Differentiating rice farmers' vulnerability to climate change and adaptability in Bangladesh

A research paper submitted by

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(Bangladesh)

in partial fulfillment of the requirements for obtaining the degree of
Masters of Arts in Development Studies

Specialization:

Agrarian, Food and Environmental Studies (AFES)

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November, 2017

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This document represents part of the author's study programme while at the Institute of Social Science. The views stated therein are those of the author and not necessarily those of the Institute.

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List of abbreviations and acronyms

AIC	Akaike Information Criterion
BARC	Bangladesh Agricultural Research Council
BBS	Bangladesh Bureau of Statistics
BIC	Bayesian Information Criterion
BMD	Bangladesh Meteorological Department
BRRI	Bangladesh Rice Research Institute
BWDB	Bangladesh Water Development Board
CSIRO	The Commonwealth Scientific and Industrial Research Organisation
CV	Coefficient of variation
DSSAT	Decision Support System for Agro-technology Transfer
FAO	Food & Agriculture Organisation
GCM	Global Climate Model
GHG	Green House Gas
HBT	High Barind Tract
HYVs	High yielding varieties
IMPACT	The International Model for Policy Analysis of Agricultural Commodities and Trade
IIA	Independence of irrelevant alternatives
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated Water Resource Management
Kg	Kilogram
MLE	Maximum likelihood estimates
MNL	Multinomial logit

MNP	Multinomial probit
NCAR	National Centre for Atmospheric Research
OLS	Ordinary least squares
SPI	Standardized Precipitation Index
T. *Aman*	Transplanted *Aman*
VIF	Variance inflation factor
WARPO	The Water Resources Planning Orgamisation

Acknowledgements

It is my greatest pleasure and opportunity to express my deepest gratitude to persons who have been influential in developing my academic career and also in my life. First of all, I am highly thankful to my supervisor, Professor Dr. Arjun Bedi who has helped me throughout my thesis preparation at ISS. He provided resourceful insights into articulating my research questions, preparing the proposal and also writing the full draft. Particularly, after attending his classes on econometrics, I could get rid of my fear for econometric analysis. I express my profound gratitude for everything I learnt from him.

I express my sincere gratitude to my second reader, Professor Dr. Oane Visser. His resourceful guidance helped me organize the framework and put arguments in discussing the results. He has been thoroughly supportive and motivational. I am also grateful to him for his timely and enlightened feedback.

I am much obliged to Dr. Mohammad Alauddin, Associate Professor of Economics at the University of Queensland for supporting me with farm level data required in the study. He provided me with relevant references and gave constructive criticism which helped me shape my paper. He has been a fatherly figure to me since I started working in his research project. I am grateful to him for giving me a leap forward to developing my research capacity.

It is my immense pleasure to express my gratitude to faculties in AFES major at ISS Dr. Cristobal Kay, Dr. Ben White, Dr. Jun Borras, Dr. Murat Arsel, Dr. Julien Gerber and especially AFES convener Dr. Mindi Schneider for giving wonderful and thought-provoking lectures in class. I was able to explore a new dimension of development thoughts while at ISS and this helped me build conceptual framework in the paper.

I am thankful to the authority of the University of Rajshahi for granting me study leave. I thank my respected seniors and other faculties in the department of Economics for inspiring me and keeping faith in me. I thank Dr. Md. Elias Hossain for continuously pushing me to pursue higher degree. I am thankful to Dr. A. N. K. Noman for appreciating my work. My sincere and heartfelt thanks go to respected Dr. Dilip Kumar Nath for all his inspiration and care.

I perceive this is a wonderful opportunity to convey thankfulness to my mentor and respected teacher, Dr. Md. Abdur Rashid Sarker, Professor in the Department of Economics at the University of Rajshahi. He is the biggest support in preparing myself to pursue higher degree and to develop my research skill. I remember his joyful appreciation on receiving the news of my candidacy acceptance at ISS. He has been selflessly supporting with his wisdom to enlighten me in agri-environmental issues. I would like to apologize to him for all the trouble I gave him and thank him for his friendly feedback in all my endeavours.

I thank all my class fellows at ISS, specially Divya Jain for her continuous motivation in writing the paper and Risa Wardatun Nihaya for her useful comments after reviewing the proposal and the first draft. I will cherish the memories I have with lovely people here.

Last but not the least, I thank my parents, my sister and my sweetest brother who have been continuously giving me mental support and love since I came to the Netherlands. I also apologize to my mom and my brother for not being with them when they needed me the most. I specially thank my dear father, Md. Jahurul Islam, Professor of English at the University of Rajshahi for my thesis proof reading and making me feel confident. I thank Shrabanti for giving tremendous support and taking care during my stay in the Hague. I remember all my well-wishers and friends for making me feel worthy of the work.

Dedication

To my iconic teacher, Professor Sanat Kumar Saha, who has been a profound and unending source of inspiration and motivation

Abstract

In the face of frequent and severe vulnerability to climate change, and extreme weather events, rice yield loss has become a burning issue to consider, particularly for developing countries which are the largest rice producers and consumers at the same time. Rice is the mainstay of Bangladesh economy and also is the staple diet for people in the country. Due to increasing change in the pattern of temperature and rainfall, farmers are exposed to both environmental hazards like droughts and floods and also livelihood shocks. However, to combat yield loss farmers adapted to short-term farming strategies which are time and location in-variant. But in vulnerability scholarship it is argued that farmers' vulnerability to environmental stress is disaster and individual specific. Likewise, adaptive capacity of farmers is determined by their access to socio-demographic, economic, institutional, knowledge, political resources. This study therefore explores spatial patterns in temperature and rainfall variability which so far have received less attention in the context of Bangladesh. The study also examines whether there is any differentiation across farmers in making adaptation choices and productivity. This study uses monthly time series data of maximum temperature, minimum temperature and rainfall for the period 1964-2012 to analyse trend, seasonality and their variability. Survey based farm level secondary data for the production year 2011-2012 have also been employed to gauge farmers' perception about temperature and rainfall change and to assess the effect of household characteristics on the choice of adaptations and land productivity of rice.

The study found larger variability in rainfall compared to temperature. Maximum temperature exhibits more increasing trend while rainfall has a more decreasing trend in *Rajshahi* compared to two other weather stations namely *Bogra* and *Ishurdi*. Farmers perceived a gradual increase in temperature and decrease in rainfall both annually and seasonally. Therefore, farmer perception is consistent with national weather variability analysis. Household head's age, education and access to agricultural credit, subsidy and electricity for irrigation have statistically significant effect on different adaptation choices and land productivity. However, lack of climate information has appeared as a major adaptation barrier. The negative effect of drought severity and the positive effect of groundwater depletion on land productivity imply more irrigation and consequently increased water stress. Differential land productivity and choice of adaptation strategies across farmers have been observed: probability of choosing water saving non-rice and horticulture crop cultivation is the highest in drought prone areas and also among large or medium farmers in this study. As all farmers extensively used irrigation in rice cultivation, farmer type has no effect on the choice of more irrigation. The findings coupled with vulnerability analysis and existing literature suggest that though scientific research driven adaptation strategies could increase land productivity, it is required to assess pre-existing socio-economic, institutional and knowledge based resource access of farmers in formulating short term adaptation policies. However, in the long run, strong monitoring of agricultural support provisions, farming related education and training, timely & adequate climate information are important in raising land productivity as well as reducing disparities among farmers.

Relevance to development studies

Food security remains a challenge due to population pressure, climate change and frequent climate extreme events in developing countries. Adaptations to changing climate in farming might be possible solution to combat yield loss and make farming households food-secure. In Bangladesh taking up adaptation strategies could increase rice yield in national documents and records. However it is argued in this study that individual farmer's capacity to make adaptation choice and consequently land productivity remains differentiated due to differential resource access. Therefore, in formulating adaptations to changing climate it is required to address pre-existing vulnerability in terms of resource access of poor farming households who are actually at the bottom of social stratification. This study aims to put an emphasis on the efficiency of resource distribution to make adaptations sustainable which in turn has the potential to contribute to achieving food security for all and aggregate welfare.

Keywords: vulnerability, climate variability, adaptation strategies, land productivity, farmer differentiation

JEL classification: Q15, Q54, B50, C22, C35

Chapter 1
Introduction, research issues and organisation of the study

1.1 Background

The impact of climate change on livelihood and the intensity of stress have been largely concerned in climate literature and vulnerability analysis. In global context, temperature and rainfall followed a changing pattern (IPCC, 2014). Particularly, extreme events such as drought, floods, cyclones, sea level rise and so on are more frequent phenomena in developing countries compared to the developed ones. Due to high population density and dependence on agriculture developing countries are more sensitive to climate change risks (Schelling, 1992). It is estimated that even a moderate increase in temperature of 1-2ºC will have an adverse impact on cereal yields (Schellnhuber et al., 2013). Thus, if the prediction of an average temperature increase of 4ºC in this century (Storm, 2009) does occur, the effects are likely to be catastrophic in terms of yield loss and loss of livelihood.

More than half of the world's population lives on rice and the relative importance of rice is increasingly growing (Maclean and Dawe, 2002). In South Asia intensification in agriculture has been largely promoted in the face of rapid population increase and Bangladesh is a suitable country in this respect for multiple cropping seasons. Bangladesh is an agricultural and rice-intensive country (Alauddin and Quiggin, 2008). Historically rice has accounted for 80% of total cropped area and 90% of total grain production (Alauddin and Tisdell, 1987; Asaduzzaman et al., 2010). The choice of crops in the country is largely motivated by monsoon and extensive irrigation facilities (Rahman, 2008). Due to its geographical location and soil topography, Bangladesh is very vulnerable to climate variability such as temperature increase and rainfall decrease causing droughts and ground water depletion since 1990s. Witnessing more frequent and longer drought periods (Rahman and Lateh, 2016), the fear continues for more drastic crop failure and water stress. This has led to the formulation of short term mitigation and adaptation strategies so that loss of production is reduced and simultaneously production is adapted to the changing climate. However, the strategies do not address spatial variability of climate variables and resource access vulnerability of farmers.

1.2 Climate change and rice cultivation in Bangladesh

Climate change and its impacts on rice farming is not a recent phenomenon in the context of Bangladesh. Average temperature increase before and during rainy season with persistent dry spells, larger seasonal rainfall variability and heavy consecutive downpour during the end of monsoon are frequently observed (Kabir et al., 2017a). Also in coastal salinity prone areas, with 10% of area lying 1 meter above the sea level and larger exposure to “tidal excursions”, the possibility of tropical cyclones and floods continues to rise (Ali, 1999). Particularly, the increasing trend in temperature and decreasing rainfall across seasons makes the north and north western parts of the country vulnerable to severe drought and groundwater depletion. However, the country could increase rice production significantly during the 2009-2012 period cultivating high yielding varieties and is keeping at an increasing pace with South Asian contribution (FAO, 2013; Shelley et al., 2016). Rice cultivation is the mainstay of Bangladesh economy and major diet to most Bangladeshis. Rice is grown all the year round in *aus* season (mid-March - August), *aman* season (end June – early January) and *boro* season (mid- November – mid-June) (BBS, 2014). Per acre yield is approximately less than double in *boro* season compared to others, and seed requirement is the highest in *aus* season. Apparently, productivity in *boro* season is continuously increasing based on a comprehensive irrigation system but it is threatened by water scarcity. Additionally, intensive irrigation after monsoon puts stress on ground and surface water availability (Alauddin and Quiggin, 2008).

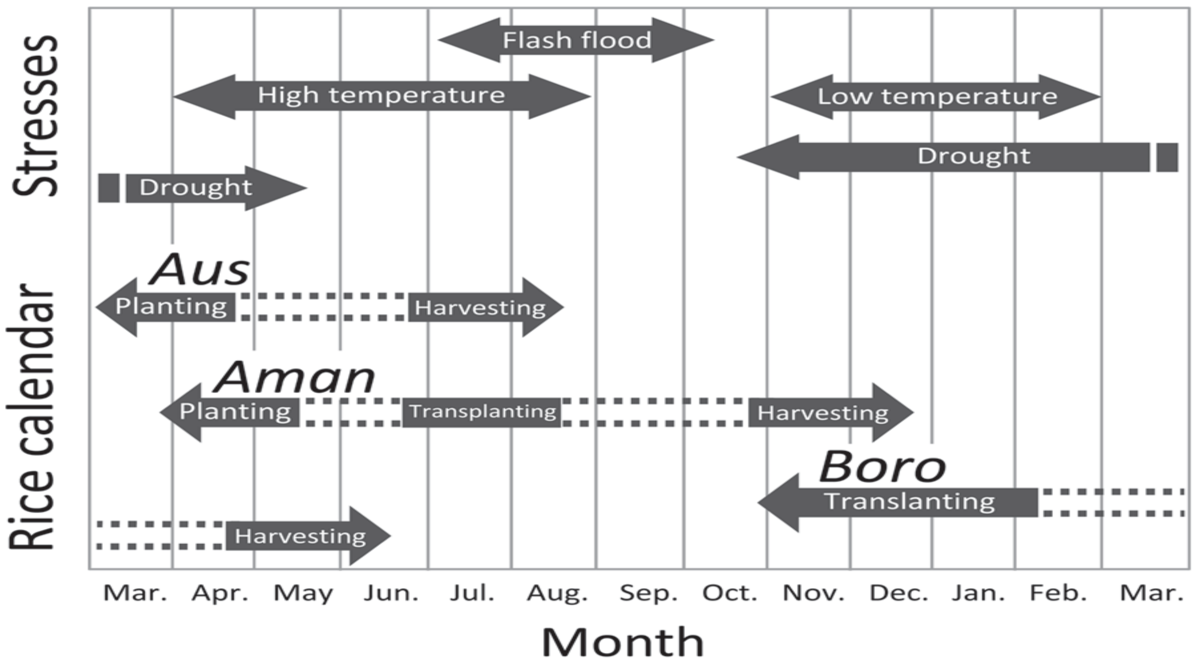

Figure 1.1: Rice calendar and climate stress in Bangladesh
Source: Adapted from Shelley et al. (2016)

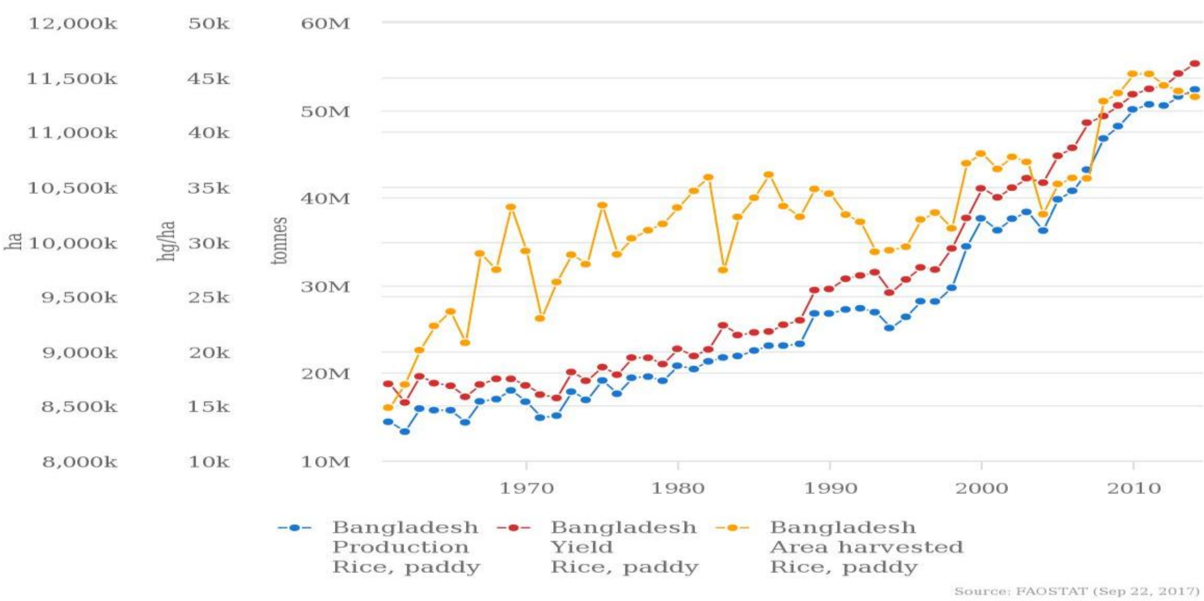

Figure 1.2: Rice production yield and harvested area over the period 1960-2012
Source: Based on FAO database

Rain-fed T.*aman* rice is also vulnerable to increased rainfall variability and consecutive heavy runoff. During *aus* season, area of arable land is continuously shrinking due to its low productivity and persistent and extreme dry spells in summer (Ruane et al., 2013; Sarker et al., 2014; Islam et al., 2017). Notwithstanding farmers adapted to HYV (high yielding varieties) rice cultivation in which farming is *land-saving* (Alauddin and Quiggin, 2008). In this regard, as Habiba et al. (2011) demonstrated, both irrigation coverage and land use had significant influence in reducing yield loss in drought affected and submerged north-western regions.

1.3 Adaptation strategies and vulnerability of farmers

Adaptation strategies are very important in the face of developing countries' extreme vulnerability to the impacts of climate change and frequent disasters (Delaporte and Maurel, 2016). Future crop yield reduction simulation encourages the strategies so that farm households become resilient during stress and adapt to climate change. The importance of adaptation has been proclaimed at global and national policy levels based on Global Climate Models (GCM) addressing food demand-supply issues and the potential of sustainable agriculture (IPCC, 2007; IPCC, 2014). These climate change adaptations mainly include disaster-tolerant and short duration rice varieties, intensive irrigation, cultivation of water saving non-rice crops, integrated crops-livestock farming, homestead gardening and so on (FAO, 2006; Yu et al., 2010; Arimi, 2014). Adaptation to HYVs and decisions about cropping techniques could reduce yield loss, fight pest attacks and diseases and increase yield at the same time. A large body of literature in this respect is observed assessing the impact of adaptation strategies and also the determinants of adaptation choices (e.g. Abid et al., 2016; Arimi, 2014; Delaporte and Maurel, 2016; Deressa et al., 2009, Hassan and Nhemachena, 2008; Sarker et al., 2013).

However, as Harmer and Rahman (2014) reviewed literature on strategies[1] commonly adapted in developing countries, they are mostly short-term and "technology based" strategies. Climate change and adaptations are not a simplified issue to consider in the short run only. Rather, it is amalgamated with long run factors such as crop price volatility, lack of knowledge and socio-economic inequality (Harmer and Rahman, 2014; Hassan and Nhemachena, 2008; Mertz et al., 2009; Sarker et al., 2013; Thwaites et al., 2014). Hence it is a matter of query regarding the capabilities of farmers to adopt and whether the strategies are economically sustainable. This leads to the formulation of the following research problem.

1.4 Statement of the research problem

Climate change adaptation strategies in farming are indifferent to spatial climate variability and the adaptive capacity since they are basically science-driven strategies based on macro level climate projections. These strategies demand larger natural, social and financial resources and the outcome of adoption for individual household depends on how access to these resources is distributed (McDowell and Hess, 2012). For instance, cultivation of HYVs requires both capital and water extensively (Alauddin and Quiggin, 2008). So, more dependence on short-term adaptation might reduce the capacity of farmers in the long run due to rising cost of inputs and crop price volatility (Kandlikar and Risbey, 2000). In vulnerability scholarship, it is argued that adaptive capacity and decision are constrained by multiple vulnerabilities, and both environmental hazards and livelihood shocks are time and location variant (Agrawal, 2010). So, farmers' vulnerability to climate change is multifaceted and adaptation largely depends on their pre-existing access to social, economic, institutional and political resources (Adger et al., 2003;

[1] In literature, often adaptation strategies and coping mechanisms are used interchangeably and in some literature as Harmer and Rahman (2014) discussed they are used differently based on short and long term processes. In this study, they are operationalized as short term adaptation strategies.

Agrawal, 2010; Ribot, 2010). This renders that one household capable at one point of time may fall into livelihood stress in changing climate and eventually lose adaptive capacity. Households capable of adopting strategies and coping mechanisms may have larger access to resources and continue to benefit. Households which have not been able to adopt may be marginalized due to climate change livelihood loss and inaccessibility to socio-economic resources.

In Bangladesh per capita arable land is comparatively low among South Asian countries (Alauddin and Quiggin, 2008). Continuing reduction in average holding size due to increased population pressure demonstrates that small and marginal farmers are dominant; 76.5% farmers own less than 1.00 acre of land and 10.2% are landless (Hossain et al., 2005). Farmer categorization[2] on the basis of land holding has a distant connection in historical land reform and tenancy pattern. However, while assessing the relationship between land entitlement and productivity, it is argued that farm size should not be the only factor causing differentiation, rather production techniques, new technology and input mixes are crucial in determining heterogeneity across farmers (Dyer, 1996). The use of chemicals, machineries and physical water for irrigation[3] has increased in cultivation of disaster tolerant HYVs (Collins and Chandrasekaran, 2012; Rahman, 2005). So, farmers with large land holdings and larger access to resources can earn more income and accordingly are able to spend substantially on different adaptation strategies and inputs (Mabe et al., 2014).

Theoretical underpinning and existing literature suggest that the adaptive capacity of farmers depends on the accessibility of resources and how they are exposed to climate variability and

[2] Farmers are categorized on the basis of own land holding size in official documents namely large, medium, small and landless (BBS, 2014). In small category marginal farmers are also included.
[3] Irrigation is undertaken using both ground and surface water.

extreme events. Accordingly, in Bangladesh, in three drought prone climatic zones[4] there are different levels of severity of drought and depletion of ground water and so is the choice of adaptation (Alauddin and Sarker, 2014). However, limited access to information about climate change and adaptation strategies, limited access to funds, limited irrigation facility, limited and lack of land ownership are major adaptation barriers in the country (Alauddin and Sarker, 2014; Arimi, 2014; Delaporte and Maurel, 2016; Deressa et al., 2009; Sarker et al., 2013). Differential capability and productivity causes differential vulnerability (Adger et al., 2003; Ribot, 2010) and capital-intensive and market oriented adaptive measures intensify social inequality and injustice (Hunsberger et al., 2015). So, short term production based adaptations actually cannot dilute the differences across farmers by increasing yield only. Often persistent livelihood shocks confronted by small, marginal and landless farmers make them take up off-farm activities, wage labour, bonded labour and even migration (Kabir et al., 2017a). In this backdrop, the study has the overall objective to understand the spatial variability of climate elements and to assess the vulnerability of farmers in making choices of adaptation and land productivity.

1.5 Research questions

This study has the following specific research questions to address the above mentioned research problem;

1. What is the trend in temperature and rainfall pattern over the period 1964-2012 and how does the trend vary across different regions?
2. How do farmers perceive temperature and rainfall change and are their perceptions consistent with the trend?
3. What factors determine the choice of adaptation strategies?
4. What factors determine land productivity?
5. Is there any difference across farmers in making adaptation choice and land productivity?

[4] Detail about climatic zones and maps are provided in Chapter 4.

1.6 Organisation of the thesis

In addition to this introductory chapter, the remainder of this paper is organized in six chapters. Chapter 2 provides conceptual framework on risk-based approach and bottom-up approach to address farmer vulnerability and differentiation across farmers. Chapter 3 reviews the literature on climate change, farmer perception about climate change, adaptation strategies and their determinants and farmer vulnerability studies. This chapter also identifies gaps in the existing literature. Chapter 4 outlines the detail of methodology employed in the research including description of study area, data source, analytical approach, model specification. Chapter 5 examines trend and seasonality in temperature and rainfall variables at regional level and farmer perception about change in these variables. It involves a holistic approach to understand why farmers are vulnerable to climate change and provides a basis of a more rigorous study using regression models to explain vulnerability to climate change. Chapter 6 examines and documents estimated results from the specified empirical models assessing the determinants of choices of adaptation strategy and land productivity along with differences across farmers. Chapter 7 concludes the study with policy implication and future research directions.

Chapter 2
Conceptual framework

2.1 Introduction

In climate literature and vulnerability scholarships, two main approaches are used, namely top-down risk analysis and bottom-up vulnerability analysis. In this study both approaches are used in a comprehensive way so that climate variability can be explored and farmer vulnerability is also assessed. This chapter outlines the conceptual framework employed in the study. Briefly, Section 2.2 sheds light on theoretical perspectives on vulnerability assessment, while Section 2.3 discusses conceptualization of adaptation strategies and adaptive capacity. Section 2.4 provides the framework in understanding the differentiation across farmers.

2.2 Vulnerability theory

In defining and determining the “magnitude of threat” and the scope of adaptation, vulnerability assessment is the primary step to undertake (Kelly and Adger, 2000). However, conceptualization of vulnerability differs in climate literature and consequently the significance of adaptation. There are two strands in vulnerability assessment, namely “outcome vulnerability” and “contextual vulnerability” as Fellmann (2012) demonstrated. “Outcome vulnerability” is measured by the adaptive capacity, and produces technological solutions to reduce future vulnerability (Ibid.). In this approach, vulnerability is assessed looking at “biophysical impact driven” exposure, sensitivity and adaptive capacity of a community or system separately (Burton et al., 2002). So, if the system or community is exposed or sensitive to climate variables and also is not capable of adapting, it becomes vulnerable. This strand of vulnerability analysis focuses on climate change impacts on aggregate production only. In this way, though these models capture climate variability over time, apparently they ignore the situational analysis of diversely and spatially distributed economy (Burton et al., 2002). Ribot (2014) also claims that the causality between vulnerability and climate risks is actually left unexplained and nature has been blamed to be ‘anthropogenic’ which normalizes pre-existing vulnerability.

On the contrary, “contextual vulnerability” is based on current condition and such analysis helps to reduce vulnerability and increase coping range in a changing climate at the same time (Fellmann, 2012). Brooks et al. (2005) described vulnerability as contextual to a system’s nature and disaster specific. Also such analysis focuses on “social stratification” which penetrates into cumulative stress posed by climate risks (Ribot, 2014). In this approach, environmental factors are responsible for sensitivity and various economic, cultural, political factors determine adaptive capacity at community level (Smit and Wandel, 2006). Following Blaikie et al. (1994), Kelly and Adger (2000) emphasized individual specific exposure to hazard, capacity to respond, adapt and recover where they assessed “social vulnerability’. The authors argued that existing resource inequality constrains poor households’ capability to adapt and therefore intensifies vulnerability for the whole community; due to increased privatisation and reduced scope of collective livelihood option. So, sensitivity, adaptive capacity and resource access are not mutually exclusive elements to analyse. Also conceptualization of vulnerability becomes more location specific, temporally variant and also recognizes the heterogeneity among individuals in a community.

2.3 Adaptation and adaptive capacity

The evaluation of adaptation helps to understand the impact a system experiences in a changing climate. Adaptation is a function of adaptive capacity which determines the coping range in a variable climate (Fellmann, 2012). Smit and Wandel (2006) define adaptations as “the manifestations of adaptive capacity and they represent ways of reducing vulnerability”.

Adaptation assessment therefore should include response of the society and the consequences of such response (Kelly and Adger, 2000). Initially the analysis of adaptation processes stemmed from global climate model predictions about past and current climate behaviour (Burton et al., 2002). These strategies influence the choice of crops and the technology used in cultivation (Ibid.). Particularly following climate change impact as the ground, adaptation strategies are pursued aiming to IPCC and Kyoto Protocol's mitigation efforts (Ayers and Forsyth, 2009). Particularly, funds were institutionalized after COP-7 in Paris in 2001 for developing countries increasingly perceiving that climate has already changed and impacts are predominant (Ayers and Forsyth, 2009; Burton et al., 2002).

In the scholarship of adaptation policy and processes, conceptualisation of adaptation plays a crucial role. Controversies and 'pluralism' around vulnerability and adaptation are important though not unanimously agreed upon in conceptualisation and methodological application (Hinkel, 2011). There are two strands of approaches to climate change and adaptation analysis- "risk based" or "top-down" approach followed in global climate modelling and the other one is "bottom-up" or community based approach where vulnerability is at the core. Referring to top-down approach employed in IPCC assessment, Hinkel (2011) pointed out that three components; 'sensitivity', "adaptive capacity" and 'vulnerability' are not jointly discussed. For instance, crop sensitivity and resilience are emphasized in measuring yield loss intensity due to changing pattern in temperature and rainfall, without referring to agricultural supply and resource distribution (Burton et al., 2002). However, adaptation decisions are actually accomplished by various economic agents, so accessibility to resources and interests of various agents might be conflicting (Adger, 2010). That is why, such risk based models assessing the processes and impacts of adaptation at aggregate level fail to observe why adaptation decision at individual level varies in the same community.

On the contrary, proponents of “bottom-up” approach criticize the risk-based approach for being ‘hypothetical’ and for not inquiring into the whole process from capacity to decision making to the adoption of strategies (Smit and Wandel, 2006). Additionally when vulnerability is at the core, the evaluation of sensitivity and adaptive capacity across areas depends upon some pre-determined selection criteria and vulnerability scores of those areas (Ibid.). Specifically, the scope of technology use and adoption of strategies depends on acceptability and vulnerability at local level (Ayers and Forsyth, 2009). That is why “bottom-up” approach is proclaimed to be more inclusive and pragmatic. This approach captures socio-demographic, economic variables and other mediating processes rendering as livelihood approach. Therefore tools are used to look at the differentiation of adaptive capacity and the impact of strategies across individuals. These tools look at current and past adaptive capacity; exposure and sensitivity to climate risks rather than relying upon priori model based projections (Smit and Wandel, 2006). So, spatial variability of climate stress and the exposure of livelihood to that stress can be explored for individuals.

In practice, adaptation is not able to reduce differentiation due to social stratification (Adger, 2010). Vulnerability analysis rather is a useful tool in explaining livelihood loss due to lack of social capital, institutional access, planning, market stability, knowledge, amongst others (Ribot, 2014). So, vulnerability analysis on the basis of adaptive capacity can explain the causal relationship of pre-existing production relations, infrastructure status quo, institutional and resource accessibility, environmental risks of yield loss, livelihood shock and marginalization. However, in doing so, both approaches should be combined in methodological application so that all biophysical, social, historical, economic, institutional, political factors are explained in current situation as well as depicted for the future (Fellmann, 2012). Following Figure 2.1 shows the flow diagrams of concepts and tools employed in two approaches in climate literature. In this study, macro level analysis focuses on the pattern of temperature and rainfall while vulnerability of farmers is assessed at micro level.

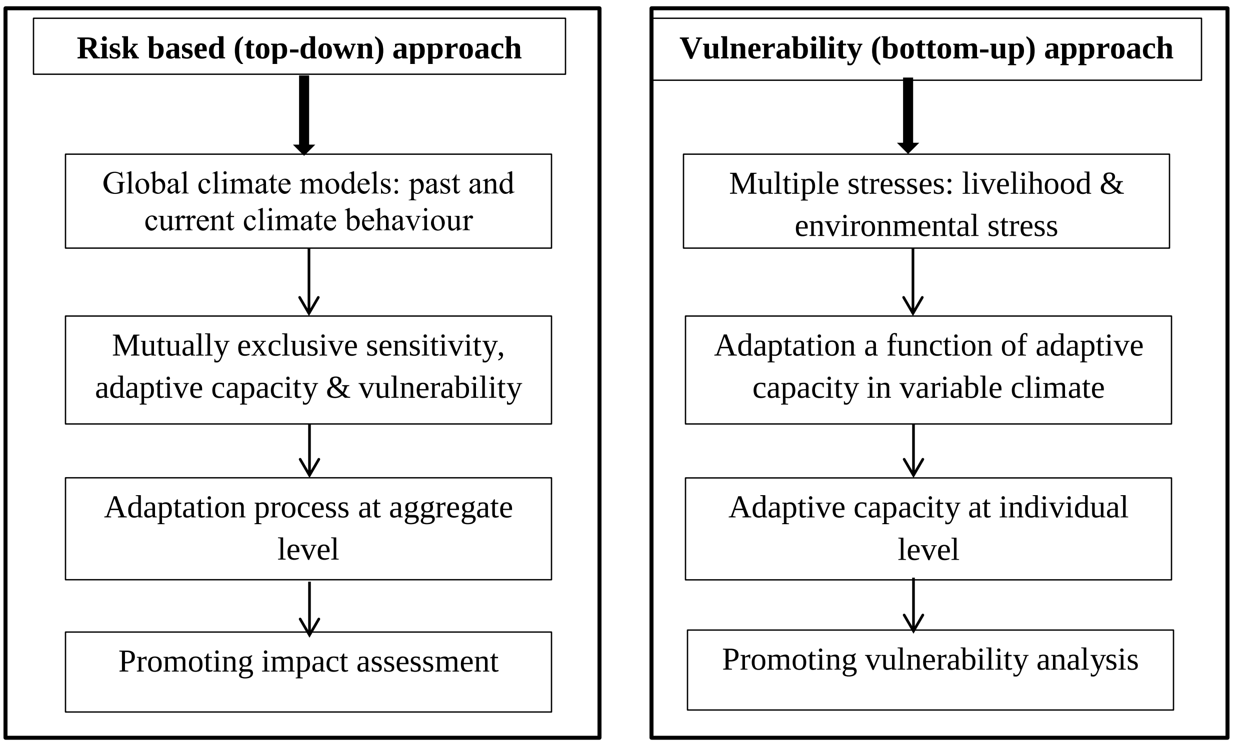

Figure 2.1: Top-down and bottom-up approaches in vulnerability analysis
Source: Author's own analysis based on literature review

2.4 Differentiation across farmers and productivity

The scientific approach to study class differentiation is rooted in political economy theory. Bernstein (2010) ascertained that farmer differentiation had occurred in the process of transition from small scale farming to petty commodity producers. Lenin observed differentiated class structure in rural setting based on tenancy pattern and labour appropriation (Akram-Lodhi and Kay, 2012). Lenin and Kautsky emphasized the technology used in cultivation and methods of cultivation to determine *peasant*[5] differentiation and differential productivity (Akram-Lodhi and Kay, 2012). Bernstein, Lenin and Kautsky all acknowledged differential resource access and control over outcome in terms of productivity. While these theories focus on factors[6] of production only, Sen (1981b) emphasized the combination of resource ownership and exchange entitlement which are shaped by class structure, production relations and institutional access to social security. For instance, in developing countries irrespective of physical size of own cultivable land, production is increasing under share-cropping, cash cropping taking land in lease and rent. Land rental and share tenancy system persuades the appropriation of surplus produced by the tenant farmer and the amount of rent shapes the differentiation across farmers (Roseberry, 1976). However, farmers are not only differentiated among themselves but also from wider society, thereby it is required to assess social, economic, political factors within farming communities as well as to connect their relationship with the society (Dalton, 1974). These relationships are basically institutional regarding purchase of seeds and other inputs, credit access, subsidy provisions and even knowledge about farming techniques.

Along with land holding and labour supply discussed in classical political economy, critical agrarian political economy brought a new dimension in looking at farmer differentiation. In contemporary agricultural modernisation, widespread mono-cropping of HYVs, chemical fertilizers, machineries are being promoted to reduce "yield gap" in changing climate (Taylor, 2014). Top-down approach promoting agricultural intensification does not actually acknowledge the

[5] Clarification about this term is given in Appendix A. However, this study includes all types of farmers involved in cultivation and the primary focus is not making any normative judgment, therefore, the study operationalizes the study population as farmers.

[6] In classical theory land, labour and capital are called as factors of production whereas in political economy approach these are termed as means of production in order to determine production relations in a social structure. Means of production is used in this approach to determine class structure and social differentiation.

differentiation embedded in the system. Also, debate is raised on the ground that all farmers do not have equal access to these technologies, hence act differently (Gray and Moseley, 2005). Such market based solutions are sensitive to price volatility requiring adequate financial resources to ensure affordability. For instance the rise of agribusiness could influence the use and the price of seeds, fertilizers and machineries (Collins and Chandrasekaran, 2012). Large farmers are less dependent on agricultural credit and simultaneously more capable of buying costly inputs (Isakson, 2015) while small holder farmers are forced to take up credit so that they can buy these inputs to increase productivity (Taylor, 2014). This could explain individual productivity decrease and eventually reduction in trade entitlement of poor households (Sen, 1981a). So, this framework of differentiation exposes individual farmer's vulnerability to climate change and explores how the vulnerability increases due to lack of own economic resources. Additionally, the control over land, labour and technical resources leads to the concentration of accumulation for large farmers (Akram-Lodhi and Kay, 2012). However, Taylor (2014) mentioned that in commercial agriculture control of land is becoming less important and agricultural intensification is responsible for increased dispossession, off-farm employment, commodification of labour and vulnerability of farmers. So, climate resilient crop varieties and associated agricultural modernisation is putting farmers in additional economic risk in a differentiated manner. This framework therefore is used to choose the variables in the study to explain the choice of adaptation and land productivity so that differentiation across rice farmers can be assessed. A rigorous review of existing literature has been done following this conceptual framework which is described in the next chapter.

Chapter 3
Review of literature

3.1 Introduction

This chapter outlines a detailed review of literature on climate change and its impact on agriculture particularly rice cultivation, adaptation strategies and vulnerability of farmers both in global and Bangladesh contexts. Section 3.2 discusses climate change and its impact on rice production. Section 3.3 focuses on farmer perception about climate change. Sections 3.4 and 3.5 respectively provide an overview of the determinants of adaptation strategies and farmers' vulnerability. Finally, gaps in the existing literature are discussed in Section 3.6.

3.2 Climate change and its impact on rice farming

In the face of global warming the concept of climate change is defined as the change in average climate variables when the variability has been continuing for a longer period of time (NRC, 2011; IPCC, 1990). Indicators of climate change are air and water temperature increase, ocean acidification and sea level rise (IPCC, 1990; IPCC, 2007; IPCC, 2014; Storm, 2009). It is estimated that temperature increased by 0.85ºC during the period of 1880-2012 and the period 1980-2012 was the warmest 30 years due to CO_2 and other GHGs emissions (IPCC, 2014). IPCC (2014) assessment revealed that 40% of anthropogenic GHGs emissions increased atmospheric concentration and the remaining is absorbed by oceans and plants causing ocean acidification and yield loss. Following Figure 3.1 depicts the projection of global yield change for the period 2010-2109. As Storm (2009) stated, there will be "irreversible and uncontrollable" global warming and disastrous impacts if CO_2 emissions are not controlled.

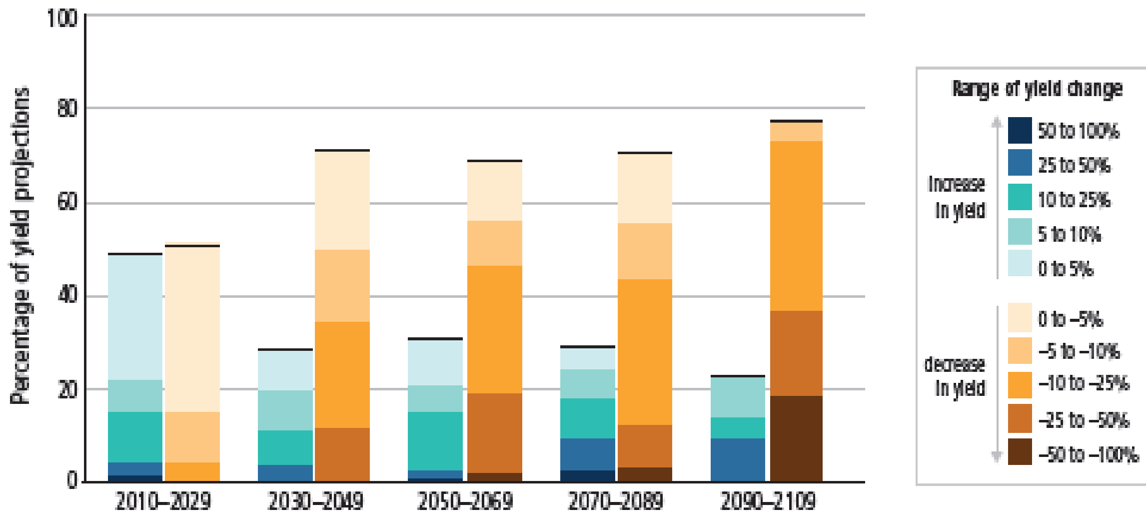

Figure 3.1: Projection about world yield change for the period 2010-2109
Source: Adapted from IPCC (2014)

Apart from long term deviating trend from average condition in climate variables, extreme events have also become recurrent phenomena. Mirza (2003) compiled IPCC assessments on the probability as well as occurrence of extreme events like high maximum and minimum temperature, increased precipitation, less cold days, increased frequency of drought, floods and tropical cyclones especially in countries of Africa, Asia, Latin America. Katz and Brown (1992) analysed climate data in 30 stations in USA and found that climate extreme events are sensitive to both average climate variables and its variability. Spinoni et al. (2014) using SPI (Standardized Precipitation Index) constructed world drought mapping for three different time periods from 1951 to 2010 and observed that drought frequency, duration and sensitivity have increased since 1990s particularly in Asia and Africa. These regions are also vulnerable to floods. Temperature increase (estimated to be 2ºC), extreme precipitation for consecutive days, shifting monsoon and lack of proper drainage of water flowing from the Ganges all are making flood situation worse and prone to cyclones in South Asia (Mirza, 2011). Accordingly, in

Bangladesh north and north-western regions are affected by drought and groundwater depletion; coastal areas are affected predominantly by rising sea level, soil erosion and salinity; and low and flat landscape is affected by water surges (Ali, 1999a; Shahid and Behrawan, 2008).

Concern about climate change actually originated from cumulative impacts occurring for decades. The projection of world population increase and required food production within a degraded ecosystem and in variable climate (FAO, 2009) played a significant role in gradual progression of climate change literature. Particularly, cropping is sensitive to temperature and rainfall amount and developing countries are largely susceptible to climate change and extremes due to geographical location. Different phenological stages of plant life require specific amount of photosynthesis and precipitation helps to control soil moisture (Rosenzweig et al., 2001). Apparently, extreme and random temperature and precipitation variability could harm plant growth making them vulnerable to growth, pests, diseases and weed spreads (Ibid.). Even seedlings can be affected by dry spell during monsoon (Arimi, 2014). Indiscriminate use of pesticides in cultivating HYVs has also caused crop health deterioration killing beneficial insects for plant growth (Braun et al., 2000). Crop simulation models like DSSAT and IMPACT provided crucial yield loss in cultivation of irrigated crops like wheat and rice in developing countries resulting from ineffective “CO_2 fertilization” (Nelson et al., 2009). Also, climate models like NCAR and CSIRO projected that yield loss will be further experienced due to increased water stress (Ibid.). In Andean, Bolivia, Valdivia et al. (2010) observed increased attacks of pests and crop diseases, water stress, conflict over water use, soil fertility and moisture loss due to increasing trend in maximum and minimum temperature and decreasing rainfall which eventually reduce yield.

Since rice farming includes both rain-fed and irrigated varieties, its sensitivity to climate change has been largely observed as well as projected in the existing body of literature (Basak et al., 2010; Dasgupta et al., 2014; Farook and Kannan, 2016; Lansigan et al., 2000; Mahmood, 1997; Masutomi et al., 2009; Peng et al., 2004; Redfern et al., 2012; Sarker et al., 2014; Wassmann et al., 2009). Rice cultivation is the most vulnerable livelihood option as observed in Thwaites et al. (2014). Rice in South, Southeast Asia passes through most critical flowering and maturing stages in temperature higher than 33ºC and faces larger vulnerability to prolonged drought, increased precipitation and floods (Wassmann et al., 2009). Lansigan et al. (2000) looking at long term effect of climate variability in Philippines observed delayed planting and yield loss of more than 50% during drought years; shortened planting period due to rainfall variability; reduction in cropping area; reduction in fertility and quality of rice; inadequate and untimely water supply. In Bangladesh context Sarker et al. (2014) observed that both maximum and minimum temperature variability have significant negative impacts on rice yield in three seasons (*aus*, *aman*, *boro*). Using DSSAT model Basak et al. (2010) observed that rice is highly sensitive to maximum temperature and minimum temperature reducing BR3[7] rice yield[8] by 31%, 17% respectively in the country. So, in the face of temperature increase Moniruzzaman (2015) observed that farmers are shifting to irrigation based rice varieties from rain-fed ones. However, global climate model produced simulations do not take into account spatial variability adequately (Kelly and Adger, 2000). Additionally, acknowledging the uncertainty and biased estimations in GCM, Masutomi et al. (2009) put forth that there are differences between near and distant future production loss. They observed that despite the probable production loss in 2020s, during 2080s it is projected to experience lower CO_2 concentration which would contribute in reducing production loss and

[7] This is a modern BRRI (Bangladesh Rice Research Institute) *boro* season HYV rice.
[8] The authors used kg per hectare as the unit of measurement for yield and the projection time period is 2008-2070.

uncertainty of climate change impact. These scenario analyses recommend at macro-level adaptation strategies to combat yield loss and make cultivation resilient to climate change. However, it is required to observe how people perceive about climate change since the decision to adapt is made at individual level.

3.3 Farmer perception about climate change

Climate change simulations and projections are not sufficient in motivating farmers to adapt (Tucker et al., 2010) and participation of farmers is required in both decision making and risk management (Patt and Schröter, 2008). Statistical simulations are naturally beyond the understandings of mass people and rather often they confuse random climate extreme events with climate change (Weber, 2010). Personal experience and climate information provided could produce different perceptions for different individuals (Ibid.) and in different locations (Valdivia et al., 2010). The reason is that perception and accordingly adaptation behaviour are influenced by existing socio-economic and cultural conditions (Patt and Schröter, 2008). Perception also varies with livelihood option and uncertainty around livelihood (Thomas et al., 2007). Random climate hazards may leave larger impacts on some individuals (Weber, 2010) but response about temperature increase, low precipitation has been used extensively in perception based literature. Also unpredictability in climate variables and delayed seasonal transition have been perceived by farmers (Thomas et al., 2007).

Assessment of factors influencing farmers' perception about climate change and response to adaptation, contributed significantly to the existing literature. One study in Zambian context observed that small farmers adapted when they perceived change in rainfall and drought intensity and frequency (Nyanga et al., 2011). However, Apata et al. (2009) ascertained that when local people understand ‘climate’ as “spiritual, emotional and physical” and in such cases it becomes crucial to analyse their perception about climate change since they already are adaptive to stress. Strong influence of spiritual notion was observed in Nyanga et al. (2011). If supernatural power is perceived as causing climate change, farmers are not motivated to adapt (Ibid.). On the contrary, in Ishaya and Abaje (2008) indigenous farmers in Nigeria perceived human activities to be responsible for climate change. Educational level of farmers (Apata et al., 2009; Nyanga et al., 2011), farm size (Apata et al., 2009; Shrestha et al., 2017), crop diversification, access to credit and extension services, increase in temperature (Apata et al., 2009), age, occupation (Shrestha et al., 2017) affect farmers’ perception about climate change and accordingly adaptation. Farmer to farmer extension and awareness generation through media also can inform farmers about recurrent climate change phenomena (Manandhar et al., 2011).

In Bangladesh context, a number of studies are found assessing perception on climate variability, livelihood stress and production loss (e.g. Alam et al., 2017; Anik and Khan, 2012; Ayeb-Karlsson et al., 2016; Islam et al., 2017; Kabir et al., 2017b). The probability of perception about moderate and high production loss is higher in severe drought prone and groundwater depleted areas as observed in Islam et al. (2017). The authors argued that perception about production loss due to climate change is crop specific and also depends on household characteristics. This is possible, because Bangladesh has three rice growing seasons. Apart from production loss farmers perceive other impacts of climate change, such as pest attacks, crop diseases, food insecurity, infrastructural destruction, biodiversity loss, health complexities (Nyanga et al., 2011; Shrestha et al., 2017; Valdivia et al., 2010; Ishaya and Abaje, 2008). So, farmers’ perception of stress is often more associated with economic risks than weather related events, since climate events and variability along with their impacts are location specific and basically farmers are accustomed to producing in local climate variability (Tucker et al., 2010). Therefore, farming implement and seed availability are principal concerns of farmers rather than climate factors (Mertz et al., 2009). Farmers are more concerned with household members' illness (Thomas et al., 2007) and market price volatility (Tucker et al., 2010). So, it is possible that farmer perception does not necessarily coincide with climate model simulations. Rather it is more related to individual's exposure to livelihood risk and vulnerability.

3.4 Adaptation strategies and their determinants

Adaptation covers both short-term solutions to combat harmful climate change impacts and simultaneously long term mechanisms to maintain livelihood in changing climate (Harmer and Rahman, 2014). The authors based on adaptation literature categorized adaptation strategies along six broad lines: a) financial, b) labour, c) technology, d) land, e) cultural and f) external support. Technology based adaptations, such as crop choice, crop variety choice and cropping time shifting in the short run have been widely used to increase production (Arimi, 2014). Some long term land use changes for crop diversification, cultivated area expansion, livestock rearing, switching to off-farm activities and migration have been observed as a significant strategies due to economic and climate shocks (Thomas et al., 2007; Tucker et al., 2010). However, farmers are often confronted with financial constraints in case of migration and land use change (Arimi, 2014). Tucker et al. (2010) observed crop mixing and cropping area expansion in Honduras while migration is dominant in both Honduras and Mexico. So, there is variability in adaptations in different locations. In most literature, climate change adaptation strategies mainly promote production based coping mechanisms. Shifting planting time, short duration cropping (Shrestha et al., 2017; Thomas et al., 2007), tree plantation, comprehensive irrigation system (Deressa et al., 2009) access to land and water resources (Ishaya and Abaje, 2008; Thomas et al., 2007), soil conservation practices (Deressa et al., 2009; Yin et al., 2016), community cultivation as *agricultural experimentation* (Thomas et al., 2007) have been largely observed. Local market condition also influences production technique and cultivation practice, for example in Nyanga et al. (2011), conservation agronomic practices are more connected to input cost, crop market and food security rather than taken as climate change adaptation. Likewise, changes in production technique like reduction or adjustment in cost of production have been observed significantly in Tucker et al. (2010).

As theory suggests, adaptation actually depends on adaptive capacity which is determined by a number of factors. Qualitative, exploratory and empirical approaches have been mostly used in this respect. Using multinomial logit and multiple regression models, a large number of studies can be found in assessing the determinants of various adaptation strategies. Poor access to water, access to fertilizer, farm size (Arimi, 2014; Hassan and Nhemachena, 2008), educational level (Alauddin and Sarker, 2014; Deressa et al., 2009), age, farm income, gender, access to credit (Deressa et al., 2009; Hassan and Nhemachena, 2008), access to extension services (Deressa et al., 2009), access to information (Arimi, 2014; Deressa et al., 2009; Alauddin and Sarker, 2014), household size, household access to electricity, distance of market, ownership of machineries, farming experience (Hassan and Nhemachena, 2008), access to subsidy, access to electricity for irrigation, severity of drought and groundwater depletion (Alauddin and Sarker, 2014) have been observed as significant factors influencing adaptation choices. However, an important implication for adaptations is that decision to adapt depends on individual experience and exposure to risk. There are differences between perceived and actual adaptation (Hassan and Nhemachena, 2008). A significant contrast can be observed between adaptive capacity and actual adaptation. A large number of farmers are not taking up any adaptation at all (e.g. Deressa et al.,

2009) and small farmers are less capable of taking up such "coping strategies due to financial, natural resource and institutional constraints (Tucker et al., 2010). So, *planned* and *actual adaptation*[9] is associated with adaptive capacity for which it is required to assess its determinants (Smit and Pilifosova, 2003). Accordingly, the concept of vulnerability is extensively used in climate change literature to understand the nature of adaptations, determining adaptation ability and also differentiating the ability (Ibid.)

3.5 Farmer vulnerability assessment

Vulnerability in developing countries is attributed to both climate change and "changes in natural resource base" (Thomas et al., 2007). Vulnerability is assessed on the basis of both the availability of and entitlement to resources (Adger et al., 2003). Studies are mostly qualitative and *livelihood approach* is commonly used tool. These studies focuses on adaptive capacity in order to understand status quo in the face of climate change and possible adverse impacts; to explore the potentiality for preparedness to face the loss and to combat the loss; and to bring adjustments aftermath (Smit and Pilifosova, 2003). The authors demonstrated that economic, technological, institutional, information, infrastructural and equity factors determine adaptive capacity which can be used to look at the scenario with and without adaptation. All these factors produce causal relationships in assessing vulnerability collectively in a social structure (Bohle et al., 1994). Following this framework most vulnerable as the authors observed are people in rural areas, who are unemployed or involved in informal sector and in cultivation, constrained by labour and social capital. Food security also becomes worse due to lower and variable production of marginal lands and simultaneously shrinkage of arable land (Ibid.).

[9] For details, see Appendix A.

Since vulnerability analysis takes into account the interaction between adaptations and *stressors* where asset determines adaptation over time (McDowell and Hess, 2012), this body of literature contributed to exploring short and long term constraints in the adaptation process. McDowell and Hess (2012) observed that in Bolivian highlands lack of financial resources limits access to land, feasibility of income and crop diversification and these stresses cumulate over time with climate risks. In Thomas et al. (2007) lack of capital, labour shortage, economic instability and political factors have been observed as livelihood threats. Eventually, lack of sufficient land, labour, knowledge (Shrestha et al., 2017; Deressa et al., 2009), unavailability and high price of good quality seeds (Ishaya and Abaje, 2008), lack of irrigation facility (Deressa et al., 2009) have been observed as significant adaptation barriers. Even cropping has been observed as *unreliable* for the households who do not have irrigation facilities due to climate hazards and input price hike (Hesselberg and Yaro, 2006). The authors classified households as *enduring*, *resilient* and *fragile*; depending on the capability to escape and cope with stress. Household size, farm size, access to land as well as the quality of land, the amount of land under irrigation, livestock ownership, income diversification, social capital contributed significantly in looking at vulnerability of different farming households (Ibid.).

Vulnerability literature could explore institutional deficiencies and differential impacts embedded in a social structure. Discriminatory social, financial and institutional capital access towards female cultivars is observed in the existing literature. Male headed households have larger access to financial and institutional resources in introducing new technology and adopting production technique (Deressa et al., 2009). Early information about climate risks is required for disaster preparedness and dissemination of weather forecasts helps farmers bring necessary adjustments for the next production year. Unpredictability and unreliability of climatic information are problematic in taking adaptation as observed in Alauddin and Sarker (2014). Local institutional factors including social and political are linked with macro level policies (Smit and Pilifosova, 2003) and they could ignore constraints of individual access to resources. For instance, poor people are more vulnerable to marginalization due to climate change and poor adaptive capacity (Smit and Pilifosova, 2003; Bohle et al., 1994). Impacts of landslides, rainfall variability, water scarcity are worse for the households who are landless, in debt, living in marginal lands, have limited scope for income diversification, have limited or no access to productive asset and information as observed by Thwaites et al. (2014). These households are also in disadvantageous situation at the trade-off between asset change since adaptations and resource use are interconnected (McDowell and Hess, 2012). Particularly, households facing any shock further lose exchange entitlements due to instant sale of produce at relatively lower prices and high prices of other necessities (Hesselberg and Yaro, 2006). Additionally, farmers lacking irrigation facilities, face productivity reduction (Thwaites et al., 2014). Pre-existing vulnerability often is responsible for decreasing social capital between rich and poor farmers (Hesselberg and Yaro, 2006). In the context of Bangladesh, poor farmers lack not only socio-economic resources but also access to political resource and social network, therefore are less capable of coping with environmental stress (Coirolo and Rahman, 2014). Moreover, the likelihood of adopting strategies is higher for large farmers, and small and holders of no land are prone to migration (Alam et al., 2016).

3.6 Gaps in existing literature

Theoretically less adaptive capacity means high risk of vulnerability. However, adaptive capacity is poorly addressed in the strand of quantitative studies in assessing vulnerability and often do not acknowledge differential impacts in changing social system (Smit and Pilifosova, 2003).

Even vulnerability analysis suffers from methodological and theoretical flaws (Bohle et al., 1994). However, it is observed in some studies while looking at spatial dimension, different social systems are compared (e.g. Grothmann and Patt, 2005; Tucker et al., 2010) rather than within the system across individuals. In the existing literature, assessment of vulnerability is undertaken developing some indicators and indices (e.g. Brooks et al., 2005; Hahn et al., 2009). Though such indicators and indices could capture spatial and temporal dimension in comparison, their validity is questionable in the context of a complex system (Vincent, 2004).

Nevertheless, in developing countries' context empirical approach to observe vulnerability to climate change has been extensively undertaken through estimating production loss and human life loss (e.g. Lansigan et al., 2000; Masutomi et al., 2009; Nelson et al., 2009; Valdivia et al., 2010; Wassmann et al., 2009). Also in Bangladesh context, quantitative assessments of socio-demographic, economic and institutional factors explaining adaptation decisions, farmers' perception about production loss, net revenue and climate change have been conducted (e.g. Islam et al., 2017; Sarker and Islam, 2016; Alam et al., 2016; Alauddin and Sarker, 2014; Mottaleb et al., 2015; Sarker et al., 2013). However, in Bangladesh, trend and seasonality in temperature and rainfall pattern have not been adequately and separately addressed for areas facing severe drought and groundwater depletion. Also, in assessing vulnerability earlier studies did not capture land productivity using empirical approach either in global or in Bangladesh context. Moreover, differential adaptation choices and land productivity across farmers has not been adequately addressed in Bangladesh context. These gaps in existing literature motivate to formulate research questions in this study.

Chapter 4
Research methodology

4.1 Introduction

This chapter outlines the details of methodology followed in order to answer the research questions. It includes description of study area, secondary data and their sources, the empirical models and their specifications employed in analysing the data. The analyses have been undertaken in the study in two different stages: a) analysis of regional level climate data and b) analysis at micro-level using survey data. Section 4.2 outlines the methodology employed to analyse regional level climate data. Section 4.3 provides the outline of methodology employed to analyse farm level data to assess differentiated farmer vulnerability to climate change and their adaptation.

4.2 Methodology for analysing climate data at regional level

4.2.1 Time series data and its sources

In order to identify climate change vulnerability, three biophysical indicators namely exposure, sensitivity and adaptive capacity; are quantifiable and also suitable for forecast, simulation and identifying coping mechanisms (Fellmann, 2012). Since rice cultivation is sensitive to temperature and rainfall pattern and so is the choice of adaption; climate data on annual maximum temperature, minimum temperature and rainfall have been used in this study to observe variability and change. This study used data for the period 1964-2012 collected from Bangladesh Meteorological Department (BMD) for weather stations[10] in *Bogra*, *Ishurdi* and *Rajshahi*. The data contain monthly observations. Monthly observations are important to check seasonality in climate variables which exhibits crucial implications for climate change (Denton et

[10] Though data for four weather stations covering the study area are available, the study included three stations due to limited availability of data for the other weather station in *Chuadanga*.

al., 2005). This is also important in the sense that rice in Bangladesh is grown in three seasons where in each season harvesting of one crop is followed by sowing the next season crop.

4.2.2 Absolute and relative variability analysis

The analysis of time series data begins with describing summary statistics of climate variables. Summary or descriptive statistics include mean[11], maximum and minimum values, measures of absolute[12] and relative[13] variability for each variable. Standard deviation shows the dispersion from the average value despite exhibiting the same mean for different variables. The higher the value of standard deviation, the larger is the variation in data. Since coefficient of variation is independent of scale and standard deviation is standardized, this tool is used to compare data and variability (Reed et al., 2002). Therefore, CV can capture variability in climate variables as well as draw comparison among them. In order to check the variability over time, it is important to look at these measures.

4.2.3 Linear trend model and seasonality analysis

Standard deviation and coefficient of variation cannot capture variability over time since variables can be plotted against their frequencies. Variables in time series data have tendency to change over time, exhibiting upward or downward movements in variables (Gujarati, 2009; Wooldridge, 2015). So, in order to observe growth rate around the local mean trend analysis is

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[11] Mean is the average value in a set of observations. In time series data, the sample mean can be used as the time series mean, since it remains constant over time.

[12] Standard deviation $sd(X) = \sqrt{\frac{Xi - \bar{X}}{n-1}}$ where, $\bar{X}$ is the sample mean and n is the number of observations measures the absolute variability of variables which is important in observing the distribution of a random variable.

[13] Coefficient of variation $CV = \frac{sd(X)}{\sigma} \times 100$ (is the mean value) measures dispersion from mean relative to the mean value, therefore it is an important tool in analysing relative variability in variables. It is computed as the percentage ratio of standard deviation to mean value.

incorporated. Particularly in monthly data, often seasonality is also observed (Wooldridge, 2015). Seasonal pattern means the change in variables in the same period or the same year. For most climate variables, seasonal patterns or cyclical movements are significant especially in *abrupt climate switches* (Denton et al., 2005). Therefore in order to observe trend and seasonality, a linear function of trend variable and seasonal dummy variables is employed. Mathematically, the model for any time series climate variable Y_t takes the form as follows,

$$Y_t = \beta_1 + \beta_2 Feb_t + \beta_3 Mar_t + \beta_4 Apr_t + \beta_5 May_t + \beta_6 Jun_t + \beta_7 Jul_t + \beta_8 Aug_t + \beta_9 Sep_t + \beta_{10} Oct_t + \beta_{11} Nov_t + \beta_{12} Dec_t + \beta_{13} t + \varepsilon_t \quad \text{………………………………(4.1)}$$

Here, the month of January has been taken as the base[14] category. The coefficients on month dummy variables, $\beta_2, \beta_3, \ldots \ldots \beta_{12}$ show the change in dependent variable over time relative to the base category. t is the trend variable. The sign taken on slope coefficient implies that there is an upward or downward movement in climate variable, Y_t. Accordingly, the slope of the trend line shows whether there is any climate change or not. This model is run for each weather station separately in order to detect spatial variability.

4.3 Methodology for analysing differential vulnerability to climate change and adaptations at micro level

4.3.1 Description of broader area

The study area for this research includes severe drought-prone and groundwater depleted areas in Bangladesh covering three climatic zones[15], i.e. western, north-western and south-central regions. Bangladesh is a subtropical monsoon country. The location of the country in South Asia

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[14] Normative judgment has been made in selecting the reference category. January is the coldest month in a year with the lowest amount of rainfall and rice is neither planted nor harvested in this month. Notably, *aman* season ends in early January and next *aus* season starts in March.

[15] There are seven climatic zones in Bangladesh. Detail map is given in Appendix B.

is between 20º34' and 26º 38' north latitude and 88º01' and 92º41' east longitude (BBS, 2017). Most of the land of this riverine country is fertile and plain except northern highland and hilly eastern parts. The average winter temperature is 17-20.6ºC, average summer temperature remains at 26.9-31.1ºC and average rainfall varies across regions (Shahid and Behrawan, 2008; Shahid, 2010). Figure 4.1 and 4.2 depict the maps of drought prone areas and elements across Bangladesh respectively. Among three climatic zones, the western region is mostly dry due to the lowest rainfall amount and maximum temperature and drought is moderately experienced in western and northern parts (Shahid and Behrawan, 2008).

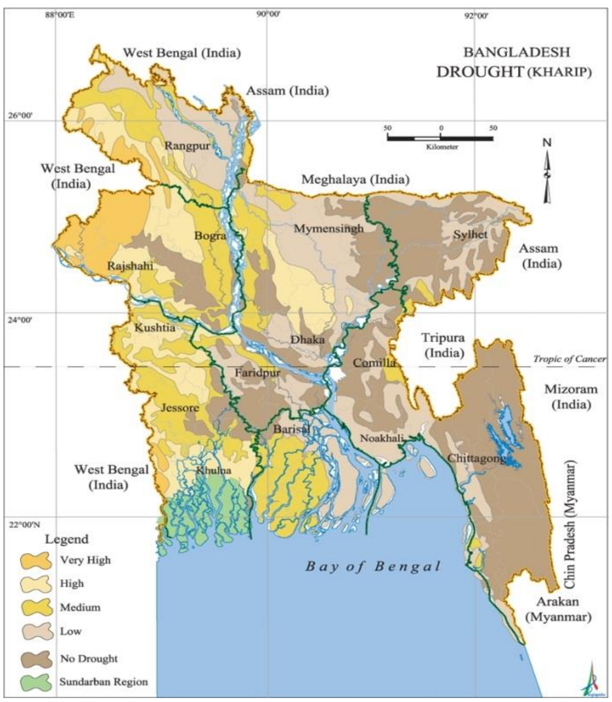

Figure 4.1: Map of drought prone areas in Bangladesh
Source: http://en.banglapedia.org/index.php

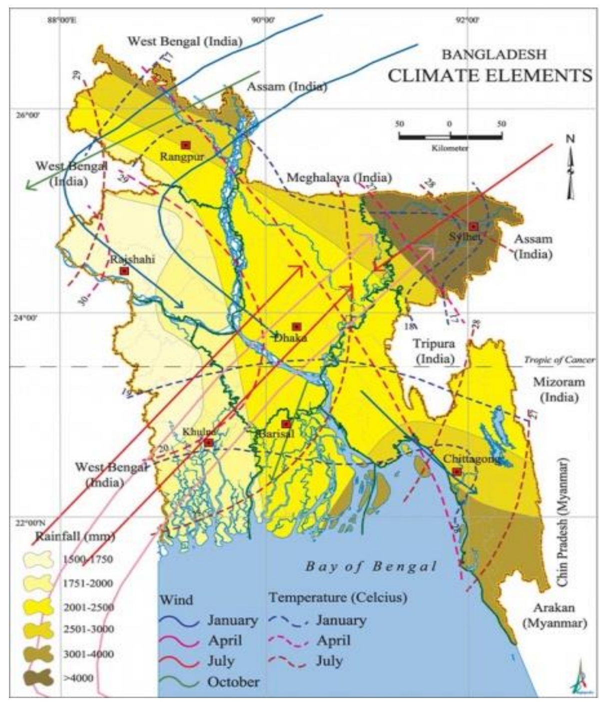

Figure 4.2 : Map of climate elements across Bangladesh
Source: http://en.banglapedia.org/index.php

Agriculture is the predominant source of livelihood in rural areas contributing 11.70% in GDP and employing 42.7% of labour force (BBS, 2017). Bangladesh is the fourth largest rice producing country in the world. In 2015-2016 financial year 51.804 million metric tons of rice was produced (BBS, 2017). Average size of farmer holding was 3.1 acres in 1960 (Rashid, 1978) and it reduced to 1.20 acres in 2005 (Quasem, 2011). Land holdings are largely fragmented and there is a predominance of small and marginal farmers. There has been also significant land use change by bringing crop diversification from double to triple crops (Islam, 2003). In production year 2014-2015, rice was mostly cultivated in seasons of *aman* (48.44%) and *boro* (42.40%) (BBS, 2014). T. *aman* is a rainfed crop and in other two seasons, irrigation is the source of water. Approximately 60% of the cultivated area is under irrigation coverage (FAO, 2013) and rice accounts for 75.01% area of total cultivated area (BBS, 2014). However, Bangladesh confronted loss in *boro* rice production in changing climate (GAIN, 2015) and *aman season* rice faces the most production losses due to natural hazards like floods, heavy downpour and water rush (BBS, 2014).

4.3.2 Description of specific study area

This study is focused on areas covering nine *upazallas* (sub-districts) in eight districts. Three districts; *Bogra*, *Chuadanga* and *Pabna* fall in north-western climatic zone. *Gazipur* is under the south-central zone and the remaining four districts, *Rajshahi*, *Chapainawabganj*, *Natore* and *Naogaon* belong to western climatic zone. Land types in these areas are sandy, silt-loamy, loamy and clayey (BBS, 2014). Land elevation in HBT[16] is high while medium, medium-low and some low topography is observed in remaining areas. An average of 84.38% area is under cultivation

[16] The *Barind* Tract includes most parts of the greater *Dinajpur, Rangpur, Pabna, Rajshahi*, *Bogra*, *Joypurhat* and *Naogaon* districts in *Rajshahi* division. Rainfall amount is low in this area and climate is mostly humid and warm which makes the area prone to drought.

(BBS, 2017). These regions widely cultivate rice, wheat, maize, fruits and vegetables. In 2008-2009, most *aman* season crop production losses occurred in *Bogra*, *Rajshahi* and *Pabna* and during *aman* seed beds were affected in *Bogra* notwithstanding higher cropping intensity compared to other eight districts (BBS, 2014). Most of these western and north-western districts are exposed to 3-6 months high to moderate level drought risk (Shahid and Behrawan, 2008), with 34.1% probability of normal and mild drought as observed in (Shahid, 2008). Calcareous grey clayey soil becomes fragile in dry season and saline in floodplains (BBS, 2017). This makes the area largely prone to drought. Particularly HBT which include mostly drought prone areas has low level of soil fertility (BBS, 2017).

4.3.3 Farm level secondary data

In selecting a sample both time and financial constraints are confronted by researcher conducting the study individually (Blaikie, 2010). Therefore, this study uses farm level data[17] from a survey based secondary source conducted in nine *upazillas* of eight districts. The data include 1,800 households including all types of farms, e.g. large, medium, small, marginal and landless. For categorization[18], the amount of own cultivable land has been considered in (GOB, 2011). Usually, farmers live in the same and adjacent villages under similar climatic conditions, therefore this study used households selected from different socio-demographic and economic backgrounds. The data included information on rice farming households' socio-demographic and economic characteristics; institutional and infrastructural accessibilities; climate change

[17] A survey conducted during the period 2011-2012 is the source of data in the research. The survey was conducted by Dr Mohammad Alauddin, Associate Professor, the University of Queensland, Australia under a project funded by ACIAR.

[18] Based on GOB (2011), farmers are categorized into large-medium (>250 decimals), small-marginal (1-249 decimals) and landless (0 decimals).

vulnerability; farmer perception about climate variability, production loss, barriers to adaptation; and actual adaptation strategies.

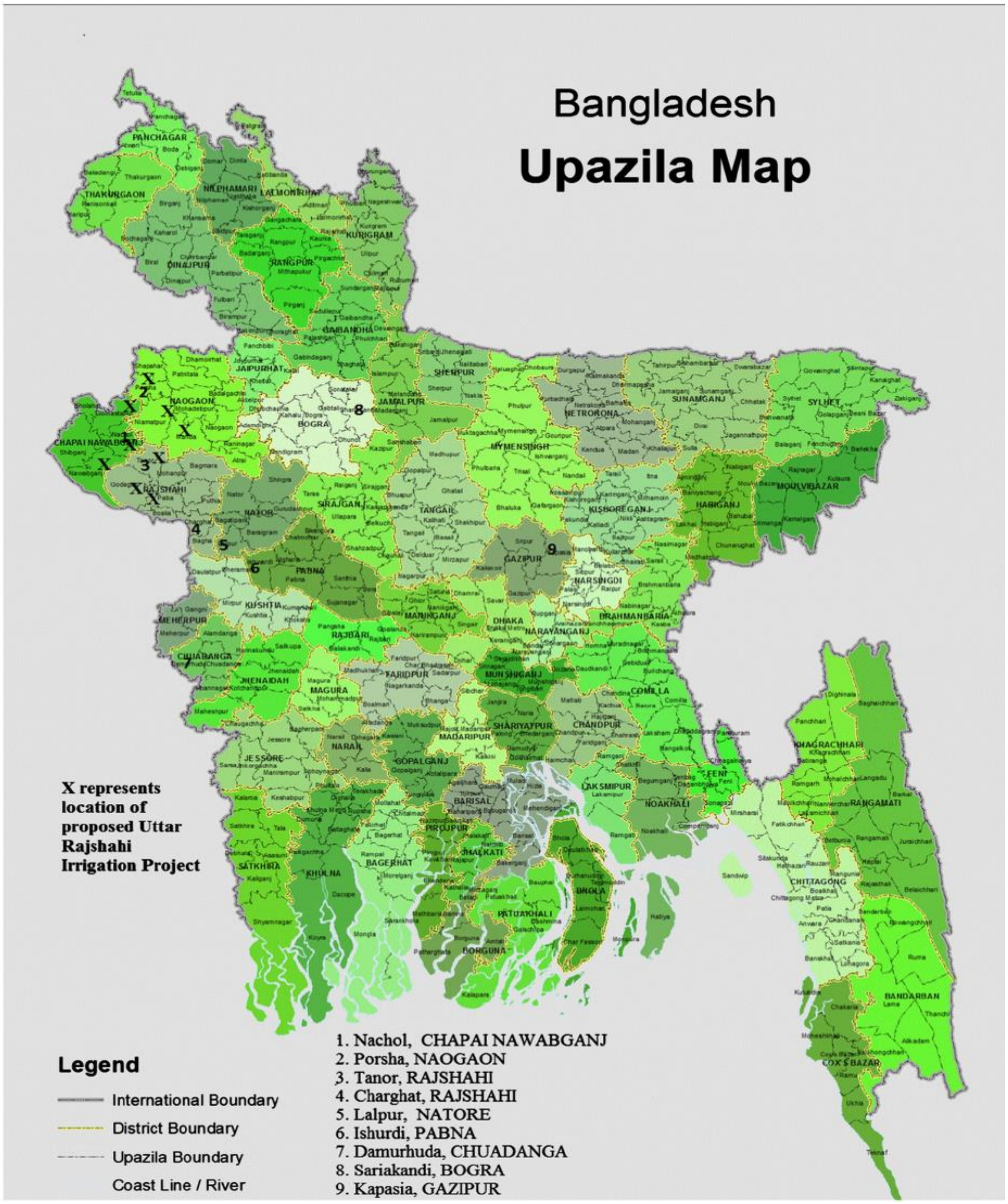

Figure 4.3: Upazilla map of Bangladesh showing study areas
Source: Adapted from Alauddin and Sarker (2014)

4.3.4 Choice of variables

Severity of drought and groundwater depletion

Both conceptual framework and existing literature demonstrate that rice cultivation is sensitive to weather variability. Therefore different strategies are adapted to increasing temperature and decreasing rainfall. However, while estimating the determinants of adaptation choices and land productivity, the effect of weather variability is not directly observable since this study uses only one cross section household data. Following Alauddin and Sarker (2014) this study includes two dummy variables of severity of drought and ground water depletion in the area as time invariant proxy[19] variables. Temperature increase and rainfall decrease cause drought and groundwater availability is reducing gradually due to intensive irrigation during post-monsoon months (Mondol et al., 2017; Shahid and Behrawan, 2008). So, the dummy variables are not perfectly correlated[20], however the areas[21] with the severity of drought and that of groundwater depletion are not mutually exclusive. In the data, 42.83% households live in severe drought prone areas and 61.72% live in areas facing severe ground water depletion. This demonstrates that dry and hot weather and water scarcity might cause substantial rice cultivation difficulties in the study area.

Socio-demographic characteristics, economic and institutional resource accessibility

In selecting context and place specific vulnerability indicators and in order to identify vulnerable groups, relative vulnerability indicators are more compelling than absolute ones (Adger, 2006;

[19] Proxy variable is required to be correlated with unobserved variable controlled for the analysis and in order to do that random error ε_i has to be uncorrelated with the proxy variable to get unbiased estimators. In omitted variable test (Ramsey test) if the p- value for F-statistics is significant, we can reject the null hypothesis of no omitted variable bias.

[20] Perfect collinearity among explanatory variables gives biased estimators, however some correlation is often common in econometric analysis.

[21] The Table showing levels of drought prone and severe ground water depleted areas is given in Appendix C.

Fellmann, 2012; Hinkel, 2011). Therefore, choice of adaptation strategy and land productivity may be different across sample households. Following a deductive approach based on the framework and literature review, household socio-demographic characteristics, economic resource, institutional and knowledge access and farmer types have been included as covariates. Table 4.1 depicts the descriptive statistics[22] of selected variables.

Table 4.1: Descriptive statistics of dependent and explanatory variables

Variables	Mean	Std. Dev.	Min	Max	Frequency (%)
Land productivity (*maund*/decimal)[23]	0.753	0.991	0.026	18	
Severity of drought					Yes= 42.83 No= 57.17
Depletion of ground water					Severe = 61.72 Otherwise= 38.28
Age	45	13.981	15	100	
Sex					Male= 98.28 Female= 1.72
Education	5.622	4.676	0	17	
Household size	5.461	2.733	1	26	
Ownership of livestock and poultry					Yes= 91.56 No= 8.44
Increased use of chemical fertilizer					Yes= 96.17 No= 3.83
Receiving climate information					Yes= 43.56 No= 56.44
Household access to credit					Yes= 49.89 No= 50.11
Receive agricultural subsidy					Yes= 43.00 N0= 57.00
Access to electricity for irrigation					Yes= 58.33 No= 41.67
Adopted any adaptation strategy					Yes= 80.44 No= 19.56
Farm types					Large-medium= 16.17% Small-marginal= 72.39% Landless= 11.44%

Note: Author's analysis based on farm level secondary data for the rice production period 2011-2012

[22] All continuous variables are reported with mean value, standard deviation, maximum and minimum values. Since dummy or categorical variables unlike normally distributed continuous variables cannot be measured in scale and, describing with mean values and standard deviation does not give functional meaning, therefore frequencies are more appropriate to provide its descriptive information.

[23] The unit of measurement is maund/decimal where 1 maund (Bangladesh) = 37.32 kg and 1 decimal = 0.01 acre.

Average age of the farmers is 45 years (approximately) meaning farmers are experienced in farming. 98.28% households are male headed which shows that farmer farming is highly dominated by male counterparts. Average education level of the household head is approximate 6 years, implying that education level is quite low in the study area. Average household size is 6 approximately, so household size is not quite large in the study area. 91.56% households have livestock and poultry ownership of any number. This scenario is common in rural areas where households have at least some chickens, ducks, cows, sheep or goats. 96.17% farmers have informed that the use of chemical fertilizer increased. This reveals the fact that rice cultivation is highly chemical intensive and market oriented and has implication of pest attacks and crop diseases. Accordingly, it has implication of health issues of farmers while applying chemical fertilizer. Only 43.56% farmers reported that they have received climate information revealing poor access to climate information in the study area. 49.89% households have access to credit and 43% received agricultural subsidy which means that a large portion of farmers confront institutional inaccessibility. Relevantly 58.33% households have access to electricity for irrigation. 72.39% households are small and marginal farmers. Therefore it is apparent that most of the households can get access to irrigation on very small amount of land. Though 80.44% farmers have taken up any of the adaptation measures, still for 19.56% households there might be crucial barriers in taking up any strategy. 16.17% farmers are large and medium, 72.39% are small and marginal farmers and 11.44% fall in landless category. These figures are compatible with national statistics; large and medium (20%) and small (80%) where small category includes marginal and landless farmers (BBS, 2008).

4.3.5 Model specification

4.3.5.1 Multinomial logit model

The analysis begins with MNL model in order to assess the factors influencing choice of adaptation strategies and to look at the differentiation across farmers in making choices. Logit or probit models are used to explain categorical variables (Wooldridge, 2015). The dependent variable in this analysis is multiple adaptation strategies. Multinomial logit model (MNL) is more commonly used for nominal outcomes since in estimating multinomial probit (MNP) model there are some practical difficulties (Cheng and Long, 2007). In MNL model for the convenience of estimation, it is a necessary condition that all the categories are mutually exclusive. MNL model estimates simultaneously all binary logits among categories or choices performing all possible comparisons (Alauddin and Sarker, 2014). The model for each category of the outcome variable is specified as,

$$lnY_{i((n|b)} = ln\frac{\text{Prob}(\,Y=n|x)}{\text{Prob}(Y=b|x)} \qquad \text{……………………..(4.2)}$$

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

$$Prob\ (Y_i|x_i) = \frac{e^{\beta_j x_i}}{\sum_{k=1}^{n} e^{\beta_k x_i}} \qquad \text{where } j = 1,2,\dots.n \qquad \text{……………(4.3)}$$

This MNL model as formulized in Greene (2003) estimates the utility from choosing one particular strategy (as shown in the numerator) relative to the sum of utilities from different choices (expressed in the denominator) (Sarker et al., 2013). MNL model requires that the odds ratio does not have impact on other probabilities; which is the assumption of independence of irrelevant alternatives (IIA)[24] in order to get an unbiased and consistent β estimator. In the complete model, the choice of adaptation strategy producing the highest utility is assumed to be influenced by socio-economic factors, institutional accessibility and farmer types. Two dummy variables, namely large-medium and small-marginal are included taking landless as the base[25] category. For each strategy the complete model is specified as follows;

$$\ln\left(Y_{i(j|b)}\middle|X_i\right) = \beta_{0,Y_i} + \beta_{1,Y_i}SeDr_i + \beta_{2,Y_i}GWDe_i + \beta_{3,Y_i}Age_i + \beta_{4,Y_i}Male_i + \beta_{5,Y_i}Edu_i + \beta_{6,Y_i}Hs_i + \beta_{7,Y_i}OwnLP_i + \beta_{8,Y_i}IncrUCF_i + \beta_{9,Y_i}RecCI_i + \beta_{10,Y_i}Cred_i + \beta_{11,Y_i}ASub_i + \beta_{12,Y_i}AcElIrr_i + +\beta_{13,Y_i}LaMed_i + \beta_{14,Y_i}SmMar_i + \varepsilon_i \qquad \text{..................(4.4)}$$

In order to determine the probability of each adaptation strategy, marginal effects are computed from the MNL model. Generally, in marginal effects each shows the probability of $Y_i = 1$, conditional upon one explanatory variable, holding others constant. This way, interpretation becomes more *meaningful* (see (Alauddin and Sarker, 2014). There are six main adaptation strategies as depicted in the following Figure 4.5. “No adaptation” has been chosen as the base category so that factors influencing different strategies in comparison with no adaptation can be assessed. Strategies adapted mainly are considered so that IIA assumption holds to run the model.

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[24] Hausman-MacFadden (Hausaman) test, Wald test and McFadden’s Lagrange multiplier test are employed to check the validity of this assumption. In the study it is not required to choose among models. Rather, the study uses likelihood ratio test to check on the exclusion restrictions.

[25] The number of landless Farmers is the smallest in the area. Since the study focuses on differentials among Farmers on the basis of resource access, for substantial comparison, small-marginal and large-medium Farmer types are included in the model. It is also important to note that most of the Farmers in developing countries are small or marginal. Accordingly, 72.39% Farmers belong to small-marginal category in the sample.

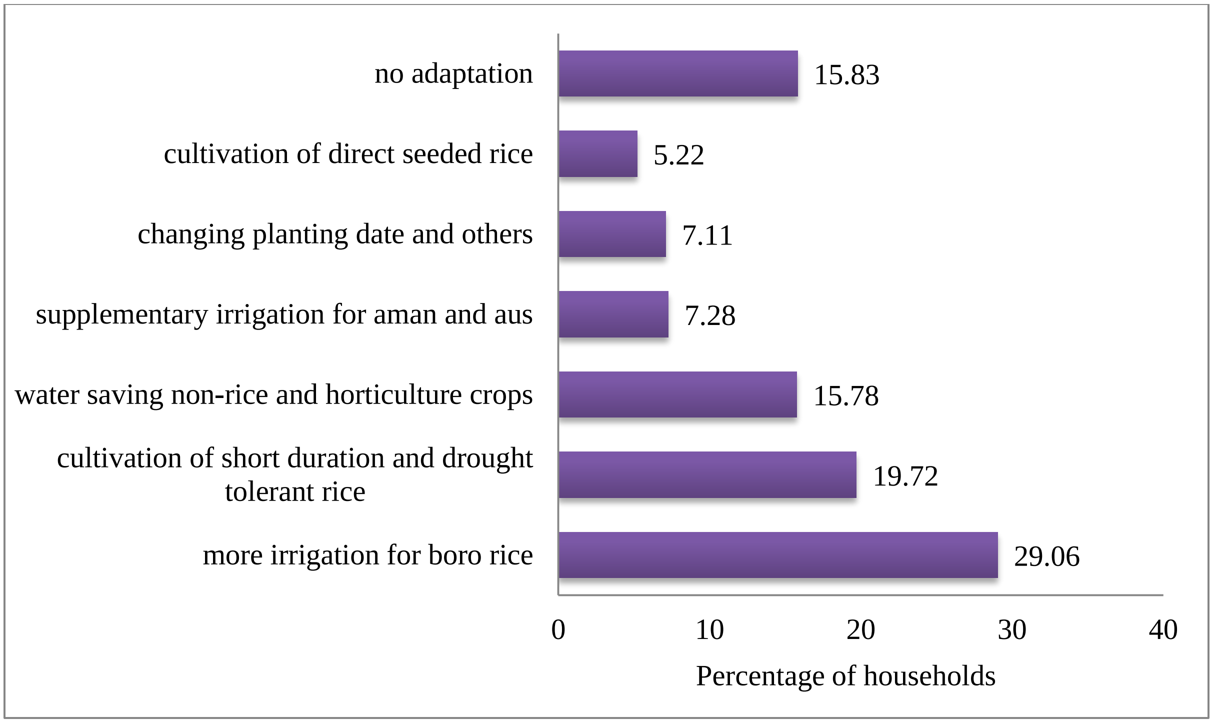

Figure 4.4: Main strategies adopted by farmers in the study area
Note: Author's analysis based on farm level secondary data for the rice production period 2011-2012

4.3.5.2 Multiple regression model

In the second stage of analysis, a multiple regression model is employed to explain land productivity of rice. Productivity is a relative concept depending on the use of a particular resource. Land productivity is directly connected with soil characteristics and farmer holdings (Rashid, 1978). Both technical and social conditions in different natural environments can influence production and productivity (Bernstein, 2010). Also Table 4.1 shows that in the study area, 80.44% households adopted any of the strategies, therefore land productivity might be influenced by adaptations. So, land productivity is taken as the outcome variable. In this study productivity is defined by the amount of rice produced in all three seasons (*aman*, *aus*, and *boro)* per unit of land. Table 4.1 shows that the average amount of land productivity in all three rice seasons collectively is 0.753 *maund* per decimal. However, in production year 2011-2012, national land productivity was only 0.319 *maund* per decimal (BBS, 2014). This is possible, because average cropping intensity in *Rajshahi* division is higher compared to total intensity. The same explanatory variables with an additional dummy variable namely, if adopted any strategy are included in multiple regression model, assessing the determinants of land productivity. Land productivity has been modelled as a function of vector of household characteristics including socio-demographic, economic, institutional accessibility, access to information and farmer types. The model is specified as follows,

$$log(ToP)_i = \beta_0 + \beta_1 SeDr_i + \beta_2 GWDe_i + \beta_3 Age_i + \beta_4 Male_i + \beta_5 Edu_i + \beta_6 Hs_i + \beta_7 OwnLP_i + \beta_8 IncrUCF_i + \beta_9 RecCI_i + \beta_{10} Cred_i + \beta_{11} ASub_i + \beta_{12} AcElIrr_i + + \beta_{13} LaMed_i + \beta_{14} SmMar_i + \varepsilon_i \quad (4.5)$$

In the model total land productivity is included with log transformation in order to look at relative changes in the variable. While analysing highly skewed data, log transformation conforms the data to normality assumption (Changyong et al., 2014). In order to get unbiased and consistent β estimators, the error term, ε_i should be uncorrelated with explanatory variables[26].

[26] This is an important condition in model specification. If ε_i is correlated with any of the explanatory variables, it might cause model misspecification error and give biased estimator by including endogenous variable in the model. However, the VIF test confirms no multicollinearity among explanatory variables. Moreover, the statistical insignificance of one coefficient does not affect the un-biasedness of other estimators (Wooldridge J. M., 2015).

Chapter 5
Estimation results: a reconciliation between climate variability and farmers' perception

5.1 Introduction

This chapter presents estimation results of trend and seasonality in temperature and rainfall and perception of farmers about temperature and rainfall change. Briefly, Section 5.2 describes absolute and relative variability in maximum temperature, minimum temperature and rainfall for three weather stations covering the study area. Section 5.3 examines and discusses trend and seasonality in climate variables and Section 5.4 explores farmer perception about change in temperature and rainfall.

5.2 Absolute and relative variability

Table 5.1 represents general characteristics of climate variables; maximum temperature, minimum temperature and rainfall for the period 1964-2012 for three weather stations.

Table 5.1: Descriptive statistics of climate variables over the period 1964-2012

Variables	Weather station	Mean	Std. Dev.	Min	Max	Coefficient of variation
Maximum temperature (ºC)	*Rajshahi*	34.42	3.93	25.60	43.80	11.40
	Bogra	34.26	3.51	25.7	43.7	10.24
	Ishurdi	34.57	4.06	25.6	44	11.75
Minimum temperature (ºC)	*Rajshahi*	16.82	6.30	3.40	25.80	37.47
	Bogra	17.28	5.84	4.9	26	33.82
	Ishurdi	16.55	6.50	3.5	25.6	39.25
Rainfall (mm)	*Rajshahi*	125.35	145.91	0.00	763.00	116.41
	Bogra	145.44	168.42	0	835	115.81
	Ishurdi	129.92	151.90	0	1167	116.91

Note: Author's analysis based on climate data for the period 1964-2012

It is observed that compared to maximum and minimum temperature, the rainfall amount has the largest relative variability over the period. Average maximum temperature was the highest in *Ishurdi*. However, both absolute and relative variability are higher compared to other two stations. Average minimum temperature and rainfall amount remained the highest for *Bogra* station with the lowest relative variability. The dispersion is observed to be lower for *Bogra* compared to other districts for all climate variables. Visually, following Figure 5.1[27] shows the comparisons of means of all climate variables among three weather stations. It is apparent that the increasing trend in mean maximum temperature and decreasing trend in mean rainfall is higher in *Rajshahi* compared to *Ishurdi*. Mean minimum temperature followed a stable trend in the three districts. In *Bogra* trends in mean maximum and minimum temperature and rainfall were stable.

[27] Here, the upper panel shows mean maximum temperature, the middle panel shows mean minimum temperature and lower panel portrays mean rainfall amount for the period 1964-2012. The blue line shows the data points and the black line is the trend line in each diagram.

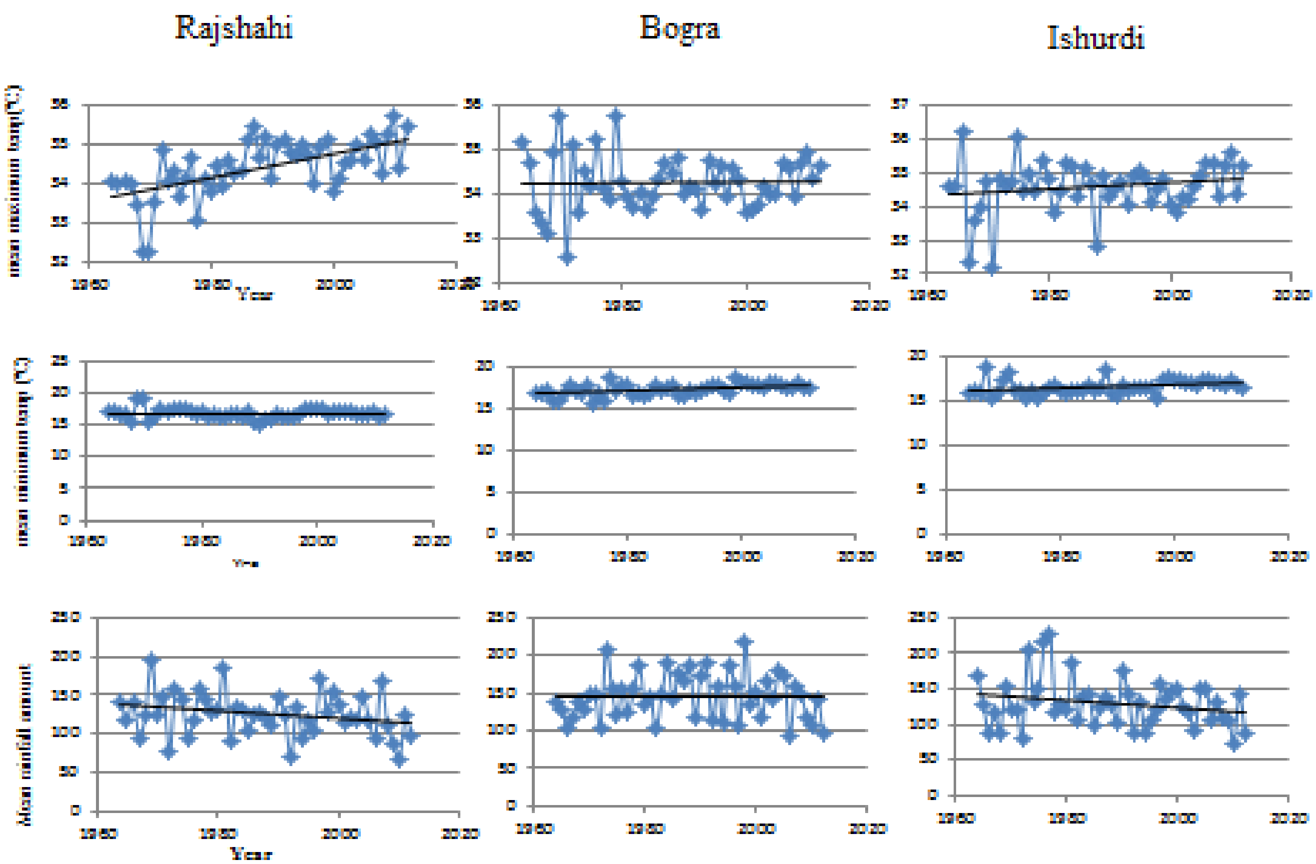

Figure 5.1: Mean values of climate variables for over the period 1964-2012
Note: Author's analysis based on climate data for the period 1964-2012

5.3 Trend and seasonality analysis of climate variables

Including time trend is important in capturing the change in variables over time which is common in time series data (Wooldridge, 2015). A trend captures long term increase or decrease in the variable. The coefficient taken on the linear time trend shows the change in the dependent variable in two consecutive periods. Table 5.2[28] shows that the linear trend coefficient is statistically significant and takes positive value for maximum temperature, therefore maximum temperature is growing over time by 0.0312ºC or may be put as in 48 years the maximum temperature has increased by 1.50ºC approximately. This trend is compatible with the results for

[28] The complete Table including both trend and seasonality analysis is provided in Appendix D.

drought-prone western districts observed in Kabir et al. (2017a). The same increasing trend is observed in *Ishurdi* though in small magnitude. In *Ishurdi* maximum temperature has increased by 0.44 ºC only. In *Bogra* the trend is not significant. In case of minimum temperature in *Rajshahi*, the data exhibit a decreasing trend, however the trend is not statistically significant. On the contrary in *Bogra* and *Ishurdi*, significant increasing trend in minimum temperature has been observed at 1.14 ºC and 0.82 ºC respectively over the period. For rainfall, in *Rajshahi* and *Ishurdi* the trend has been decreasing over time. Rainfall decreased by 23.04mm and 23.86mm respectively in the 48 year period. Though there is no significant trend observed in rainfall in *Bogra*. However, the positive sign taken on the coefficient indicates that rainfall in the district has increased by 1.51mm over the period which is contrasted to *Rajshahi* and *Ishurdi*.

Table 5.2: Trend in climate variables over the period 1964-2012 in three stations

Variables	Maximum temperature			Minimum temperature			Rainfall		
	Rajshahi	*Bogra*	*Ishurdi*	*Rajshahi*	*Bogra*	*Ishurdi*	*Rajshahi*	*Bogra*	*Ishurdi*
Time trend	0.0312***	0.00108	0.00915*	-0.00368	0.0238***	0.0171***	-0.480*	0.0314	-0.497*
	(0.00419)	(0.00537)	(0.00521)	(0.00491)	(0.00427)	(0.00481)	(0.248)	(0.280)	(0.287)
Constant	27.00***	27.86***	28.01***	7.314***	7.430***	6.057***	22.07	6.521	18.22**
	(0.230)	(0.209)	(0.386)	(0.270)	(0.224)	(0.252)	(13.63)	(7.217)	(7.383)
Observations	588	588	588	588	588	588	588	588	588
R-squared	0.869	0.760	0.816	0.930	0.934	0.932	0.668	0.663	0.590

Note: Author's analysis based on climate data for the period 1964-2012
Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

While checking seasonality in the data, statistical significance of almost all month dummies indicates that there has been significant seasonal variation in maximum temperature, minimum temperature and rainfall. In the months of April and May, maximum temperature is higher on average compared to the month of January. In Bangladesh, summer officially starts in mid-April. In case of minimum temperature, the effects of July and August are higher compared to January which is monsoon in the country. This means that during monsoon temperature increased over the period. Monsoon starts in June. The effect of July is the largest in rainfall relative to January. Rainfall exhibits larger monthly variability and similar results have been observed in Shahid (2010) and Kabir et al. (2017a). However, increasing rainfall during monsoon and pre-monsoon period bears significance in making crop choice (Moniruzzaman, 2015), groundwater level availability and drought occurrence (Shahid and Hazarika, 2010). Dry winter season starts in November and remains till February (Rashid, 1978). However it is observed that during the months of November to February, minimum temperature increased significantly. This means that even during winter there has been increase in average temperature over the period.

5.4 Farmers' perception about temperature and rainfall change

Farmers' perception is important to check the validity of macro level climate data, especially when climate data is not available covering the whole study area (Shrestha et al., 2017). Climate data of only three weather stations were available over 1964-2012 period which did not cover all eight districts. Therefore, this study explores farmer perception about temperature and rainfall change using survey based secondary data for the production period 2011-2012. In the data, farmers' perception is assessed over past 10 years. Figure 5.2 shows that most of the farmers observed temperature increase annually, in summer and during monsoon. The perception is in line with macro level data exhibiting an increasing trend in maximum temperature. Perception about temperature increase has also been reported in earlier studies (e.g. Ishaya and Abaje, 2008; Manandhar et al., 2011; Mertz et al., 2009; Shrestha et al., 2017). In winter farmers perceived both increase and decrease in temperature almost equally. Most of them reported a decrease in temperature. In maximum and minimum temperature time series analysis in the preceding segment it is observed that there is less increase in temperature during the months of November, December and February compared to January. During this period *boro* season transplanting starts and low temperature could make plants vulnerable to drought (Shelley et al., 2016). Also September to October is the driest period and there is possibility of drought as farmers perceived in Ayeb-Karlsson et al. (2016). Frequent heat waves in summer cause crops loss and even scarcity of drinking water (Ibid.). So, the perception of temperature decrease in winter carries important implication in rice yield and irrigation system.

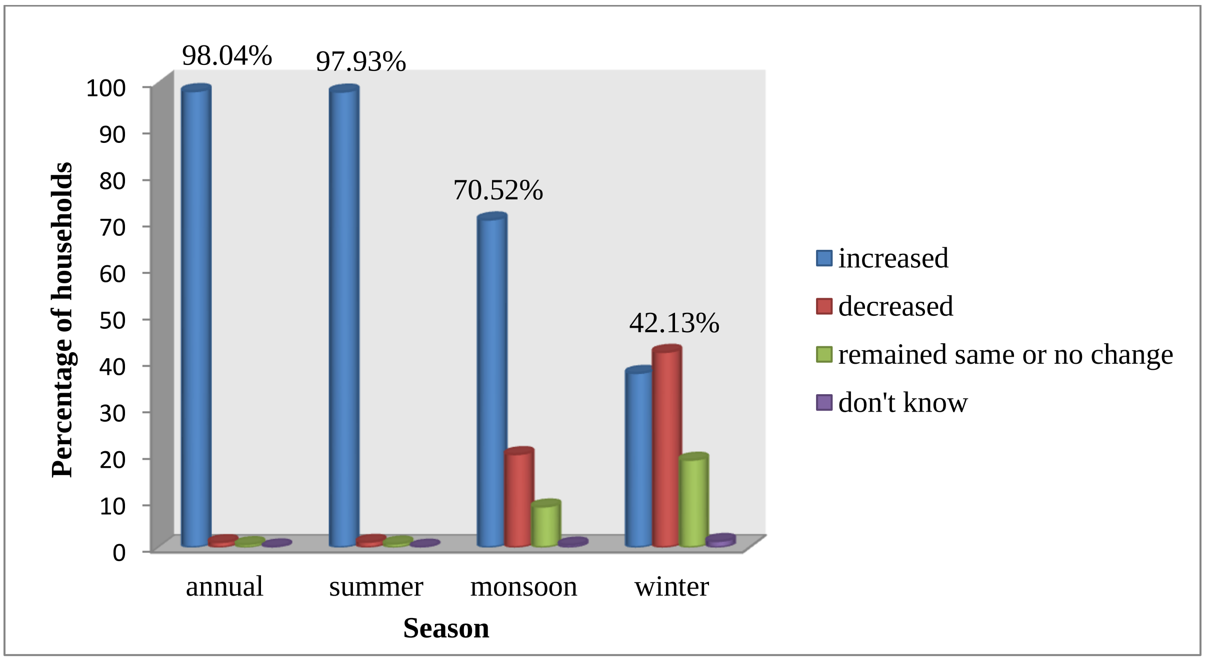

Figure 5.2: Farmers' perception about temperature change
Note: Author's analysis based on farm level secondary data for the rice production period 2011-2012

Following Figure 5.3 depicts farmers' perception about rainfall change over past 10 years. Most of the farmers reported that the amount of rainfall decreased annually and in all three seasons. However, in monsoon some reported that there is increase in rainfall. From time series data analysis, it is observed that despite decreasing trend over the period, rainfall data exhibit larger cyclical variation and there is increasing effect during monsoon months (June to September). However, farmers' perception does not vary much across seasons.

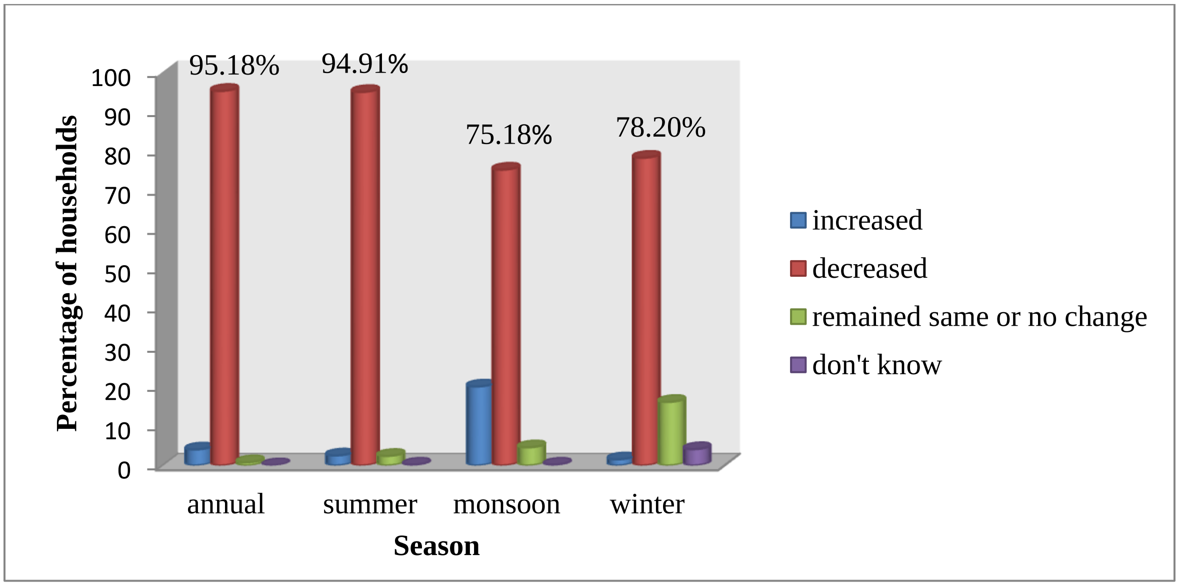

Figure 5.3: Farmers' perception about rainfall change
Note: Author's analysis based on farm level secondary data for the rice production period 2011-2012

In the existing literature both rainfall decrease and increase have been perceived by farmers along with spatial variability. Variation in rainfall can be observed due to different elevations and land use (Shrestha et al., 2017). Often the variability in precipitation is crucial in causing drought. Particularly, pre-monsoon and post-monsoon rainfall could reduce stress on groundwater level (Shahid, 2010). However, delayed rainy season and dry spells affect particularly rain-fed rice crops and further affect ground water availability to be required for irrigated varieties (Ruane et al., 2013). Farmers perceived that the amount of rainfall is an important cause in drought occurrence as depicted in Figure 5.4. Insufficient rainfall and delayed rainfall are two major causes for occurring drought in the area as perceived by farmers.

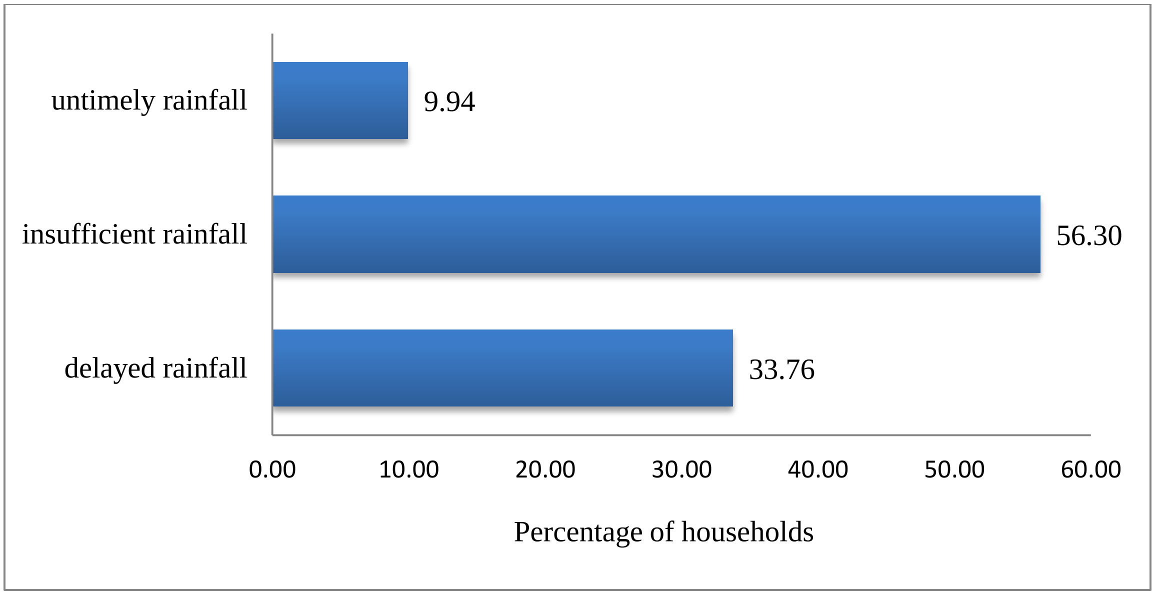

Figure 5.4: Farmers' perception about variability in rainfall causing drought
Note: Author's analysis based on farm level secondary data for the rice production period 2011-2012

Usually, farmers perceive climate stress when their livelihood is vulnerable to the stress and accordingly they choose to adapt (Ayers and Forsyth, 2009). Water scarcity due to temperature increase and rainfall variability, is the dominant issue in both drought prone and severe ground water depleted areas. Therefore, there is less possibility of spatial variability in perception among farmers. The study has the limitation in analysing severe drought occurrence at macro level. Farmers' perception is important since based on their knowledge they make the adaptation choice and also decide when to adapt. Since most of the farmers reported temperature increase and rainfall decrease, this provides the basis for estimating the factors explaining the choice of adaptation strategies and land productivity in the study area.

Chapter 6
Estimation results: adaptation choices and land productivity across farmers

6.1 Introduction

This chapter provides estimation results on determining land productivity and adaptation choices and the heterogeneity among farmers. Section 6.2 provides in brief some general insights about main adaptation strategies across farmers and major barriers to adapt. Section 6.3 provides MNL model results assessing the factors determining adaptation choices. Section 6.4 discusses multiple regression model results assessing the factors determining land productivity.

6.2 Main adaptation strategies of farmers and their barriers

6.2.1 Main adaptation strategies of farmers

The following Figure 6.1 represents the strategies adapted by types of farmers; large-medium, small-marginal and landless so that differential choice across farmers can be depicted. There are 6 strategies farmers mainly adapted in the study area. The study focuses on short-term on-farm planned adaptations[29]. Most adopted strategies for all farmers are irrigation for *boro* rice, cultivation of short duration and drought tolerant rice and cultivation of water saving non-rice and horticulture crops. Irrigation based *boro* season cultivation is rapidly increasing in the country (Shelley et al., 2016). Though the difference across farmers is small, it is evident that both large-medium (27.84%) and small-marginal (29.93%) took up more irrigation for *boro* rice compared to landless farmers (25.24%). This clearly demonstrates that landless farmers have less access to irrigation facilities. Farmers either use their own irrigation equipment, or they purchase or borrow them (Hossain et al., 2013). Landless farmers (25.24%) cultivated short duration and drought tolerant rice more compared to large-medium (19.24%) and small-medium (18.96%)

[29] See Appendix A for a detail description on planned adaptation and agricultural adaptation options promoted in Bangladesh.

farmers. Short duration rice is actually preferred to combat short-term food supply issues. Adaptations to drought tolerant rice varieties have been largely promoted by DEA (Department of Agricultural Extension) and also subsidized by the government (Shelley et al., 2016). Large-medium farmers (23.02%) adopt more water saving non-rice and horticulture crops than others. These crops include wheat, maize, oilseeds, potato, pulses, chickpea, sweet gourd, onion, mango, and so on (Alauddin and Sarker, 2014; BBS, 2014). So, large-medium farmers have larger advantage in diversifying crops.

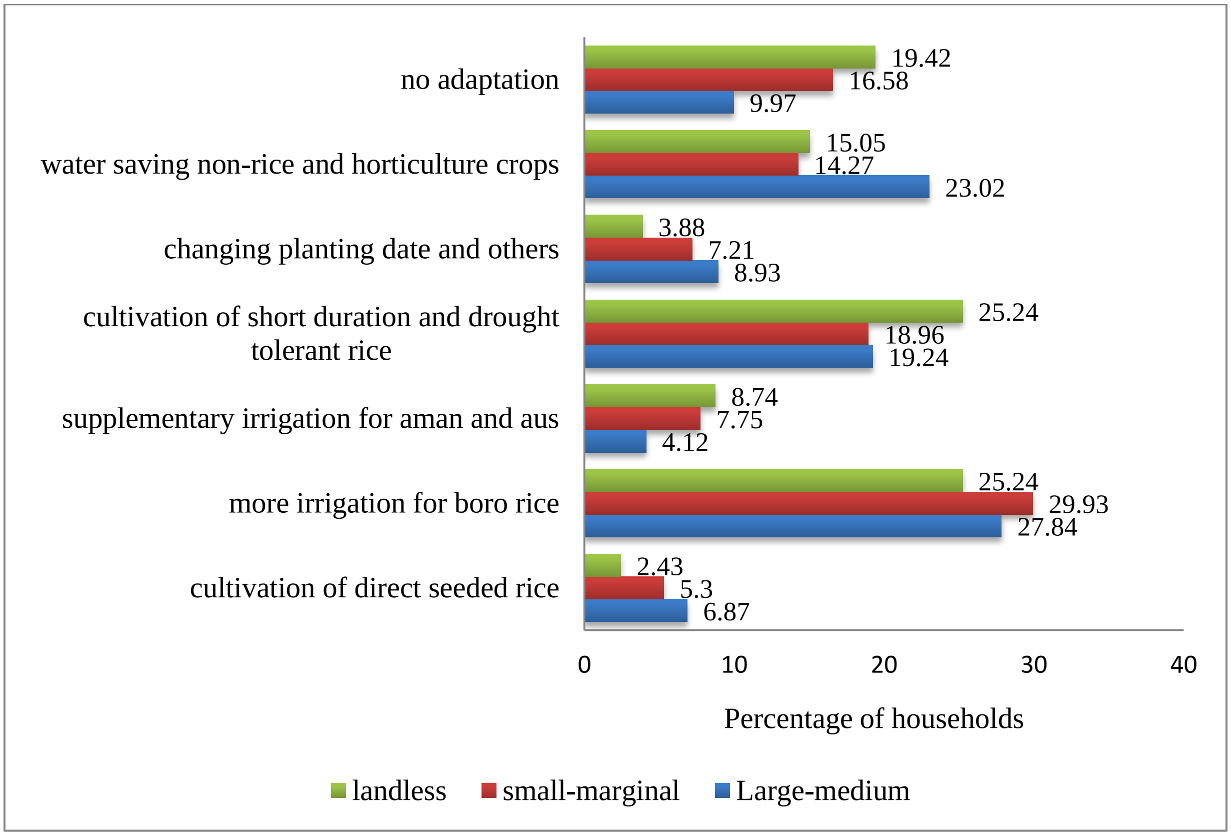

Figure 6.1: Main cropping strategies adapted by farmer types
Note: Author's analysis based on farm level secondary data for the rice production period 2011-2012

Direct seeded rice, supplementary irrigation in *aman* season and changing planting dates are least adapted strategies in the study area. Direct seeded rice is a broadcast variety, widely cultivated in Asian countries where both water scarcity and labour shortage are high (Kumar and Ladha, 2011). The variety cultivated during *boro* season is relatively new in Bangladesh. However, large-medium peasants are cultivating direct seeded rice more compared to small-marginal and landless farmers. Supplementary irrigation during *aman* and *aus* seasons is often required due to inadequate and delayed rainfall. Small-marginal and landless farmers used supplementary irrigation more than large-medium farmers. Changing planting dates and others such as changing harvesting date, use of water saving technology and so on (Alauddin and Sarker, 2014) are more preferred by large-medium farmers compared to small-marginal and landless farmers. Finally, 19.42% landless and 16.58% small-marginal farmers did not take up any strategy and these frequencies are almost double the large-medium farmers' (9.97%).

6.2.2 Barriers to adaptation

Institutional accessibility of farmers such as financial institution for credit, extension services and information about climate condition has significant effect on the choice of adaptation (Alam et al., 2016). The following Figure 6.2 shows that farmers mostly (20.15%) lack information about climate change. This scenario is crucial, because information and knowledge is important to build perception which further influence adaptation (Apata et al., 2009). Accordingly farmers lack information about appropriate adaptation technique (18.24%) and drought tolerant variety (17.41%). Lack of adequate irrigation facility (18.51%) and lack of financial resources in terms of credit, money or saving (14.03%) are also crucial barriers faced by farmers. Similar constraints are mentioned in earlier studies (e.g. Deressa et al., 2009; Sarker et al., 2013; Shrestha et al., 2017) which are also in line with vulnerability scholarship.

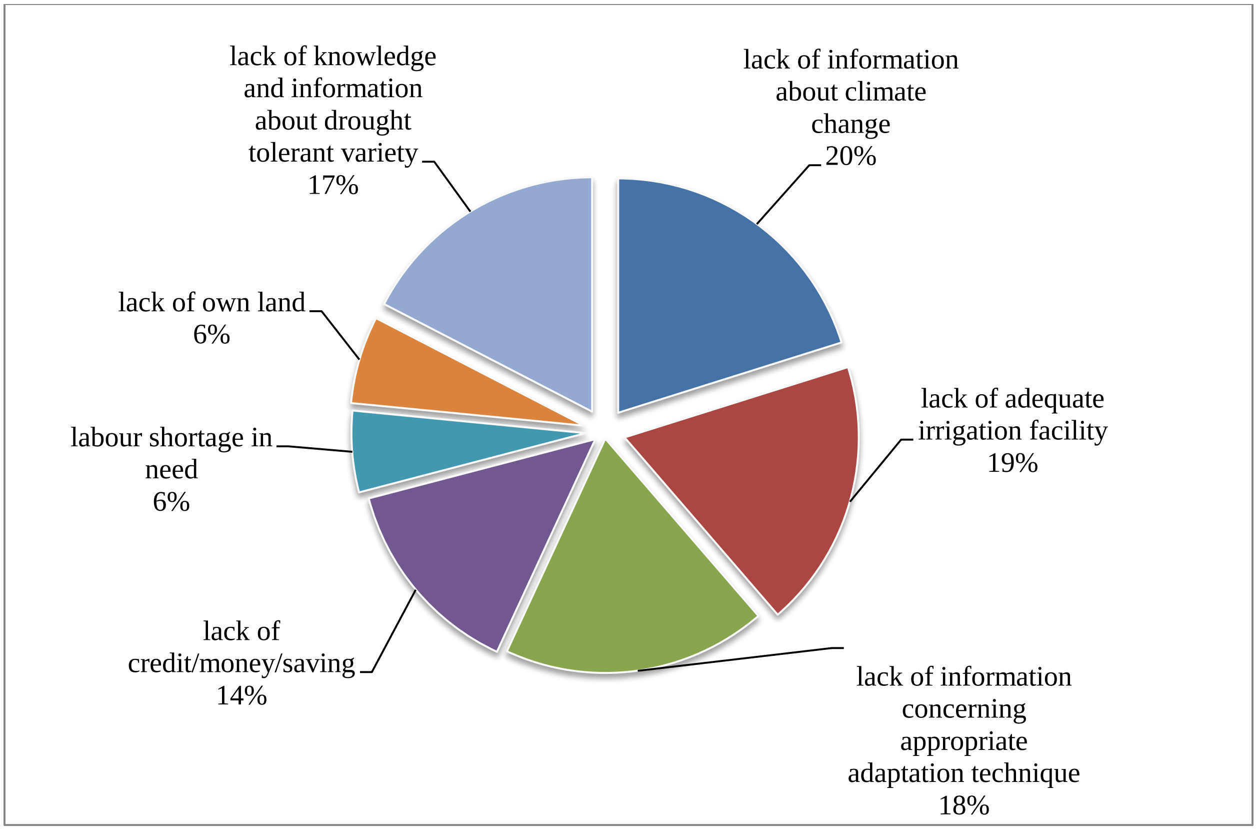

Figure 6.2: Major barriers to adaptation
Note: Author's analysis based on farm level secondary data for the rice production period 2011-2012

6.3 MNL model results

6.3.1 Determinants of choice of adaptation strategies

Table 6.1 shows the results of MNL estimation. The coefficients are reported in terms of marginal effects of regressors on the probability of choosing each of adaptation strategies[30]. The log-likelihood ratio[31] for MNL model[32] is -3013.098. Results show that severity of drought increases the probability of supplementary irrigation for *aman* and *aus* seasons by 7.3 percentage points. Since *aman* season crop is a rain-fed variety, it is possible if there is increasing tendency

[30] No adaptation is the base category.
[31] Since MNL is a maximum likelihood estimation, LR ratio shown above is the minimized log likelihood. Here, LR (Chi^2) tests that at least one of the explanatory variables' coefficient is equal to zero. The p-value of Chi^2 is 0.000 confirmed that we can reject the null hypothesis.
[32] Model fit analysis is provided in Appendix E.

of temperature and less precipitation, farmers would use supplementary irrigation. Farmers are more likely to cultivate water saving non-rice and horticulture crops (28.5 percentage points). Mondol et al. (2017) demonstrated that drought occurs in Bangladesh every 2.5 years and often farmers keep horticulture crops as potential alternative during drought year when they face yield loss in conventional cropping (Anik and Khan, 2012). On the contrary, a farmer is less likely to cultivate direct seeded rice (7.6), cultivation of drought tolerant rice (7.2) and the probability of using more irrigation for *boro* season rice reduces the most by 10.4 percentage points. This demonstrates that irrigation system is not satisfactory in the study area.

On the contrary, if there is severe ground water depletion in the area, the probability of choosing all the strategies increases except supplementary irrigation (9.95) and cultivation of water saving crops (28.9%). Moreover, irrigation for *boro* season, cultivation of direct seeded rice and shifting planting dates are important main strategies. *Boro* season cultivation requires comprehensive irrigation depending on groundwater and climate change increases the rate of using more irrigation (Shahid, 2011) which would impose further stress on groundwater level. Water scarcity is a major driver for cultivating direct seeded rice and comparatively low cost of production is making the variety more economically attractive to farmers (Kumar and Ladha, 2011). Also in Ayeb-Karlsson et al. (2016) farmers in western districts in the country are switching to mango production in the face of increasing drought and water scarcity risk. There are differences in making decision whether to adapt or not in different climate shocks as observed in Alauddin and Sarker (2014). Severity of groundwater depletion and drought not only influence the decision to adapt or not to adapt but also which strategy to choose.

Table 6.1: Estimated marginal effects on main adaptation strategies from MNL model

Variables	cultivation of direct seeded rice	more irrigation for *boro* rice	supplementary irrigation for *aman* and *aus*	cultivation of short duration and drought	changing planting date and others	water saving non-rice crops and horticulture
Severity of drought	-0.0764***	-0.104***	0.0731**	-0.0725**	0.0123	0.285***
	(0.0152)	(0.0340)	(0.0294)	(0.0287)	(0.0176)	(0.0499)
Ground water depletion	0.0462***	0.0691**	-0.0995***	0.0173	0.0448**	-0.289***
	(0.0130)	(0.0340)	(0.0295)	(0.0279)	(0.0195)	(0.0497)
Age	-0.000846**	-0.000918	-0.000343	0.00125*	-0.000651	0.000886
	(0.000411)	(0.000818)	(0.000473)	(0.000698)	(0.000478)	(0.000651)
Sex	-0.0708	-0.374	-0.0489	0.0238	0.836	-0.212
	(2.390)	(13.41)	(3.624)	(7.836)	(43.61)	(9.018)
Educational level	0.00105	-0.00118	-0.00138	0.00667***	-0.00384***	0.00184
	(0.00121)	(0.00251)	(0.00148)	(0.00217)	(0.00145)	(0.00202)
Household size	0.000324	0.00310	0.00146	-0.00552	0.000633	-0.00121
	(0.00197)	(0.00416)	(0.00258)	(0.00386)	(0.00231)	(0.00358)
If owns any livestock or poultry	-0.00152	-0.0140	-0.0165	-0.0174	0.0388	0.0778**
	(0.0197)	(0.0390)	(0.0199)	(0.0321)	(0.0299)	(0.0357)
If increased use of chemical fertilizer is needed	-0.0498**	0.0847	-0.0193	0.0949	-0.00298	-0.0256
	(0.0209)	(0.0632)	(0.0292)	(0.0593)	(0.0309)	(0.0419)
If receive any climate information	-0.0371***	0.0687***	-0.00872	0.0232	-0.00235	-0.0365**
	(0.0119)	(0.0216)	(0.0125)	(0.0188)	(0.0123)	(0.0174)
Access to agricultural credit	0.00151	0.00991	-0.0124	-0.0125	0.0149	0.0148
	(0.0104)	(0.0215)	(0.0123)	(0.0187)	(0.0121)	(0.0167)
If receive any agricultural subsidy	0.00502	-0.0383*	-0.0533***	0.0492***	0.00277	0.0470***
	(0.0106)	(0.0220)	(0.0140)	(0.0187)	(0.0123)	(0.0170)
Electricity access or connection for irrigating land	0.00415	0.0411*	-0.0146	0.0822***	-0.0625***	-0.0812***
	(0.0104)	(0.0216)	(0.0119)	(0.0193)	(0.0127)	(0.0164)
If farmer is small or marginal	0.0377	0.0474	-0.00287	-0.0785***	0.0441*	-0.00163
	(0.0234)	(0.0364)	(0.0183)	(0.0285)	(0.0247)	(0.0276)
If farmer is large or medium	0.0625**	0.0359	-0.0430	-0.0829**	0.0719**	0.0643*
	(0.0266)	(0.0460)	(0.0273)	(0.0370)	(0.0285)	(0.0335)
Number of observations	1,800					
Log-likelihood ratio	-3013.098					
Pseudo R^2	0.0676					

Note: Author's analysis based on farm level secondary data for the rice production period 2011-2012
Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

An extra year of education increases the probability of cultivating short duration and drought variety rice and decreases the probability of shifting planting dates, though the magnitude is quite small. Moreover it has no significant impact on other choices implying poor educational level of farmers in the study area. Ownership of livestock or poultry has a significant positive impact of the probability of cultivating water saving non-rice crops of 7.8 percentage points. This is important, because ownership of livestock and poultry could ensure additional income and the income can be used for crop diversification. An additional year of the household head reduces the probability of direct seeded rice cultivation and increases the probability of short duration and drought tolerant rice cultivation. This may be so, as farmers grow older or as they have more farming experience, they are able to assume better about the changes in temperature and decide upon rice variety suitable in changing climate. Gender has no effect on adaptation choices which is in line with the findings in Delaporte and Maurel (2016). If the use of chemical fertilizer is increased and if the farmer receives any climate information, the probability of cultivation of direct seeded rice reduces. Kumar and Ladha (2011) mentioned that in direct seeding, it is more difficult to control pests and weeds since selection of right chemical inputs and timing of application is crucial, therefore increased use of chemical fertilizer discourages farmers making the choice.

Temperature and precipitation changes and soil characteristics are challenging for *boro* rice cultivation at different stages of irrigation water demand (Shahid, 2011). Prior information about climate has significant positive effect in case of probability of using more irrigation for *boro* season rice. If farmers receive prior information about changes, they can make the decision accordingly how much water to use or required. Likewise, if farmer gets prior information, the probability of water saving non-rice crop cultivation reduces. Access to agricultural subsidy reduces the probability of using irrigation for *boro* by 3.8 percentage points and supplementary irrigation for *aman* and *aus* seasons by 5.3 percentage points. This implies poor subsidy facility for irrigation in the area. In the country most of the irrigation is undertaken using small scale equipment like deep tube-well, shallow tube-well and pumps, since public BWDB has been quite expensive (Hossain, 1988). However, subsidy has positive effect of 4.9 on the probability of cultivating short duration and drought variety rice and the same of 4.7 on the probability of water saving non-rice crops. Bangladesh has a comprehensive seed distribution system since green revolution happened and also fertilizers are significantly subsidized. Access to electricity for irrigating land increases the probability of using irrigation in *boro* season and cultivating short duration and drought tolerant rice. Since these two strategies are largely adopted (see Figure 4.4) in the study area, the result suggests that, electricity connection for irrigating the land has been satisfactory. However, the probability of shifting dates and cultivation of water saving crops reduces if there is access to electricity for irrigation. This is possibly because, in these cases there is little requirement of irrigation in adopting these choices.

6.3.2 Differential choice of adaptation strategies across farmers

Adaptation is cost-sensitive, therefore larger farms are more likely to adapt than small size farms (Alauddin and Sarker, 2014). Accordingly, looking at the differences of probability of choosing strategies, results show that if the farmer is large or medium, there is higher probability of cultivating direct seeded rice, shifting dates and cultivation of water saving non-rice and horticulture crops; and lower probability of short duration and drought variety cultivation. A farmer being small or marginal has a significant negative impact on cultivation of short duration and drought tolerant rice and positive impact on shifting dates of plantation. Short duration and drought varieties help farmers fight short term seasonal hunger. Therefore, reduction in the probability for a small or marginal farmer is less compared to a large or medium farmer. The difference between the probabilities of choice of adaptation strategies in the model is statistically significant[33]. Though a farmer being small or marginal has no effect on water-saving non-rice cultivation, the negative sign taken on the coefficient bears important implication. This implies that small and marginal farmers are not capable of incorporating crop diversification. This finding is in line with Alam et al. (2016). Farmer type also has no effect on both the irrigation based adaptation choices. This is possible because, Table 6.1 shows that supplementary irrigation is less taken up by all farmers and almost all the farmers irrespective of type used more irrigation for *boro* rice cultivation. Irrigation system in rural areas is comprehensive and small scale water distribution projects, particularly IRWM project in *Rajshahi* division largely supported irrigation round the year. However, sometimes during stress, pond water is sold or given in rent to rice farmers (Ayeb-Karlsson et al., 2016). The authors stated that deep tube-wells and ponds are potential alternatives during drought and inadequate rainfall, however, it depends on who have access to and ownership of these sources. Even conflicts and violence for drinking water are common in these cases, and thereby social capital among farmers decreases.

6.4 Multiple regression model results

6.4.1 Determinants of land productivity

Theoretical framework suggests that land productivity is not influenced by the quantity and quality of land only, but it also depends on household socio-demographic, economic characteristics, inputs and technology used in cultivation. From MNL model analysis, it is evident that if farmers have high institutional access, such as climate information, subsidy, electricity connection for irrigation, they are more likely to make adaptation choices accordingly

[33] The test in the difference between two Farmer type dummies exhibits the $p-$value of 0.0868, therefore we can reject the null hypothesis of no difference.

which might influence land productivity as well. Particularly, large-medium farmers are more likely to adapt crop diversification which could ensure larger resource accessibility. However, on average 15.33% households (see Figure 6.1) did not take up any of the strategies and the frequencies for landless and small-marginal farmers are almost double the frequency of large-medium farmers. Using "no adaptation" as the reference category in MNL model, it is not possible directly to explain how these factors might affect the households not taking up any of the strategies. Also, as theory suggests, when vulnerability is contextual individual adaptive capacity depends on resource access. So, only looking at differential choice of adaptations is not adequate to demonstrate the differentiation among farmers. This leads to the second stage of analysis on the determinants of land productivity. Table 6.2 shows OLS estimation results for land productivity for rice production year 2011-2012. Robust[34] R^2 for OLS model is 0.084. The coefficients taken on the regressors determine their effects on total land productivity in all three seasons during rice production period 2011-2012.

Results show that severity of drought and ground water depletion significantly influence land productivity. Land productivity of rice reduces by 34.8% if there is severity of drought. During drought period there is increased stress of water availability for irrigation which actually could cause lower yield (Ayeb-Karlsson et al., 2016). However, the productivity increases by 27.3% if there is severe ground water depletion. The reason is that groundwater irrigation is extensively used in drought prone areas to cultivate HYVs which is suitable for restoring soil moisture and increasing cropping intensity (Yu et al., 2010). MNL results show that that groundwater depletion in the area increases the likelihood of cultivating direct seeded rice and irrigation for

[34] The convenience in using heteroskedasticity robust standard procedure in large samples is that it is not required to know whether the error has constant variance (Wooldridge J. M., 2015).

boro rice. However, increased use of groundwater might deplete the level of water availability further.

Table 6.2: Determinants of land productivity from multiple regression model

Variables	Land productivity
Severity of drought	-0.348***
	(0.0434)
Ground water depletion	0.273***
	(0.0386)
Age	-0.00248**
	(0.00119)
Male	-0.0378
	(0.0488)
Educational level	0.00862***
	(0.00321)
Household size	0.0123
	(0.00754)
If owns any livestock or poultry	-0.00366
	(0.0572)
If increased use of chemical fertilizer is needed	-0.0435
	(0.0612)
If receive any climate information	0.0322
	(0.0279)
Access to agricultural credit	0.0693**
	(0.0279)
If receive any agricultural subsidy	0.0888***
	(0.0279)
Electricity access or connection for irrigating land	0.0886***
	(0.0276)
If adopted any strategy	0.0344
	(0.0368)
If the farmer is small/marginal	0.0915**
	(0.0413)
If the farmer is large/medium	0.184***
	(0.0573)
Constant	-0.710***
	(0.116)
Observations	1,725
$Prob > F$[35]	0.000
$Robust\ R^2$	0.084
Mean VIF[36]	1.40

Note: Author's analysis based on farm level secondary data for the rice production period 2011-2012
Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

[35] The joint significance of a regression is tested with *F*-statistic and the *p-value* suggests that all the independent variables jointly can explain the variation in land productivity.

[36] VIF is an important tool used in detecting multicollinearity among explanatory variables. The mean value of 1.40 (general rule of thumb; VIF of 4) suggests that the explanatory variables are not correlated.

Among socio-demographic characteristics, age and educational level of the household head have effect on total land productivity. If there is an extra educational year spent, land productivity increases by 0.08%. With increasing level of education, farmers are more aware of climate and cultivation information, therefore more likely to take up diversified adaptation strategies and technologies (Deressa et al., 2009; Sarker et al., 2013) which consequently could increase production. Economic significance of the variable suggests that average educational level is poor in the area. Gender has no significant effect on land productivity. This may be because only 1.72% households[37] are female headed. Though household size and ownership of livestock and poultry are not observed as significant variables in influencing land productivity, the sign taken on the coefficients and economic significance have some important implications. It is found that if there is an additional member in the household, land productivity increases by 1.23%. If the household has more members, it is possible to reduce labour cost by employing family labour. Additionally, larger households with more earning members may diversify their income which could be used in purchasing agricultural inputs and also adopting strategies. It is also observed that if the household has ownership of livestock and poultry, land productivity reduces by 0.03%. Possession of livestock and poultry could ensure some extra income from selling milk or eggs, even the sale of animals. Particularly, during climate stress, this is one of the adaptation strategies (Mertz et al., 2009). HYVs are highly chemical intensive and these chemicals could pollute both surface and groundwater. Alongside, price hike of these chemicals is continuing which could make small holders more vulnerable (Collins and Chandrasekaran, 2012). However, increased use of fertilizer has no significant effect on land productivity.

[37] See descriptive statistics in Table 4.1 in Chapter 4.

Both access to credit and agricultural subsidy have positive effects on land productivity. Land productivity increases by 6.9% and 8.8% respectively if a farmer has access to credit and receive any subsidy. This means that if farmers have institutional accessibility they can increase their production. Access to climate information has not been found significant. This may be possible if climate information system is not largely available in the study area. Table 4.1 shows that more than half of the study households receive no prior climate information. However, the size of the coefficient implies that if farmers get prior information, productivity increases by 3.22%. Prior information is important, because this increases the likelihood of perceiving production loss due to climate change (Islam et al., 2017). Prior information and knowledge helps to decide whether to adapt or not (Apata et al., 2009). It is evident from Figure 6.2 that there are substantial financial and knowledge resource barriers in the study area. With regard to this, actual adaptation has no effect on land productivity.

6.4.2 Differential land productivity of farmers

Difference in land productivity of small-marginal and large-medium farmers[38] has been observed in the model. If the farmer is small or marginal, land productivity increases by 9.15% and if the farmer is large or medium, productivity increases by 18.4% which is almost double the effect that small or marginal farmer has[39]. This portrays the scenario that pre-existing differential socio-economic and institutional accessibility has influence over land productivity which reproduce differential outcomes. For small and marginal farmers production increase per unit of land remains a crucial challenge, because cultivation costs them a substantial amount of rent payment for land along with production inputs. Tenure status is an important contributor to the adoption

[38] The base category is landless.
[39] $p-$value of 0.0322 in testing the relative productivity difference between small-marginal and large-medium Farmer type confirms that, we can reject the null hypothesis of no difference.

of diversified technology and cropping (Sarker et al., 2013). Nasrin and Uddin (2013) observed the asymmetry in tenural arrangements and found lower return in *boro* rice production for share tenants compared to cash tenants. Land productivity sensitivity could be attributed to a number of factors. For instance possibility of income generation from livestock and poultry rearing rather than from cropping, crop diversification, income diversification, higher educational level of large-medium farmers which has also been explained in Delaporte and Maurel (2016). Accordingly, Kabir et al. (2017a) observed that rice productivity is less economically feasible than diversified cropping in changing climate and during 1990-2000, large and medium farmers were largely into livestock production. Moreover, information about climate and adaptation strategies contributes significantly in taking up actual adaptation (Bryan et al., 2009; Deressa et al., 2009). Therefore in this study, small-marginal farmers could increase their land productivity comparatively less.

Chapter 7
Conclusion, policy implications and limitation

7.1 Summary of results

Temperature and rainfall patterns are significant in understanding the scenario of cropping, especially for rice cultivation due to its high sensitivity to climate variables. Accordingly, since production technique based adaptation strategies have been dominantly formulated in developing countries' rice cultivation, it has a direct impact on national production and productivity of individual farmer. This study therefore, examined absolute and relative variability; analysed trend and seasonality in maximum and minimum temperature and rainfall for three weather stations. The study also assessed the determinants of choice of adaptation strategies and land productivity. Finally, this study shed lights on differential land productivity and choice of adaptation strategies across farmer types.

While examining climate data, high absolute and relative variability have been observed in rainfall for the study period (1964-2012). Minimum temperature data exhibited larger absolute and relative variability compared to maximum temperature. In case of differential variability across weather stations, it has been observed that temperature and rainfall had less variability than *Rajshahi* and *Ishurdi*. Strong evidence of increasing trend in maximum temperature and decreasing trend in rainfall has been found in *Rajshahi* and *Ishurdi*. On the contrary, significant increasing trend in minimum temperature has been found in *Bogra*. In order to look at the compatibility of farmer perception with climate model during rice production period 2011-2012, this study used frequency distribution of annual and season wise temperature and rainfall changes. Most of the farmers perceive that temperature has increased annually and rainfall has decreased over time. A shortfall in rainfall has also been mostly reported in three different seasons namely summer, winter and monsoon. However, most farmers perceived that in winter temperature has decreased over time. This perception conforms to climate model analysis where in seasonality analysis, in cold months, temperature increase is less compared to other months.

In determining the choice of different adaptations strategies, severity of drought has been discouraging for the cultivations of direct seeded rice, drought-tolerant and short duration rice and irrigation for *boro* rice. It encouraged extensively the choice of water-saving non-rice and horticulture crops. Severe ground water depletion, on the contrary, has been most discouraging for the cultivation of water saving non-rice and horticulture crops. Age and educational level of the household head; ownership of livestock or poultry; increased use of chemical fertilizer; farmer access to climate information, subsidy and electricity for irrigating land have a strong statistical and economic effect on making different choices of strategies. Finally, large-medium farmers are more likely to choose non-rice and horticulture crops in which small-marginal farmers have no effect. In case of shifting planting date, significant difference has been found between these two groups. While assessing the determinants of land productivity, strong influence of severity of drought and groundwater depletion has been found. Among household socio-demographic characteristics, age and educational level of the household head significantly influenced land productivity. Among the institutional factors farmers' access to credit, subsidy and electricity for irrigation significantly affected land productivity. In case of differential impacts, large-medium farmers could increase land productivity almost double the small-marginal farmers. Farmers' access to climate information has no effect on land productivity which reveals poor climate information dissemination in the study area.

7.2 Policy implications

Despite taking up comprehensive irrigation and cultivating high yielding varieties, rice cropping in Bangladesh has an increasing risk of temperature increase and inadequate rainfall. Also drought tolerant, direct seeded and short duration rice varieties replacing local varieties are prone to pest attacks and diseases requiring increased use of chemicals and intensive irrigation. However, long term capacity in coping with rising cost of inputs is actually ignored in short-term adaptations as Kandlikar and Risbey (2000) argued. So, these adaptations are shaped by market forces and macro level policies which could destroy local and collective knowledge as Storm (2009) demonstrated. Therefore In this study, differential access to resources could explain differential land productivity and choice of strategies among farmers. This study also explored that most important barriers are socio-economic and knowledge resource constraints. Sufficient investment and support services in agriculture are inadequate in the country as Alauddin and Sarker (2014) stated. At union level farmers are receiving advice on timing and quantity of input use, water saving cultivation and agronomic practices. However, this is not sufficient to reduce vulnerability of farmers where most of them are small and marginal holders. It is necessary to inform farmers of climate risks in an understandable way as Smit and Pilifosova (2003) stated, and this depends on the efficiency of the existing institutions. Also, insufficient subsidy received by these farmers could not improve capacity to taking up costly strategy in the face of rising prices of seeds, chemical inputs and labour. Moreover, target group for credit and subsidy support could be faulty if large farmers have more political connection (Alauddin and Sarker, 2014). Particularly, marginal and landless farmers who cultivate land taking land in rent or lease from large farmers cannot utilize agricultural credit received since they often use it for current consumption purpose. Therefore, the government should take proper initiative in correcting existing differential institutional access of farmers, developing comprehensive monitoring system and increasing need based support services to farmers.

7.3 Limitation and future research directions

This study is limited to analysing temperature and rainfall patterns at regional level. Extreme events like drought and flood patterns are crucial to explore the reconciliation of macro level trend with farmer perception about climate change more precisely. Furthermore, while looking at differentiation across farmers, this study did not analyse the determinants of adaptation choices and land productivity controlled for three different types of farmers due to insufficient number of large-medium and landless farmers. Future researchers should collect enough data from all segments of farmers to make more micro-level analysis. Finally, this study is focused on only drought prone and severe groundwater depleted areas of Bangladesh. Salinity prone coastal areas where floods and storm surges are frequent are not included which leaves the scope of further research in exploring spatial climate variability, differential choice of adaptation strategies and land productivity.

References

Abid, M., J. Scheffran, U. Schneider and M. Ashfaq (2015) 'Farmers' perceptions of and adaptation strategies to climate change and their determinants: the case of Punjab province, Pakistan', *Earth System Dynamics* 6(1): 225.

Abid, M., U. A. Schneider and J. Scheffran (2016) 'Adaptation to climate change and its impacts on food productivity and crop income: Perspectives of farmers in rural Pakistan', *Journal of Rural Studies* 47**:** 254-266.

Adger, W. N. (2006) 'Vulnerability', *Global Environmental Change* 16(3): 268-281.

Adger, W. N. (2010) 'Social capital, collective action, and adaptation to climate change', *Economic Geography* 79(4): 387-404.

Adger, W. N., S. Huq, K. Brown, D. Conway and M. Hulme (2003) 'Adaptation to climate change in the developing world', *Progress in development studies* 3(3): 179-195.

Agrawal, A. (2010) 'Local institutions and adaptation to climate change', *Social dimensions of climate change: Equity and vulnerability in a warming world* 2**:** 173-178.

Akram-lodhi, A. H. and C. Kay (eds) (2012) *Peasants and globalization: Political economy, agrarian transformation and development*, New York: Routledge.

Alam, G. M., K. Alam and S. Mushtaq (2016) 'Influence of institutional access and social capital on adaptation decision: Empirical evidence from hazard-prone rural households in Bangladesh', *Ecological Economics* 130: 243-251.

Alam, M. S., N. Sasaki and A. Datta (2017) 'Waterlogging, crop damage and adaptation interventions in the coastal region of Bangladesh: A perception analysis of local people', *Environmental Development* 23: 22-32.

Alauddin, M. and J. Quiggin (2008) 'Agricultural intensification, irrigation and the environment in South Asia: Issues and policy options', *Ecological Economics* 65(1)**:** 111-124.

Alauddin, M. and M. A. R. Sarker (2014) 'Climate change and farm-level adaptation decisions and strategies in drought-prone and groundwater-depleted areas of Bangladesh: an empirical investigation', *Ecological Economics* 106: 204-213.

Alauddin, M. and C. Tisdell (1987) 'Trends and projections for Bangladeshi food production: an alternative viewpoint', *Food Policy* 12(4): 318-331.

Ali, A. (1999) 'Climate change impacts and adaptation assessment in Bangladesh', *Climate research* 12(2/3): 109-116.

Anik, S. I. and M. A. S. A. Khan (2012) 'Climate change adaptation through local knowledge in the north eastern region of Bangladesh', *Mitigation and Adaptation Strategies for Global Change* 17(8): 879-896.

Apata, T. G., K. Samuel and A. Adeola (2009) 'Analysis of climate change perception and adaptation among arable food crop farmers in South Western Nigeria', Contributed paper prepared for presentation at the international association of agricultural economists' 2009 conference, Beijing, China, August 16, 2009.

Arimi, K. (2014) 'Determinants of climate change adaptation strategies used by rice farmers in Southwestern, Nigeria', *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)* 115(2): 91-99.

Asaduzzaman, M., C. Ringler, J. Thurlow and S. Alam (2010) 'Investing in crop agriculture in Bangladesh for higher growth and productivity, and adaptation to climate change', Bangladesh Food Security Investment Forum: 26-27.

Ayeb-karlsson, S., K. Geest, I. Ahmed, S. Huq and K. Warner (2016) ‘A people-centred perspective on climate change, environmental stress, and livelihood resilience in Bangladesh’, *Sustainability Science* 11(4): 679-694.

Ayers, J. and T. Forsyth (2009) ‘Community-based adaptation to climate change’, *Environment: science and policy for sustainable development* 51(4): 22-31.

Basak, J. K., M. A. Ali, M. N. Islam and M. A. Rashid (2010) ‘Assessment of the effect of climate change on *boro* rice production in Bangladesh using DSSAT model’, *Journal of Civil Engineering (IEB)* 38**:** 95-108.

BBS (2008) ‘Agriculture Census Report’, Dhaka: Government of Bangladesh.

BBS (2014) ‘Yearbook of Agricultural Statistics of Bangladesh’, Dhaka: Government of Bangladesh.

BBS (2017) ‘Statistical Yearbook of Bangladesh, 2016’, Dhaka: Statistics Division, Ministry of Planning.

Bernstein, H. (2010) *Class dynamics of agrarian change*, Sterling: Kumarian Press.

Blaikie, N. W. H. (2010) *Designing social research*, UK: Polity press Cambridge.

Blaikie, P., T. Cannon, I. Davis and B. Wisner (1994) *At risk: Natural hazards, people’s vulnerability and disasters*, London: Routledge.

Bohle, H. G., T. E. Downing and M. J. Watts (1994) ‘Climate change and social vulnerability: toward a sociology and geography of food insecurity’, *Global Environmental Change* 4(1): 37-48.

Braun, A. R., G. Thiele and M. Fernández (2000) *Farmer field schools and local agricultural research committees: complementary platforms for integrated decision-making in sustainable agriculture*, London.

Brooks, N., W. N. Adger and P. M. Kelly (2005) ‘The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation’, *Global Environmental Change* 15(2): 151-163.

Bryan, E., T. T. Deressa, G. A. Gbetibouo and C. Ringler (2009) 'Adaptation to climate change in Ethiopia and South Africa: options and constraints', *environmental science & policy* 12(4): 413-426.

Burton, I., S. Huq, B. Lim, O. Pilifosova and E. L. Schipper (2002) 'From impacts assessment to adaptation priorities: the shaping of adaptation policy', *Climate policy* 2(2-3): 145-159.

Coirolo, C. and A. Rahman (2014) 'Power and differential climate change vulnerability among extremely poor people in Northwest Bangladesh: lessons for mainstreaming', *Climate and Development* 6(4): 336-344.

Collins, E. and K. Chandrasekaran (2012) 'A wolf in sheep’s clothing? An analysis of the ‘sustainable intensification’of agriculture', Friends of the Earth International. http://www. foei. org/. Accessed September, 21, 2015.

Changyong, F., W. Hongyue, L. Naiji, C. Tian, H. Hua and L. Ying (2014) 'Log-transformation and its implications for data analysis', *Shanghai archives of psychiatry* 26(2)**:** 105.

Cheng, S. and J. S. Long (2007) 'Testing for IIA in the Multinomial Logit Model', *Sociological Methods & Research* 35(4)**:** 583-600.

NRC (2011) *Advancing the science of climate change*, Washington D C: National Academies Press.

Dalton, G. (1974) 'How exactly are peasants “exploited”?', *American Anthropologist* 76(3): 553-561.

Dasgupta, S., M. Hossain, M. Huq and D. Wheeler (2014) 'Climate change, soil salinity, and the economics of high-yield rice production in coastal Bangladesh', Policy Research Working Paper: World Bank Group.
Delaporte, I. and M. Maurel (2016) 'Adaptation to climate change in Bangladesh', *Climate policy*, 1-14.
Denton, G. H., R. B. Alley, G. C. Comer and W. S. Broecker (2005) 'The role of seasonality in abrupt climate change', *Quaternary Science Reviews* 24(10): 1159-1182.
Deressa, T. T., R. M. Hassan, C. Ringler, T. Alemu and M. Yesuf, (2009) 'Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia', *Global Environmental Change* 19(2): 248-255.
Dyer, G. (1996) 'Output per acre and size of holding: The logic of peasant agriculture under semi-feudalism', *The Journal of Peasant Studies* 24(1-2)**:** 103-131.
FAO (2006) 'Livelihood adaptation to climate change variability and change in drought prone areas of Bangladesh: Developing institutions and options', Rome: Food and Agriculture Organization of the United Nations.
FAO (2013) 'Agriculture data', *Agricultural production*.
FAO (2009) 'How to Feed the World in 2050', Rome: High-Level Expert Forum.
Farook, A. J. and K. S. Kannan (2016) 'Climate Change Impact on Rice Yield in India–Vector Autoregression Approach', *Sri Lankan Journal of Applied Statistics* 16(3): 161-178.
Fellmann, T. (2012) 'Change-related vulnerability in the agricultural sector: reviewing conceptual, Building Resilience for Adaptation to Climate Change in the Agriculture Sector', Proceedings of a Joint FAO/OECD Workshop 23-24 April 2012, Food & Agriculture Org, 37.
GAIN (2015) 'Bangladesh Grain and Feed Annual 2015', Washington D C: USDA.
GOB (2011) 'Yearbook of Agricultural Statistics of Bangladesh', Dhaka: Ministry of Planning.
Gray, L. C. and W. G. Moseley (2005) 'A geographical perspective on poverty–environment interactions', *The Geographical Journal* 171(1): 9-23.
Greene, W. H. (2003) *Econometric Analysis*, Boston: Prentice-Hall.
Grothmann, T. and A. Patt (2005) 'Adaptive capacity and human cognition: the process of individual adaptation to climate change', *Global Environmental Change* 15(3): 199-213.
Gujarati, D. N. (2009) *Basic econometrics*, Singapore: Tata McGraw-Hill Education.
Habiba, U., R. Shaw and Y. Takeuchi (2011) 'Drought risk reduction through a socio-economic, institutional and physical approach in the northwestern region of Bangladesh', *Environmental Hazards* 10(2)**:** 121-138.
Hahn, M. B., A. M. Riederer and S. O. Foster (2009) 'The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change—A case study in Mozambique' *Global Environmental Change* 19(1)**:** 74-88.
Harmer, N. and S. Rahman (2014) 'Climate change response at the farm level: a review of farmers' awareness and adaptation strategies in developing countries', *Geography Compass* 8(11): 808-822.
Hassan, R. and C. Nhemachena (2008) 'Determinants of African farmers' strategies for adapting to climate change: Multinomial choice analysis', *African Journal of Agricultural and Resource Economics* 2(1): 83-104.
Hesselberg, J. and J. A. Yaro (2006) 'An assessment of the extent and causes of food insecurity in northern Ghana using a livelihood vulnerability framework', *GeoJournal* 67(1): 41-55.
Hinkel, J. (2011) 'Indicators of vulnerability and adaptive capacity: Towards a clarification of the science–policy interface', *Global Environmental Change* 21(1): 198-208.

Hossain, M. (1988) 'Nature and impact of the green revolution in Bangladesh', Intl Food Policy Res Inst.
Hossain, M., W. Jaim, M. Alam and A. Rahman (2013) 'Rice biodiversity in Bangladesh: adoption, diffusion and disappearance of varieties', *A statistical report from farm survey in 2005*, Dhaka: Research and Evaluation Division BRAC.
Hossain, M., F. Naher and Q. Shahabuddin (2005) 'Food security and nutrition in Bangladesh: progress and determinants', *Electronic Journal of Agricultural and Development Economics* 2(2)**:** 103-132.
Hunsberger, C., E. Corbera, S. M. Borras Jr, R. De La Rosa, V. Eang, J. C. Franco et al. (2015) 'Land-based climate change mitigation, land grabbing and conflict: understanding intersections and linkages, exploring actions for change', MOSAIC Working Paper Series No, 1.
IPCC (1990) 'Climate change: The IPCC scientific assessment', Mass, Cambridge, 289-306.
IPCC (2007) 'Climate Change 2007: impacts, adaptation and vulnerability: contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change', UK: Cambridge University Press, 79-132.
IPCC (2014) 'Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change', UK: Cambridge University Press, 2-31.
Isakson, S. R. (2015) 'Derivatives for Development? Small-Farmer Vulnerability and the Financialization of Climate Risk Management', *Journal of Agrarian Change* 15(4): 569-580.
Ishaya, S. and I. Abaje (2008) 'Indigenous people's perception on climate change and adaptation strategies in Jema'a local government area of Kaduna State, Nigeria', *Journal of geography and regional planning* 1(8): 138.
Islam, S. (2003) *Banglapedia: national encyclopedia of Bangladesh*, Asiatic society of Bangladesh.
Islam, Z., M. Alauddin and M. A. R. Sarker (2017) 'Determinants and implications of crop production loss: An empirical exploration using ordered probit analysis', *Land Use Policy* 67: 527-536.
Kabir, M. J., M. Alauddin and S. Crimp (2017a) 'Farm-level adaptation to climate change in Western Bangladesh: An analysis of adaptation dynamics, profitability and risks', *Land Use Policy* 64: 212-224.
Kabir, M. J., R. Cramb, M. Alauddin, C. Roth and S. Crimp (2017b) 'Farmers' perceptions of and responses to environmental change in southwest coastal Bangladesh', *Asia Pacific Viewpoint*.
Kandlikar, M. and J. Risbey (2000) 'Agricultural impacts of climate change: if adaptation is the answer, what is the question?', *Climatic change* 45(3-4)**:** 529-539.
Katz, R. W. and B. G. Brown (1992) 'Extreme events in a changing climate: variability is more important than averages', *Climatic change* 21(3): 289-302.
Kelly, P. M. and W. N. Adger (2000) 'Theory and practice in assessing vulnerability to climate change andFacilitating adaptation', *Climatic change* 47(4): 325-352.
Kumar, V. and J. K. Ladha (2011) 'Direct seeding of rice: recent developments and future research needs', *Adv. Agron* 111(297.4)**:** 299-391.
Lansigan, F., W. De Los Santos and J. Coladilla (2000) 'Agronomic impacts of climate variability on rice production in the Philippines', *Agriculture, ecosystems & environment* 82(1)**:** 129-137.
Lei, Y., C. Liu, L. Zhang and S. Luo (2016) 'How smallholder farmers adapt to agricultural drought in a changing climate: A case study in southern China', *Land Use Policy* 55: 300-308.

Mabe, F. N., G. Sienso and S. Donkoh (2014) 'Determinants of choice of climate change adaptation strategies in northern Ghana', *Research in Applied Economics* 6(4)**:** 75-94.
Maclean, J. L. and D. C. Dawe (eds) (2002) *Rice almanac: Source book for the most important economic activity on earth*, Manilla, Philippines and CABI, Wallingford, UK: International Rice Research Institute, 253.
Mahmood, R. (1997) 'Impacts of air temperature variations on the *boro* rice phenology in Bangladesh: implications for irrigation requirements', *Agricultural and forest meteorology* 84(3)**:** 233-247.
Manandhar, S., D. S. Vogt, S. R. Perret and F. Kazama (2011) 'Adapting cropping systems to climate change in Nepal: a cross-regional study of farmers' perception and practices', *Regional Environmental Change* 11(2): 335-348.
Masutomi, Y., K. Takahashi, H. Harasawa and Y. Matsuoka (2009) 'Impact assessment of climate change on rice production in Asia in comprehensive consideration of process/parameter uncertainty in general circulation models', *Agriculture, ecosystems & environment* 131(3): 281-291.
Mcdowell, J. Z. & J. J. Hess (2012) 'Accessing adaptation: Multiple stressors on livelihoods in the Bolivian highlands under a changing climate', *Global Environmental Change* 22(2)**:** 342-352.
Mertz, O., C. Mbow, A. Reenberg and A. Diouf (2009) 'Farmers' perceptions of climate change and agricultural adaptation strategies in rural Sahel', *Environmental management* 43(5): 804-816.
Mirza, M. M. Q. (2003) 'Climate change and extreme weather events: can developing countries adapt?', *Climate policy* 3(3): 233-248.
Mirza, M. M. Q. (2011) 'Climate change, flooding in South Asia and implications', *Regional Environmental Change* 11(1): 95-107.
Mondol, M. A. H., I. Ara and S. C. Das (2017) 'Meteorological Drought Index Mapping in Bangladesh Using Standardized Precipitation Index during 1981–2010', *Advances in Meteorology* 2017, doi:10.1155/2017/4642060.
Moniruzzaman, S. (2015) 'Crop choice as climate change adaptation: Evidence from Bangladesh', *Ecological Economics* 118**:** 90-98.
Mottaleb, K. A., M. K. Gumma, A. K. Mishra and S. Mohanty (2015) 'Quantifying production losses due to drought and submergence of rainfed rice at the household level using remotely sensed MODIS data', *Agricultural Systems* 137**:** 227-235.
Nasrin, M. and M. T. Uddin (2013) 'Land tenure system and agricultural productivity in a selected area of Bangladesh', *Progressive Agriculture* 22(1-2): 181-192.
Nelson, G. C., M. W. Rosegrant, J. Koo, R. Robertson, T. Sulser, T. Zhu, C. Ringler, S. Msangi, A. Palazzo and M. Batka (2009) *Climate change: Impact on agriculture and costs of adaptation*, Intl Food Policy Res Inst, 1-12.
Nyanga, P. H., F. H. Johnsen and J. B. Aune (2011) 'Smallholder farmers' perceptions of climate change and conservation agriculture: evidence from Zambia', *Journal of Sustainable Development* 4(4):73-85.
Patt, A. G. and D. Schröter (2008) 'Perceptions of climate risk in Mozambique: implications for the success of adaptation strategies', *Global Environmental Change* 18(3): 458-467.
Paul, B. K. (1998) 'Coping mechanisms practised by drought victims (1994/5) in North Bengal, Bangladesh', *Applied Geography* 18(4)**:** 355-373
Peng, S., J. Huang, J. E. Sheehy, R. C. Laza, R. M. Visperas, X. Zhong et al. (2004) 'Rice yields decline with higher night temperature from global warming', Proceedings of the National academy of Sciences of the United States of America, 101(27), 9971-9975

Quasem, M. A. (2011) 'Conversion of agricultural land to non-agricultural uses in Bangladesh: Extent and determinants', *The Bangladesh Development Studies* 34(1): 59-85.
Rahman, M. R. and H. Lateh (2016) 'Meteorological drought in Bangladesh: assessing, analysing and hazard mapping using SPI, GIS and monthly rainfall data', *Environmental Earth Sciences* 75(12)**:** 1-20.
Rahman, S. (2005) 'Environmental impacts of technological change in Bangladesh agriculture: farmers' perceptions, determinants, and effects on resource allocation decisions', *Agricultural economics* 33(1)**:** 107-116.
Rahman, S. (2008) 'Determinants of crop choices by Bangladeshi farmers: a bivariate probit analysis', *Asian Journal of Agriculture and Development* 5(1):30**.**
Rashid, H. (1978) *Geography of Bangladesh*, United States of America: Westview Press, 201-246.
Redfern, S. K., N. Azzu and J. S. Binamira (2012) 'Rice in Southeast Asia: facing risks and vulnerabilities to respond to climate change', *In: Building resilience for adaptation to climate change in the agriculture sector*, Proceedings of a Joint FAO/OECD Workshop 23–24 April 2012, 23**:** 295-314.
Reed, G. F., F. Lynn and B. D. Meade (2002) 'Use of coefficient of variation in assessing variability of quantitative assays', *Clinical and diagnostic laboratory immunology* 9(6)**:** 1235-1239.
Ribot, J. (2010) 'Vulnerability does not fall from the sky: toward multiscale, pro-poor climate policy', *Social dimensions of climate change: Equity and vulnerability in a warming world* 2**:** 47-74.
Ribot, J. (2014) 'Cause and response: vulnerability and climate in the Anthropocene', *Journal of Peasant Studies* 41(5): 667-705.
Roseberry, W. (1976) 'Rent, differentiation, and the development of capitalism among peasants', *American Anthropologist* 78(1): 45-58.
Rosenzweig, C., A. Iglesias, X. Yang, P. R. Epstein and E. Chivian (2001) 'Climate change and extreme weather events; implications for food production, plant diseases, and pests', *Global change & human health* 2(2): 90-104.
Ruane, A. C., D. C. Major, H. Y. Winston, M. Alam, S. G. Hussain, A. S. Khan et al. (2013) 'Multi-factor impact analysis of agricultural production in Bangladesh with climate change', *Global Environmental Change* 23(1): 338-350.
Sarker, M. A. R., K. Alam and J. Gow (2013) 'Assessing the determinants of rice farmers' adaptation strategies to climate change in Bangladesh', *International Journal of Climate Change Strategies and Management* 5(4): 382-403.
Sarker, M. A. R., K. Alam and J. Gow (2014) 'Assessing the effects of climate change on rice yields: An econometric investigation using Bangladeshi panel data', *Economic Analysis and Policy* 44(4): 405-416.
Sarker, M. A. R. and Z. Islam (2016) 'Investigating the Effects of Sociodemographic, Farm and Institutional Characteristics on Climate-driven Loss in *Aman* Rice Productivity in Bangladesh', *In:* Alauddin, M., M. K. Mujeri and D. K. Nath (eds) *Bangladesh: Yesterday, Today and Tomorrow*. Dhaka: Sahitya Prakash.
Schelling, T. C. (1992) 'Some economics of global warming', *The American Economic Review* 82(1): 1-14.
Schellnhuber, H. J., B. Hare, O. Serdeczny, M. Schaeffer, S. Adams, F. Baarsch et al. (2013). 'Turn down the heat: climate extremes, regional impacts, and the case for resilience', Washington D C: World Bank.

Sen, A. (1981a) 'Ingredients of famine analysis: availability and entitlements', *The quarterly journal of economics* 96(3): 433-464.
Sen, A. (1981b) 'Poverty and famines: an essay on entitlement and deprivation', *In:* Gittinger, P. J., J. Leslie and C. Hoisington (eds) *Food Policy: Integrating Supply, Distribution and Consumption*, Baltimore and London: The Johns Hopkins University Press, 198-204.
Shahid, S. (2008) 'Spatial and temporal characteristics of droughts in the western part of Bangladesh', *Hydrological Processes* 22(13): 2235-2247.
Shahid, S. (2010) 'Rainfall variability and the trends of wet and dry periods in Bangladesh', *International Journal of Climatology* 30(15): 2299-2313.
Shahid, S. (2011) 'Impact of climate change on irrigation water demand of dry season *Boro* rice in northwest Bangladesh', *Climatic change* 105(3)**:** 433-453.
Shahid, S. and H. Behrawan (2008) 'Drought risk assessment in the western part of Bangladesh', *Natural hazards* 46(3): 391-413.
Shahid, S. and M. K. Hazarika (2010) 'Groundwater drought in the northwestern districts of Bangladesh', *Water resources management* 24(10): 1989-2006.
Shelley, I. J., M. Takahashi-nosaka, M. Kano-nakata, M. S. Haque and Y. Inukai (2016) 'Rice cultivation in Bangladesh: present scenario, problems, and prospects', *Journal of International Cooperation for agricultural Development* 14: 20-29.
Shrestha, R. P., N. Chaweewan and S. Arunyawat (2017) 'Adaptation to Climate Change by Rural Ethnic Communities of Northern Thailand', *Climate* 5(3): 57.
Siddiqui, A. H. (2014) 'Impact of Climate Change of the Coastal Ecosystem in Bangladesh', *International Journal of Research and Innovations in Earth Science* 1(2): 64-72.
Smit, B. and O. Pilifosova (2003) 'Adaptation to climate change in the context of sustainable development and equity', *Sustainable Development* 8(9): 879-912.
Smit, B. and J. Wandel (2006) 'Adaptation, adaptive capacity and vulnerability', *Global Environmental Change* 16(3)**:** 282-292.
Spinoni, J., G. Naumann, H. Carrao, P. Barbosa and J. Vogt (2014) 'World drought frequency, duration, and severity for 1951–2010', *International Journal of Climatology* 34(8): 2792-2804.
Storm, S. (2009) 'Capitalism and climate change: Can the invisible hand adjust the natural thermostat?', *Development and Change* 40(6): 1011-1038.
Taylor, M. (2014) *The political ecology of climate change adaptation: Livelihoods, agrarian change and the conflicts of development*, New York: Routledge.
Thomas, D. S., C. Twyman, H. Osbahr and B. Hewitson (2007) 'Adaptation to climate change and variability: farmer responses to intra-seasonal precipitation trends in South Africa', *Climatic change* 83(3): 301-322.
Thwaites, R., D. Race and K. Alexander (2014) 'Differential impacts of climate change on communities in the middle hills region of Nepal', *Natural hazards* 74(2): 815-836.
Tomlinson, I. (2013) 'Doubling food production to feed the 9 billion: a critical perspective on a key discourse of food security in the UK', *Journal of Rural Studies* 29: 81-90.
Tucker, C. M., H. Eakin and E. J. Castellanos (2010) 'Perceptions of risk and adaptation: Coffee producers, market shocks, and extreme weather in Central America and Mexico', *Global Environmental Change* 20(1): 23-32.
Uddin, M. N., W. Bokelmann and J.S. Entsminger (2014) 'Factors affecting farmers' adaptation strategies to environmental degradation and climate change effects: A farm level study in Bangladesh', *Climate* 2(4)**:** 223-241.
Valdivia, C., A. Seth, J. L. Gilles, M. García, E. Jiménez, J. Cusicanqui, F. Navia and E. Yucra (2010) 'Adapting to climate change in Andean ecosystems: Landscapes, capitals, and perceptions

shaping rural livelihood strategies and linking knowledge systems', *Annals of the Association of American Geographers* 100(4): 818-834.
Vincent, K. (2004) 'Creating an index of social vulnerability to climate change for Africa', Working Paper, *Tyndall Center for Climate Change Research* 56: 41.
Wassmann, R., S. Jagadish, K. Sumfleth, H. Pathak, G. Howell, A. Ismail et al. (2009) 'Regional vulnerability of climate change impacts on Asian rice production and scope for adaptation', *Advances in Agronomy* 102: 91-133.
Weber, E. U. (2010) 'What shapes perceptions of climate change?' *Wiley Interdisciplinary Reviews: Climate Change* 1(3): 332-342.
Wooldridge, J. M. (2015) *Introductory econometrics: A modern approach*, Canada: Nelson Education.
Yin, X., J. E. Olesen, M. Wang, I. Öztürk, H. Zhang and F. Chen (2016) 'Impacts and adaptation of the cropping systems to climate change in the Northeast Farming Region of China', *European Journal of Agronomy* 78: 60-72.
Yu, W., M. Alam, A. Hassan, A. S. Khan, A. Ruane, C. Rosenzweig et al. (2010) *Climate change risks and food security in Bangladesh*, London: Earthscan.

Appendices

Appendix A

Concepts used in adaptation process

Autonomous and planned adaptation Adaptation formulation is categorized as planned and autonomous in the existing literature. When adaptation action is taken locally by individual farmer without institutional interference, it is called autonomous adaptation. On the contrary any adaptation regulated and facilitated by institutions such as local or national government, national and international non-governmental organisations is defined as planned adaptation. The study focuses on the adaptation strategies planned by national institutions and implemented at regional level. For example, rice variety cultivated in the study area are invented by BRRI and BARC, promoted and distributed by the Department of Agriculture Extension under local government. Irrigation is managed by WARPO, IWRM, BWDB and other small scale projects. Apart from these, training on water saving crop farming, irrigation timing, fertilizer application, priori climate pattern information is also provided to farmers by local AEOs (Agriculture Extension Officers). However, response to adaptation is actually made by the individual farmer or the community. In the study, it is argued that adaptations regulated by institutions are planned but the response may be autonomous, explained by selected variables in terms of resource access. There is a divergence between planned and actual adaptation Actual adaptation eventually defines the adaptive capacity of an individual farmer. The following Figure A.1 shows agricultural adaptations options in Bangladesh.

Peasant In *peasant studies* and in political economy approach, *peasants* are distinguished from farmers. The argument in historical analysis of agrarian studies, rests upon the discrimination against the socially and economically subordinated class of farmers. For example, in medieval times agricultural labourers were commonly termed as *peasants.* In political economy approach and contemporary critical agrarian thinkers address the differentiation in *peasantry* in terms of resource ownership and gradual dispossession happening in the face of global capitalism. Also, activists have largely popularized the term *peasant* in movements addressing these issues since 1990s (Edelman, 2013).

Project Name	Agency	Location	Sample Activities
Reducing Vulnerability to Climate Change	CARE	Satkhira, Gopalganj, Rajshahi	Drought-tolerant crop cultivation; Tree and plant nursery activities; Floating gardens and homestead vegetable gardens
Livelihood Adaptation to Climate Change (LACC) Phase I	FAO, DAE,	Chapai, Nawabganj, Natore, Naogaon, Pirojpur, Khulna	Homestead gardening; Drought-tolerant fruit tree gardening; Rainwater harvesting in mini ponds for supplementary irrigation for t. aman
Livelihood Adaptation to Climate Change (LACC) Phase II	FAO, DAE	Rajshahi, Chapai Nawabganj, Natore, Naogaon, Pirojpur, Khulna	Adaptation options have been identified but not implemented yet
Disappearing Lands: Supporting Communities Affected by River Erosion	Practical Action Bangladesh	Gaibandha	Sand bar vegetable cultivation in char lands; Floating bed vegetable cultivation
Assistance to Local Community on Climate Change Adaptation and DRR in Bangladesh	Action Aid Bangladesh	Naogaon, Sirajganj, Patuakhali	Homestead vegetable gardening; Rice demonstrations; Chickpea cultivation; Community based pond management for supplementary irrigation
Barind Integrated Area Development Project	BMDA	Northern part of Bangladesh	Groundwater irrigation; Management of surface water for crop production; Excavation of mini ponds
Asia-Pacific Forum for Environment and Development	BCAS	Rajshai, Naogaon, Sirajganj, Gaibandha, Kurigram Shunamganj, Faridpur, Pirojpur, Cox's Bazar, Satkhira, Patuakhali, Barisal	Zero-tillage maize cultivation; Chickpea cultivation; Relay cropping of sweet gourd; Floating bed vegetables cultivation

Figure A.1: Different agricultural adaptation options in Bangladesh
Source: Adapted from Yu et al. (2010)

Appendix B

Climatic zones in Bangladesh

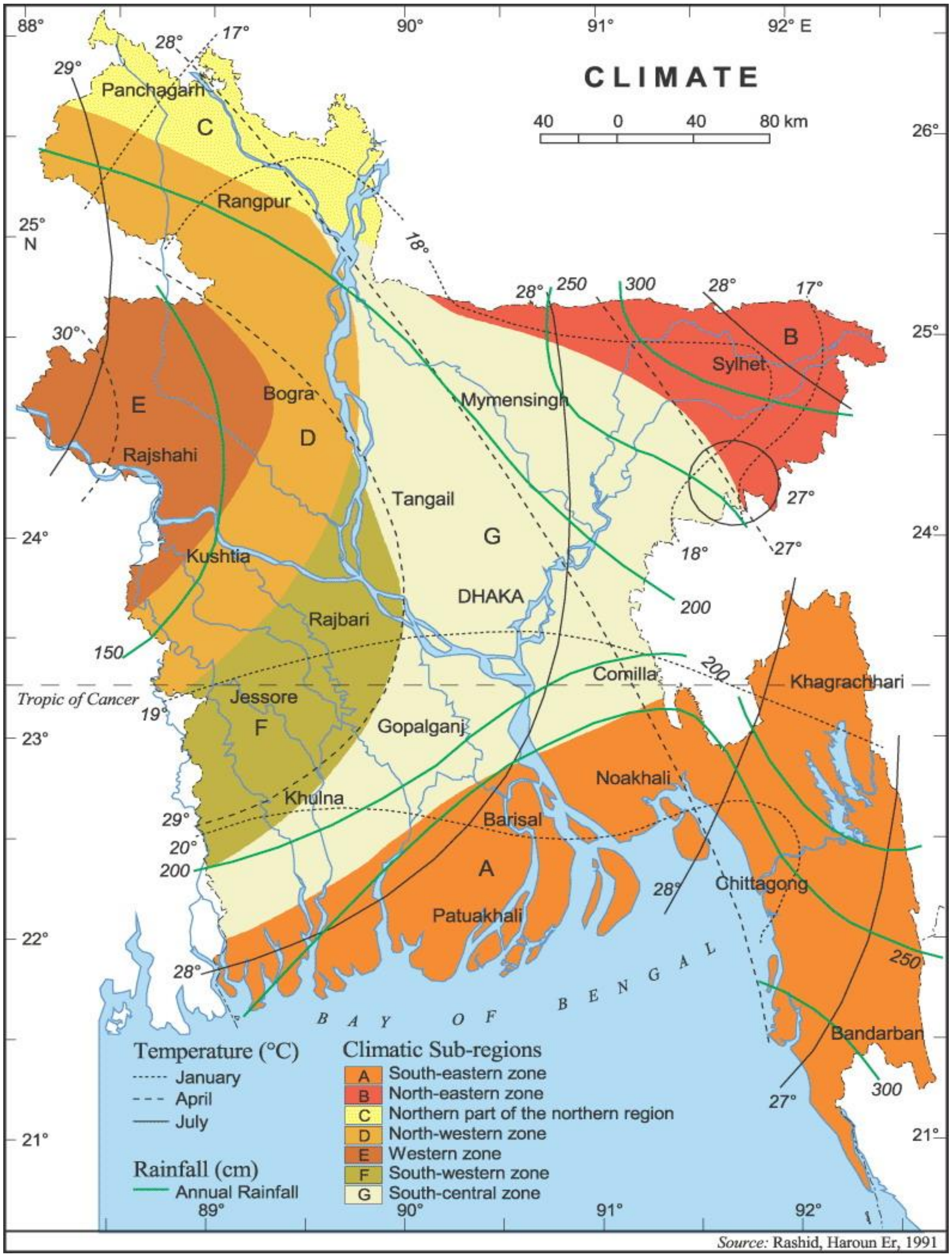

Figure B.1: Map of climatic zones in Bangladesh
Source: http://en.banglapedia.org/index.php

Appendix C

Level of drought and groundwater depletion in the study area

Table C.1: Level of drought and groundwater depletion in the study area

District	Drought	Ground water depletion
Bogra	moderate	moderate
Chapainawabganj	severe	severe
Chuadanga	moderate	moderate
Gazipur	moderate	severe
Naogaon	severe	severe
Natore	severe	severe
Pabna	moderate	moderate
Rajshahi	severe	severe

Source: Adapted from Alauddin and Sarker (2014) and Islam et al. (2017)

Appendix D

Trend and seasonality analysis of maximum temperature, minimum temperature and rainfall data

Table D.1: Trend and seasonality in climate variables over the period 1964-2012

Variables	Maximum temperature			Minimum temperature			Rainfall		
	Rajshahi	*Bogra*	*Ishurdi*	*Rajshahi*	*Bogra*	*Ishurdi*	*Rajshahi*	*Bogra*	*Ishurdi*
February	4.469***	3.859***	3.792***	1.578***	1.910***	1.902***	2.347	3.163	9.837***
	(0.290)	(0.326)	(0.414)	(0.341)	(0.303)	(0.340)	(17.17)	(2.619)	(3.593)
March	9.694***	8.486***	9.471***	5.380***	5.608***	5.759***	13.71	11.67***	22.92***
	(0.290)	(0.311)	(0.434)	(0.341)	(0.319)	(0.315)	(17.17)	(3.502)	(4.854)
April	11.54***	10.61***	11.70***	10.96***	10.51***	11.27***	46.35***	72.31***	72.55***
	(0.290)	(0.368)	(0.434)	(0.341)	(0.287)	(0.340)	(17.17)	(10.73)	(10.28)
May	11.18***	9.884***	11.23***	12.64***	12.33***	13.57***	123.1***	181.1***	166.6***
	(0.290)	(0.365)	(0.466)	(0.341)	(0.276)	(0.298)	(17.17)	(12.90)	(14.37)
June	9.947***	8.492***	9.382***	15.43***	14.54***	16.06***	252.1***	315.0***	269.6***
	(0.290)	(0.310)	(0.463)	(0.341)	(0.268)	(0.301)	(17.17)	(24.88)	(24.38)
July	7.214***	6.873***	6.802***	16.98***	15.92***	17.40***	323.5***	374.7***	311.5***
	(0.290)	(0.228)	(0.381)	(0.341)	(0.248)	(0.266)	(17.17)	(21.47)	(21.86)
August	7.318***	7.533***	6.671***	16.73***	16.09***	16.99***	251.5***	287.4***	248.7***
	(0.290)	(0.246)	(0.376)	(0.341)	(0.225)	(0.474)	(17.17)	(20.38)	(19.12)
September	7.159***	7.441***	6.702***	15.73***	14.90***	16.92***	262.5***	277.9***	264.9***
	(0.290)	(0.227)	(0.352)	(0.341)	(0.278)	(0.264)	(17.17)	(18.48)	(18.43)
October	6.494***	6.653***	5.859***	11.91***	11.19***	12.47***	106.5***	128.3***	109.2***
	(0.290)	(0.230)	(0.360)	(0.341)	(0.390)	(0.336)	(17.17)	(16.24)	(15.56)
November	4.131***	4.798***	4.080***	6.006***	6.012***	6.498***	3.816	5.224	10.78***
	(0.290)	(0.266)	(0.422)	(0.341)	(0.316)	(0.305)	(17.17)	(3.248)	(3.955)
December	0.563*	1.829***	0.269	1.755***	2.069***	1.890***	-2.163	0.755	2.959
	(0.290)	(0.334)	(0.359)	(0.341)	(0.278)	(0.311)	(17.17)	(3.402)	(3.406)
Time trend	0.0312***	0.00108	0.00915*	-0.00368	0.0238***	0.0171***	-0.480*	0.0314	-0.497*
	(0.00419)	(0.00537)	(0.00521)	(0.00491)	(0.00427)	(0.00481)	(0.248)	(0.280)	(0.287)
Constant	27.00***	27.86***	28.01***	7.314***	7.430***	6.057***	22.07	6.521	18.22**
	(0.230)	(0.209)	(0.386)	(0.270)	(0.224)	(0.252)	(13.63)	(7.217)	(7.383)
Observations	588	588	588	588	588	588	588	588	588
R-squared	0.869	0.760	0.816	0.930	0.934	0.932	0.668	0.663	0.590

Note: Author's analysis based on time series climate data for the period 1964-2012
Standard errors in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Appendix E

Multinomial logit model summary

Table E.2: MNL model fit statistics detail

Test	Statistics
Log-Lik Intercept Only	-3231.564
Log-Lik Full Model	-3013.098
D(1695)	6026.196
LR(84)	436.932
Prob > LR	0.000
McFadden's R^2	0.068
McFadden's Adj R^2	0.035
Maximum Likelihood R^2	0.216
Cragg & Uhler's R^2	0.222
Count R^2	0.289
Adj Count R^2	-0.002
AIC	3.465
AIC*n	6236.196
BIC	-6678.747
BIC'	192.694

Note: Author's analysis based on farm level secondary data for the rice production period 2011-2012