for framing sustainable adaptation strategies for farming communities, both in Bangladesh and other jurisdictions facing similar issues. Bangladesh has made significant progress in food production, especially of rice. However, ensuring food security remains a daunting challenge. It is important for the agricultural economy to maintain the current production trends under the adverse socio-climatic conditions farmers are facing in the context of a declining water table, declining rainfall and per capita availability of land, and soil and land degradation.

Adaptation to these extreme events is to be considered as complementary responses to addressing climatic vulnerability.

This research shows that the use of groundwater is the most commonly used option for farmers to cope with water scarcity. Farmers are found to be practicing a few sustainable options although at a lesser extent. For instance, during the field visit it was observed that a local non-government organisation was encouraging farmers to use conservation tillage along with mulching to improve soil moisture and thus reduce crop failure in dry years. These initiatives need to be strengthened through appropriate research and development and extension services. Government and non-government organisations need to work together to design an integrated plan of action to implement such initiatives. Water scarcity and drought conditions are a reality, at least in some parts of Bangladesh. Increased reliance on groundwater for irrigation is not a long-term sustainable solution. Therefore, the whole water resources management issue needs a rethinking from a policy-making perspective. Research and extension of high yielding, drought and disease-tolerant rice varieties, soil and water conservation and low-water consuming crops are necessary. Farmers showed their readiness for adopting such adaptation practices. Government policies and adaptation strategies at the local level should also focus on improving water productivity and land management, and enhancing the efficiency of water usages. A policy refocus is required for a conjunctive use of surface and groundwater irrigation to maintain agricultural productivity and to determine environmentally sustainable levels of groundwater extraction. Drought adaptation strategies should refocus on building ecological resilience in an integrated fashion in line with reduced reliance of groundwater and increasing water harvesting and achieving enhanced efficiency of surface water irrigation and adopting conservation farming.

Sustainable irrigation water management could be an answer for long-term drought management in the study region. Further expansion of groundwater infrastructure is not sustainable on environmental and social grounds. Rather, surface water irrigation should be expanded. A large-scale dam is not viable in northwest Bangladesh. An increase in surface water storage capacities through various small-scale water harvesting systems can reduce soil erosion through collecting excessive surface runoffs which can be used for supplementary irrigation. Another viable long-term solution to water scarcity in the region could be the development of a surface water reservoir and storage through diverting water flows from the Ganges and Mahananda Rivers as long as their environmental flows for healthy river ecosystems are maintained.

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