UNIVERSITY OF Hull

A Farm Level Study of the Impact of Climate Change on Agriculture and Farmers' Adaptation in Bangladesh

Thesis submitted for the degree of Doctor of Philosophy

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Dedication

To my father Md Tariful Islam and my mother Mrs Anowara Begum.

Acknowledgement

This research work is a blessing to me from the Almighty. I thank Allah for giving me the opportunity and strength to complete it (Alhamdulillah).

Completion of this PhD project and writing the thesis has been a challenging journey. I should acknowledge that this work is the result of many individuals' time, energy and resources. During this journey, there were several occasions on which the final destination seemed unattainable to me. As the end is in sight now, I am expressing my deepest gratitude to those whose support, encouragement and guidance helped me throughout these years.

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Abbreviations and Acronyms

ADB	Asian Development Bank
BBS	Bangladesh Bureau of Statistics
BER	Bangladesh Economic Review
CO_2	Carbon Dioxide
CR	Compass and Rope
CV	Coefficient of Variation
DAE	Department of Agricultural Extension
DSSAT	Decision Support System for Agro-technology Transfer
EM-DAT	Emergency Event Database
FSU	Fourth Stag Units
FY	Fiscal Year
GDP	Gross Domestic Product
GoB	Government of Bangladesh
GPS	The Global Positioning System
IPCC	Intergovernmental Panel on Climate Change
LFS	Labour Force Survey
Mm	Millimetre
MoA	Ministry of Agriculture
NGO	Non-Governmental Organizations
NR	Net Revenue
^{0} C	Degree Celsius
^{0} ′	Degrees and Minutes
PPP	Purchasing Power Parity
PSU	Primary Stage Units

Q	Yield/Quantity of Production
RMG	Ready-made-garment
SAAO	Sub Assistant Agricultural Officer
SD	Standard Deviation
SR	Self-reported
SSU	Secondary Stage Units
TC	Total Cost
Tk.	Taka (Currency of Bangladesh)
TSU	Tertiary Stage Units
UAO	Upazila (sub-district) Agricultural Officer
UK	United Kingdom
US	United States
USA	United States of America

Abstract

This research investigates the impact of climate change on agriculture and farmers' adaptation in a setting of a developing country. Empirical investigation is based on first hand survey data collected from rice farms situated in different climatic zones across Bangladesh.

This thesis is composed of seven chapters. Chapter 1 discusses the background and motivation, aims, scope and rationale for choosing Bangladesh as the context for this research. A brief overview of the Bangladesh economy, its agriculture and the climate change situation from the historical perspective is contained in Chapter 2. Chapter 3 describes in detail the data collection procedure and some basic statistics of the data.

Chapter 4 explores the impact of climate change (changes in temperature and rainfall) on cost, yield and net revenue of rice farms. While previous studies only explored the impact either on net revenue (Ricardian approach) of farms or on the yield (Production function approach) of a crop, this chapter explores the impact of climate change on cost of production as well as on yield and net revenue. Therefore, this study adds to the existing literature by providing a fuller picture regarding the impact of climate change on agriculture from a micro perspective.

To see how farmers' make adaptation decisions in response to perceived climate change, Chapter 5 investigates farmers' perception of climate change and its determinants. Findings here add to the existing limited literature to understand farmers' perception and the factors that influence perception.

Chapter 6 then analysed farmers' adaptation strategies so far taken, the barriers they face and the determinants of adaptation decisions. Moreover, for the first time in the literature this study examines the determinants of overcoming obstacles related to different adaptation strategies for the facilitation of farm-level adaptation in developing countries.

Finally, Chapter 7 concludes the thesis with a summary of findings with relevant policy recommendations, the contribution of this research and some possible directions for future research.

Chapter 1: Introduction

1.1 Introduction

Climate change and its impact on the agricultural sector is one of the major concerns in the world today. To reduce the effect of climate change, farmers need to recognise the characteristics of the changes that are taking place and respond accordingly through appropriate adaptation strategies. This thesis presents an empirical investigation on the impact of climate change on agriculture and farmers' adaptation in the setting of Bangladesh, a developing country. Empirical investigation presented here is based on primary survey evidence collected in 2015-16 from rice farms situated in all climatic zones across the country.

In this chapter, the background to, and motivation for, this thesis are described in Section 1.2. The section introduces scientific knowledge concerning climate change, its impact on agriculture in general and particularly on developing countries, and the adaptation of farmers to climate change. The focus of this study is presented in Section 1.3, followed by the aims in Section 1.4. The rationale for choosing Bangladesh as the context for this research is discussed in Section 1.5. The chapter ends with an outline of the thesis giving a brief description of each chapter.

1.2 Background and Motivation of the Study

1.2.1 Climate Change

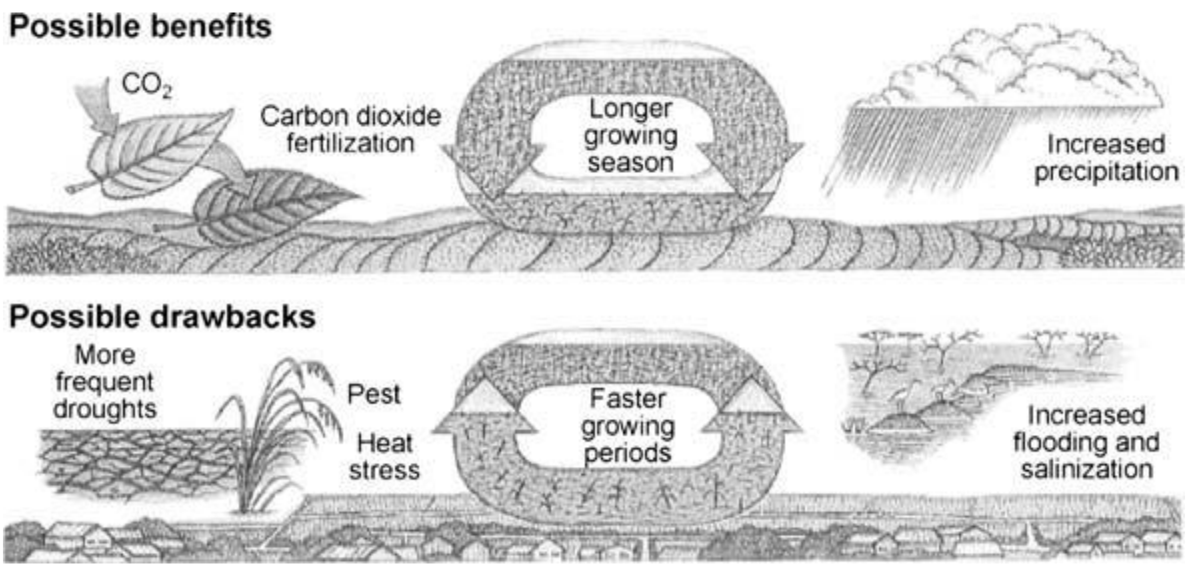
The climate of a region is its weather, especially that characterised by temperature, clouds, precipitation, humidity and wind, averaged over a long period of time (NASA, 2011). In this respect, climate change refers particularly to the changes in temperature and precipitation over a long period. Scientific evidence indicates that the global climate has altered considerably over the last century (IPCC, 2007), which is one of the major concerns for the global community today.

The global mean surface temperature has risen over the last century and the trend has increased since the mid-20th century (IPCC, 2014a). Daily temperature extremes are more frequent and intense since the middle of the last century. It is also predicted that the global surface temperature will increase by a further 2.6-4.8^0 C by 2050-2100 relative to 1986-2005 (IPCC, 2013). Because of increases in global temperature, the ice sheets of Greenland and the Arctic are melting, contributing to sea levels rising. The global mean sea level rose by 0.19 metres over the period of 1901-2010 and is expected to increase at a faster rate than observed in the previous century (IPCC, 2014a). Changes in precipitation level have also been observed globally. It is predicted that areas of high latitude and the equatorial pacific will have increases in annual mean precipitation, whereas many low and mid-latitude and subtropical regions will experience reductions in annual mean precipitation (IPCC, 2014a). Apart from the changes in temperature and precipitation, extreme climate events such as heat waves, droughts, floods and cyclones are also projected to be greater in frequency and in intensity in the future (IPCC, 2014a).

1.2.2 Climate Change and Agriculture

The agricultural sector will feel the effect of climate change because of its heavy dependence on the prevailing climate, specifically temperature and rainfall (Rosenzweig & Parry, 1994; Parry et al., 1999; Lobell & Field, 2007). It will alter the availability of water resources, as well as the overall productivity of crop and grazing land, and livestock (IPCC, 2014a). Moreover, extreme events like drought and flood can destroy the whole harvest. Even a slight change in the climate variation may have effects on crop plant growth and yield. However, agriculture may benefit or lose depending upon the nature of the change. Major contributing determinants will include increasing atmospheric carbon dioxide concentration, changes in temperature and precipitation resulting in changes in the growing season, changes in pests and diseases, and changes in extreme events like drought and floods (Figure 1.1).

Figure 1.1: Effects of changing climate on agro-ecosystem



Source: Bongaarts (1994)

The effect of climate change on agriculture is also expected to differ by location depending on the contributing factors. For instance, Phelan et al. (2014) found that the increased temperature and elevated atmospheric CO_2 concentrations are likely to increase regional rainfall and wheat production in Tasmania. In contrast, Uleberg et al. (2014) found that northern Norway would face challenges like unstable winters, increased autumn precipitation and possibly more weeds and diseases in future. However, assessing many studies covering a wide range of regions and crops, the latest report of IPCC concludes that the negative impact of climate change on crop yields have been more common than the positive impacts (IPCC, 2014a). Overall, the biophysical shocks of climate change has been predicted to reduce the global yield of crop production by 17% by 2050 (Nelson et al., 2014).

The adverse effects of climate change on agricultural production are likely to be felt more in the lower latitude countries where most developing countries are situated (IPCC, 2014a). The agricultural sector is often the most important sector for a developing country. It provides the staple to the economy, contributes significantly to GDP, provides employment to a large part of labour force, and contributes to poverty reduction (Hertel & Rosch, 2010). Crops are already grown in those countries at threshold levels of heat and moisture (Fankhauser et al., 2008). Therefore, any change in temperature and precipitation is likely to affect the agricultural production in those countries (Parry et al., 1999; Parry et al., 2004; Mendelsohn, 2008) and, consequently, it will affect the national income and employment in those countries (World Bank, 2013).

1.2.3 Agricultural Adaptation to Climate Change

The scientific and policy communities have recognized that adaptation offers opportunities to reduce the potential negative effects of climate change (IPCC, 2007; 2014b). Adaptation is defined as any adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2014a). In the case of agriculture, the individual producers are the main actors in adaptation (Konrad & Thum, 2014). Therefore, from the farmers' perspective, any action or strategic decision taken at the farm level to reduce the adverse effects or to capture the benefits, in response to the changes in the climate variables, is adaptation to climate change.

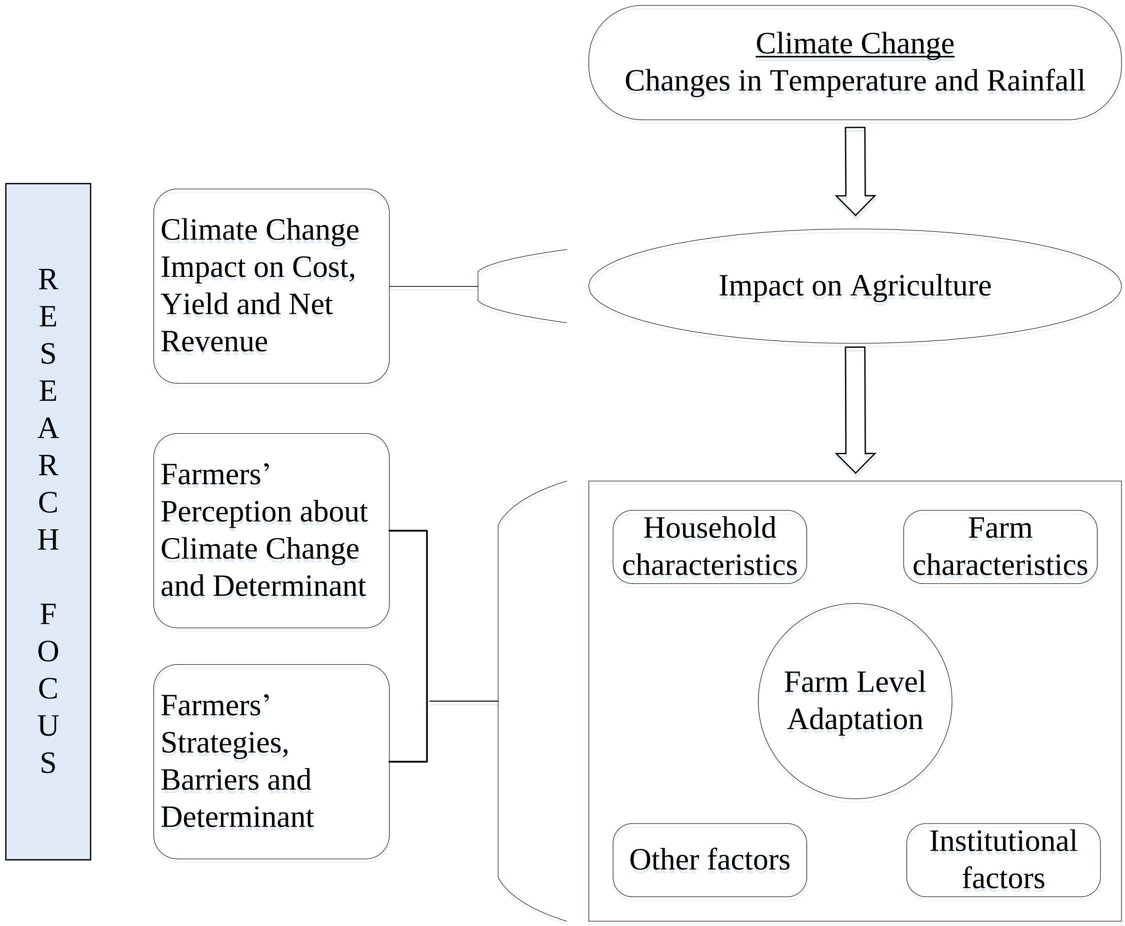
Strategic decisions taken by farmers as adaptation are also place and context specific (IPCC, 2014a). One of the concerns for adaptation is that the scale and interconnectedness of impacts may be different in different places (Adger & Barnett, 2009). Moreover, in developing countries, farmers' capacity to adapt has also been questioned because of their vulnerability to both climate and socio-economic constraints (Mertz et al., 2009a). In addition, adaptation actions already in place may not be sustainable or be maladaptive (Adger & Barnett, 2009). Therefore, from the policy perspective, quantifying the effects of climate change on agriculture, as well as understanding the constraints and opportunities related to farmers' adaptation in a particular context in which adaptation takes place, are important research issues (Adger & Barnett, 2009).

1.3 Focus of the Study

Changes in the climate variables, in particular changes in temperature and rainfall, can affect the agricultural production system in a number of different ways. For instance, changes in rainfall may change the need and use of supplementary irrigation (Pathak et al., 2014); or changes in temperature may change the need and use of irrigation, fertilizer and pesticides. As the input use is changing, so it may affect the cost of production. Therefore, one way to investigate the impact of climate change on agriculture would be explore any changes in the cost of production due to the changes in climate variables (i.e. temperature and rainfall). Another way to investigate the impact of climate change would be changes in crop yield, as the changes in temperature and rainfall may affect the crop plant growth and consequently the yield (Rosenzweig et al., 2001). Moreover, net revenue of the farm may change because of changes in yield and/or costs of production due to climate change. Therefore, another way to see the climate change impact would be the changes in net revenue due to the changes in climate variables. Considering all these, the first focus of this study is to see the effect of changes in climate variables on the cost of production, yield and the net revenue (shown in Figure 1.2).

Economic rationality suggests that adverse impacts will cause farmers to take adaptive adjustments at the farm level, as they want to maximize profits. However, the literature on farmers' adaptation to climate change and the technology adoption suggests that there are several factors that influence adoption decisions (Smit et al., 1996). In this respect, farmers' perceptions about the problem are an important factor that underpins farmers' decision to make any changes in farming practices (Ervin & Ervin, 1982; Maddison, 2007). Therefore, the second area of focus of this research is to explore farmers' climate change beliefs and the determinants of those beliefs, as shown, again, in Figure 1.2.

Figure 1.2 : Research focus of this study



However, there may be determinants that influence the farmer to undertake adaptation to climate change (Deressa et al., 2011; Tessema et al., 2013). In addition, there may be barriers that hinder farmers from undertaking adaptation strategies (Howden et al., 2007; Nielsen & Reenberg, 2010). Moreover, adaptation strategies taken by farmers are place and context specific (Adger et al., 2007; Below et al., 2010). Therefore, the third and final focus of this research is to analyse farmers' adaptation strategies, the barriers they face and factors that influence them to undertake adaptation, as well as the factors that help them to overcome the barriers (shown in Figure 1.2).

1.4 Research Aims

The purpose of this research is to contribute to the growing knowledge on climate change and enhance our understanding of the impact of climate change on agriculture and farmers' adaptation. With this broad aim, this study bases its investigation on Bangladesh, which is one of the most vulnerable countries in the world to climate change. Moreover, the focus is specifically on the rice crop, which is one of the important staples for Bangladesh, as it is in many other countries across the world. The specific aims of this study are:

1. To determine the effects of climate change on cost, yield and revenue of rice production in Bangladesh.
2. To identify Bangladeshi rice farmers' perceptions about climate change and what determines those perceptions.
3. To identify how Bangladeshi rice farmers are adapting to climate change and what determines the nature of that adaptation, including any constraints.

This thesis, therefore, has three important pieces of empirical economic research, each of which addresses one of the aspects mentioned above. The first piece of economic research investigates the impact of climate change by estimating the sensitivity of cost, yield and revenue of rice farms to temperature and rainfall. The second and third pieces of economic research are related to adaptation, which is essential to reduce the impact of climate change. What differentiates them is that the second piece of research focuses on farmers' perceptions regarding climate change, which will clearly influence them in taking adaptation decisions. The third piece of research investigates several aspects of farmers' adaptation, including the adaptation strategies they have so far taken, the barriers they face while taking adaptation, and the determinants of their adaptation decisions. These three areas of research are based on primary evidence obtained by a survey of Bangladeshi rice farmers undertaken by the researcher in 2015/16, and secondary evidence collected from key Bangladeshi agencies at that time.

Bangladesh is traditionally an agricultural country where agriculture consists of both crop and non-crop agriculture. Crop agriculture mainly consists of production of rice, wheat, and pulses, while non-crop agriculture comprises livestock, fishery and forestry. Crop agriculture is the main part in terms of agricultural contribution in the GDP as well as absorbing the labour force of the country. In the crop sector, among all the crops, rice is the main crop grown in the country. Rice is the staple food of most Bangladeshi people also. Rice farming covers about 77% of the total cropped area consisting of about 13.9 million hectares (BBS, 2011). Therefore, with this research focussing on rice farming, it is contributing to the research on a key crop in Bangladesh.

There are three varieties of rice grown in Bangladesh: Aman, Boro, and Aus. Among these three, Aman and Boro are the two main crops, while Aman rice is grown all over the country, covering more areas in the growing period. Moreover, Aman is a rain-fed monsoon crop, while Boro is completely dependent on irrigation. Rain-fed crops are likely to be affected more in the face of climate change, due to the reduction of rainfall as well as temperature increase. For the analysis of the impact of climate change, this research has particularly focused on Aman rice. With this focus, this research provides a rich understanding of the Aman rice farmers' adaptation issues.

1.5 Rationale for Choosing Bangladesh as the Context of this Study

This research intends to contribute to the literature of climate change impact on agriculture and farmers' adaptation in developing countries. For that reason, a developing country, Bangladesh, is purposely selected because of its vulnerability to climate change due to its geographic location and socio-economic conditions (World Bank, 2013). Along with vulnerability to temperature and rainfall changes, the country is vulnerable to natural disasters like floods, drought, sea level rise, storm surge and cyclones (Rawlani & Sovacool, 2011). It faced 174 separate natural disasters between 1974 and 2003 (Reid et al., 2007) and such events are projected to get worse in future (Dasgupta et al., 2011). With a small land area of 147,570 sq. km it has 162.9 million population, making it one of the most densely populated countries in the world (World Bank, 2016a). Moreover, 74% of her population are living in rural areas and 31.5% of population are living below the poverty line (BER, 2014).

The economy of Bangladesh is highly dependent on agriculture, in which 48% of the labour force are directly involved (BER, 2014). Moreover, it provides the staples to the Bangladesh population. Agricultural production is under pressure from both demand and supply sides because of population growth and climate variability. Therefore, quantifying the effect of climate change on agriculture as well as farmers' adaptation are urgent research areas for Bangladesh. Although there are studies on the impact of climate change on agriculture, all of them investigated on crop yield only (Basak et al., 2010; Kobayashi & Furuya, 2011; Sarker et al., 2012; Thurlow et al., 2012; Bala & Hossain, 2013; Sarker et al., 2014). As for research on adaptation issues, some studies are descriptive in nature (Ahmed, 2000; Harun-ur-Rashid & Islam, 2007; Thomas et al., 2013) and some are focused on a specific area (Habiba et al., 2012; Sarker et al., 2013; Alauddin & Sarker, 2014; Alam, 2015). The impact of climate change on agriculture using farm level data sampled across the country as well as farmers' adaptation is absent in the literature for Bangladesh. Therefore, overall, this research will contribute to the expanding literature on the impact of climate change in agriculture and farmers' adaptation for developing countries in general as well as provide an original contribution to the literature for Bangladesh.

1.6 Outline of the Thesis

There are seven chapters in this thesis. Along with the evidence-based description of climate change in Chapter 2 and the description of the farm survey carried out for the purposes of the analysis which is described in Chapter 3, Chapters 4, 5, and 6 are the three main empirical chapters of the thesis containing the economic analysis. Each of these three analytical empirical chapters is written as a standalone paper, having its own literature review, methods and data description, findings, discussion and conclusion. As each of these three chapters is independent of the others, inevitably there are overlaps, for example, in the data description as they are principally using the same source of evidence in the farm survey. A brief outline of each chapter is as follows:

Chapter 2 provides a brief overview of Bangladesh. In this chapter, a brief history of the country is provided along with an account of its geography, and some general features of the economy. A brief overview of the country's agriculture is given, which stresses agriculture's contribution and importance to the economy as well as outlining the extent of government's support for the sector. The situation of natural calamities and their effect on the economy are also briefly described. A key area of coverage in this chapter is climate change in Bangladesh. The climate change situation for Bangladesh as well as the climate variability among different climatic zones within the country is analysed using the last fifty years' of climate data (temperature and rainfall) which was made available by the Bangladesh Meteorological Department. It uses simple statistical tools, like mean, standard deviation, coefficient of variation and trends, to characterise the nature of climate change that has taken place in Bangladesh.

Chapter 3 describes the survey design, study sites and procedure for conducting the farm survey in Bangladesh, the data from which provided the primary evidence used in the research reported in this thesis. Apart from describing the survey procedure, descriptive statistics of the collected data are also presented and discussed. Where national statistics are available, comparison is also made. The collected data consist of a rich set of information related to the socio-economic condition, demography, institutional accessibility, cost and quantity of production for 432 rice farmers from different climatic zones in Bangladesh. In addition, information relating to farmers' perceptions about the changes in climate variables, adaptation strategies they have so far taken, and barriers they face while taking adaptation are included. This data set forms an original contribution resulting from this research effort.

In Chapter 4, the impact of climate change on agriculture is explored for a particular rice crop, Aman rice. Analysis is based on examining the relationships between temperature and rainfall, as climate variables, and three different dependent variables: net revenue, yield, and cost of production. Each regression analysis is undertaken separately and is able to measure the effect of temperature and rainfall on the three variables. Along with the whole growth period of Aman rice, climate variables are also considered in accordance with the three important phases of the development of the rice crop: the sowing, flowering and ripening phases. Linear and quadratic specifications of climate variables are explored here also.

Chapter 5 is the second empirical chapter, and here farmers' perceptions of climate change and its determinants are explored. Although it is believed that climate change perception is one of the important factors that influence agents to take mitigation or adaptation decisions, a solid theoretical grounding is missing in the literature. Therefore, before the empirical analysis, a theoretical framework for farmer's adaptation decision is developed, which shows the importance of farmer's perceptions of climate change. Employing the farm level survey data, the empirical study analyses what farmers' are perceiving regarding changes in the climate system. Having identified farmers perceptions, these are then compared with actual climate data to examine their broad correspondence. Finally, the factors influencing farmers' perceptions of climate change are also examined. Using a logit regression model several determinants related to farmers socio-economics variables are identified.

The final empirical chapter is Chapter 6. In this chapter, issues relating to farmers' adaptation decisions are explored. This chapter identifies the adaptation strategies that farmers are pursuing, the barriers that farmers are facing while undertaking adaptation and the factors that are affecting their decisions to adapt. The analysis again employs farm-household level survey data of 432 farmers from seven climatic zones in Bangladesh. Simple probit, Heckman probit and multinomial logit models are applied to examine the determinants of farmers' decisions on adaptation to climate change. This research also investigates whether and to what extent farmers' socio-economic variables play a role in explaining how rice farmers can overcome obstacles relating to adaptation.

Chapter 7 is the concluding chapter of this thesis. In this chapter, a summary of the findings of each chapter is provided. The implications of the findings are then explored, with relevant policy recommendations drawn. The contribution of this research, its limitations and directions for future research are also highlighted.

Chapter 2: The Agriculture and Climate of Bangladesh

2.1 Introduction

The purpose of this chapter is to provide a brief overview of Bangladesh, in which this research is based. Including this introductory section, the chapter consists of eight main sections. In the next three sections a brief history, location and general features of the economy are described. In Section 5, a brief overview of the country's agriculture is given, where agriculture's contribution and importance in the economy as well as government's support for this sector are described. The situation of natural disasters and its effect on the economy is briefly described in Section 6. The climate change situation is shown in the Section 7, followed by the conclusion.

With the exception of the climate change section (Section 2.7), the evidence reported in this chapter is based on reviewing books, journal articles, and government and international development agencies' documentation. The researcher's own analysis is conducted on climate data collected from Bangladesh Meteorological Department. The data and the analytical procedure are described at the beginning of that section.

2.2 Brief History

In 1947 under the abolition of the British colony in India, two countries were formed, partitioning British India based on religion. Two geographically separate regions for Indian Muslims were created, known as East Pakistan (now known as Bangladesh) and West Pakistan (now known as Pakistan). These two parts of Pakistan are separated, more than twelve hundred miles apart by India, a homeland for Indian Hindus. East Pakistan quickly became the subordinate partner in the new country (Lewis, 2011). With the rise of internal economic exploitation and widespread discrimination in the social and political arenas, East Pakistan was compelled to lead an independence movement. East Pakistan achieved independence after nine months of bloody armed conflict and became Bangladesh in 1971. Presently the country is constitutionally enshrines secular parliamentary democratic country.

2.3 Location

Bangladesh is low-lying and located on the largest delta in the world, formed by the alluvial plain of the Ganges and the Brahmaputra rivers (Huq & Shoaib, 2013). It is situated on the Indian subcontinent between India and Southeast Asia. The country is bordered by India in the west, north and northeast, by Myanmar on the southeast, and by the Bay of Bengal in the south (Shown in Figure 2.1). It lies between $20^{0}25'$ and $26^{0}38'$ north latitude and between $88^{0}01'$ to $92^{0}40'$ east longitude. The country borders two different environments because of its location: the Himalayas to the north and the Bay of Bengal to the south. From the climate perspective, the country is situated in the subtropical zone and lies on the Tropic of Cancer.

Figure 2.1 : Maps showing the location of Bangladesh

Source: (Worldatlas, n. d.)

2.4 General Features of the Economy

The area of the country is about 56977 square miles (i.e. 147570 square kilometres). The population was recorded as approximately 149.77 million in the 2011 census (BBS, 2016a) and estimated as 162.9 million in 2016 (World Bank, 2016a). It is the eighth most populous country in the world (Worldometers, 2017) with a population density of 1077 per square kilometre in 2015 (GoB, 2016). Almost 90% of her population is Muslim, about 9% is Hindu and the remainder are Buddhists, Christians, Animist and others. Religion and family lie at the centre of social life offering a framework for general social conduct (Lewis, 2011: 25). Almost all the people of Bangladesh speak one language, Bengali. The people are culturally homogenous and the social order is predominantly patriarchal.

Three-quarters of its population live in rural areas, making Bangladesh a predominantly rural society. Although the contribution of agriculture in GDP is low it absorbs most of the employment (Table 2.1). In the industrial sector, the garment industry is the main contributor, which manufactures ready-made garments mainly for western retailers. Bangladesh is now the world's second largest garment exporter (World Bank, 2016a). The ready-made-garment (RMG) sector accounted for more than 80 percent of total exports in financial year (1 July – 30 June) 2016.

Table 2.1 : Sectoral overview of Bangladesh economy

	Agriculture	Industry	Services
Shares of GDP (%), 2014 **	16.01	30.42	53.57
Shares of employment (%), 2014 **	45.1	20.8	34.1
Labour employed (million), 2013*	26.2	12.1	19.8
Productivity, 2013 ♣ *	0.36	1.33	1.64

Source: * ADB (2017); ** BBS (2016a); ♣ Ratio of sector's shares in GDP and employment

The financial market is also relatively underdeveloped and as a result the economy was not affected by the recent turmoil in emerging markets and developed economies (World Bank, 2016a). Infrastructural conditions are also poor in Bangladesh. According to the *Global Competitiveness Report 2015-16*, among 140 countries of the world it was ranked 107; the overall infrastructure score was 2.6 on a 1-7 scale (World Economic Forum, 2015). The comparative scenario of different infrastructure (like roads, railways, ports and electricity) can be understood from Table 2.2.

Table 2.2 : The Global Competitive Index ranking and scores, 2015-2016

Country	Overall Country Ranking	Scores on				
		Overall Infrastructure	Roads	Railroad	Port	Electricity
Switzerland	1	6.2	5.9	6.6	4.6	6.8
India	55	4.1	4.1	4.1	4.2	3.7
Bangladesh	107	2.6	2.9	2.5	3.6	2.7
Guinea	140	1.8	1.9	1.4	2.9	1.3

Source: World Economic Forum (2015), Ranking out of 140 countries, score on a 1-7 scale, with 7 being the best.

Bangladesh gained low-middle-income country (LMIC) status in 2014 and per capita income was $1,409 in FY2016 (World Bank, 2016a). The GDP growth rate was 7.1% with the inflation rate at 5.9% in the fiscal year 2016 (ADB, 2017). Overall, Bangladesh's GDP per capita is very low compared to developed countries and even low in comparison to other South Asian countries (ADB, 2016).

Table 2.3 : Some basic statistics about Bangladesh economy

	2016
Population, million	162.9*
GDP, current US$ billion	221.0*
GDP per capita, current US$	1409*
GDP growth rate, %	7.1**
Average Annual Inflation, %	5.9**
Government Revenue, % of GDP	9.9**
Government Expenditure, % of GDP	13.0**
Public Debt, % of GDP	27.2**
External Debt, % of GDP	11.7**
Domestic Debt, % of GDP	15.5**
Exchange rate, annual average to the US$	78.3**
Persons per bed in Govt. hospitals	1652***
Persons per registered physician	2628***
Improved drinking water coverage, %	97.9***
Improved sanitation facility, %	63.5***
Literacy rate 7+ years, %	63.6***
Unemployment rate, % of LF	4.3****

Source: *World Bank (2016a); **ADB (2017); ***GoB (2016), ****LFS (2013)

Poor governance and growing inequality are the two core problems the Bangladesh economy has faced since its independence (Lewis, 2011). Apart from those, reduction of poverty is the major challenge for the country. According to the international extreme poverty line of $1.90 per day at 2011 Purchasing Power Parity (PPP) the poverty rate in Bangladesh was 18.5% in 2010, the most recent year for which a household survey is available (World Bank, 2016b). According to this estimate, there are around 28 million extreme poor. According to Bangladesh government's calculation using the cost of basic needs method, around 31.5% of population are poor of which 17.6% are extreme poor who cannot even meet their food item cost (shown in Table 2.4).

Table 2.4 : Poverty situation in 2010

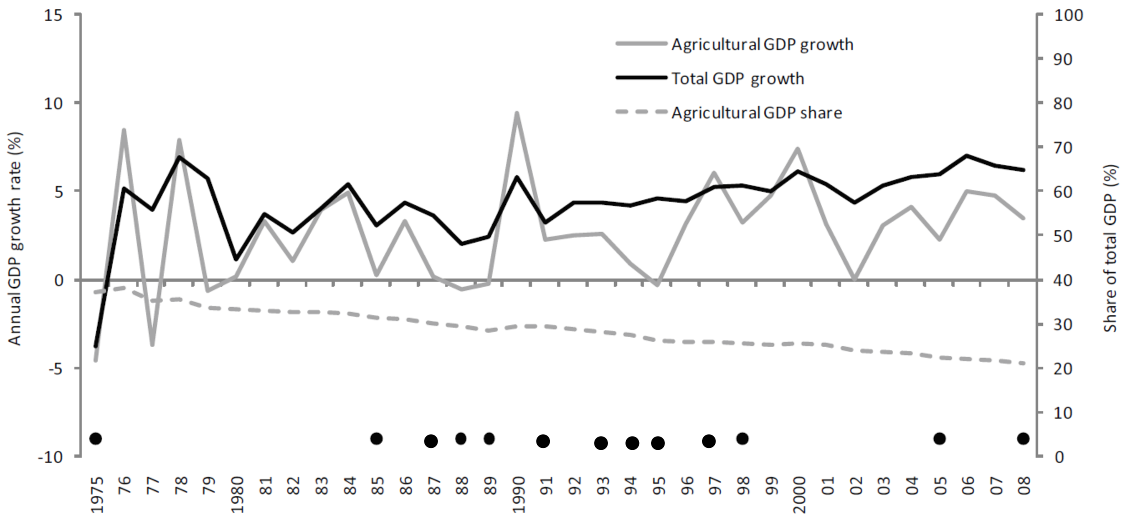
<table>
<tr><th>Poverty line</th><th>Description</th><th colspan="2">Poverty headcount rate (%)</th></tr>
<tr><td>$1.25 in 2005 PPP*</td><td>Monthly TK. 1801 in 2010 prices</td><td>National</td><td>43.3</td></tr>
<tr><td>$ 1.90 in 2011 PPP*</td><td>Monthly TK. 1297 in 2010 prices</td><td>National</td><td>18.5</td></tr>
<tr><td rowspan="3">Bangladesh Government's Upper Poverty Line**</td><td rowspan="3">Using Cost of Basic Needs (CBN) method considering both food and non-food items</td><td>National</td><td>31.50</td></tr>
<tr><td>Rural</td><td>35.20</td></tr>
<tr><td>Urban</td><td>21.3</td></tr>
<tr><td rowspan="3">Bangladesh Government's Lower Poverty Line**</td><td rowspan="3">Using Cost of Basic Needs (CBN) method considering food items scaled at 2122 k. calories per person per day</td><td>National</td><td>17.60</td></tr>
<tr><td>Rural</td><td>21.10</td></tr>
<tr><td>Urban</td><td>7.70</td></tr>
</table>

Source: *World Bank (2016b); **HIES (2010)

2.5 Agriculture in Bangladesh

A huge population with limited land no doubt creates an extremely unfavourable land-labour ratio in Bangladesh. However, Bangladesh is predominantly dependant on its agriculture for its GDP growth. The agricultural sector employs about half of its labour force and contributes close to one-quarter of its total GDP. However, there are year-to-year fluctuations in agricultural contribution in the GDP. This is mainly because of damage to crop production due to the occurrence of various natural disasters, including drought, cyclones and floods. Historical data clearly show evidence of the importance of agriculture in the GDP as well as the negative impact of climate disasters on GDP.

Figure 2.2 : Agricultural and total GDP growth trends, 1975-2008

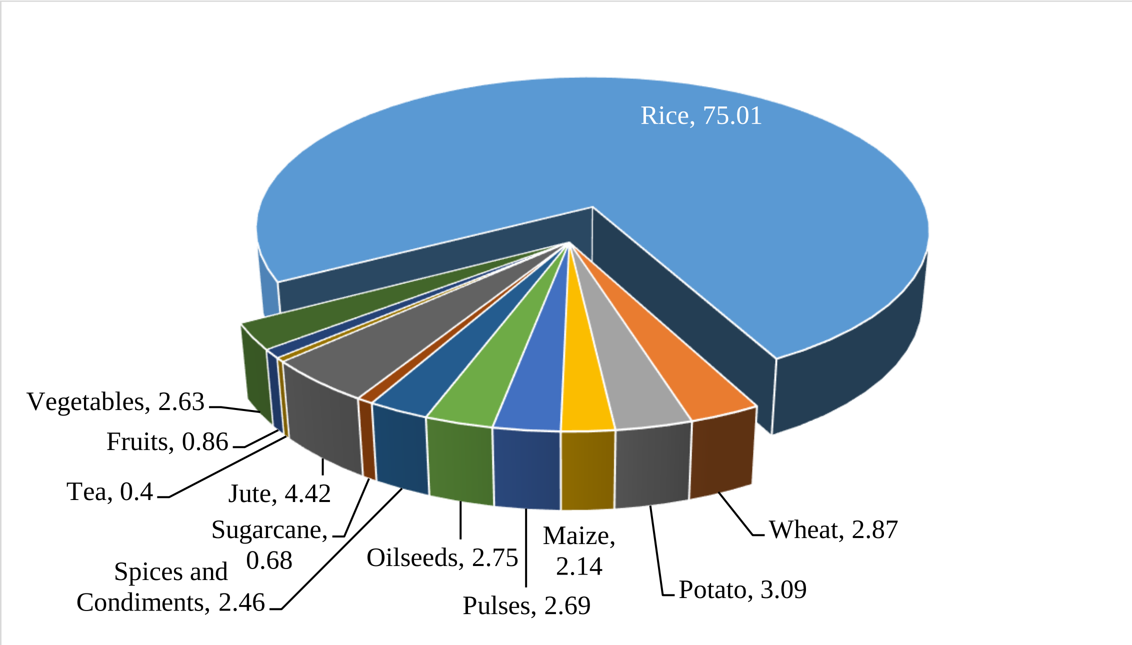


Source: Yu et al. (2010); Black dots represent years where the historical climate data indicate major occurrences of climate disasters including floods, drought and cyclones.

Using data for 1975-2008 Yu et al. (2010) showed that although agriculture's share in the GDP has declined since 1975, agricultural growth fluctuations are the cause contributing to the fluctuations of the GDP growth rate of the country. Moreover, agricultural growth and consequently the total GDP growth decreased in those years when climatic disasters occurred in Bangladesh (shown in black dots in Figure 2.2).

Crops is the major sub-sector of the agricultural sector, comprising about half of the total agricultural GDP (Lewis, 2011). However, fishing is also another important sub-sector for agriculture as well as for the local diet, comprising around a quarter of agricultural GDP (GoB, 2016). Rice is the dominant crop among all the crops grown in Bangladesh. Around three quarters of the country's cropped area is used to grow rice and it is the staple food of the country (Figure 2.3). Being the major component of people's diet, it is vital for the food security of the country and plays a major role in domestic policy related to business and social welfare. That is why Bangladesh is sometimes called a rice economy (Majumder, 2013).

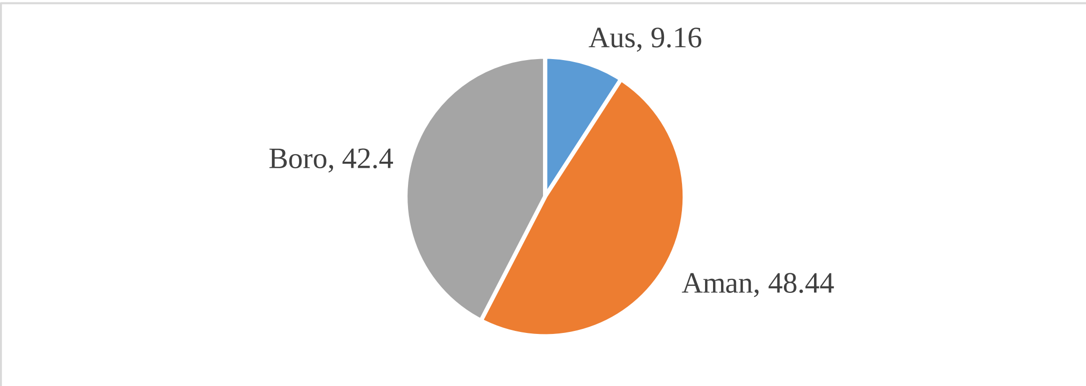
Figure 2.3 : Area under cultivation of different crops in 2014-2015 (percentage)



Source: BBS (2016b)

Three rice crops, locally known as Aman, Boro and Aus, are cultivated. Aman rice is a rain-fed crop grown in the rainy season from July to December. Boro is mainly an irrigated crop, grown from December to May. Aus is also a rain fed crop grown from April to August. Aman rice is the main crops grown widely in Bangladesh, comprising half of its arable land during the growing season (shown in Figure 2.4)

Figure 2.4 : Proportion of different rice varieties in total rice cultivated area in year 2014-15



Source: (BBS, 2016b)

Farmers are using some machinery in their farming, particularly for ploughing and irrigation purposes. The planting and harvesting tasks on farms continue to be undertaken using numerous workers (Alam et al., 2009). Use of other modern technology such as high yielding varieties, chemical fertilizers and pesticides is widespread in farming practices in Bangladesh (Rahman & Thapa, 1999; Rahman, 2002; 2003a).

The country is not self-sufficient in food production as Bangladesh has to import items every year. For example, Bangladesh imported rice equivalent to approximately Taka 42.96 billion which was 1.17% of its total import value in the year 2014-15 (BBS, 2016a).

Overall, the country is facing several constraints in the development of its agricultural sector. The major constraints for the development of agricultural sector are high levels of rural poverty, low agricultural productivity, poorly functioning input and output markets, lack of enabling rural investment climate, weak rural institutions, and last but not least, vulnerability to natural disasters (Alam et al., 2009).

2.5.1 Government's Role in Agricultural Development

For the development of the agricultural sector, the Bangladesh government has a separate ministry named Ministry of Agriculture (MoA). Through its various departments, it is responsible to formulate policy, and plan, administer and monitor different projects for the development of the agricultural sector. Apart from this, the Ministry, especially through the Department of Agricultural Extension (DAE), is responsible for providing direct services to the farmers at the grass root level[1]. Although DAE is the main extension service provider to the country, its effectiveness has often been questioned. Recently, analysing the role of the DAE in a particular project Chowdhury et al. (2014) found that the DEA failed to meet the stakeholders needs.

To support farmers, the government provides agricultural inputs like fertilizer, diesel and electricity for irrigation, and other inputs at a subsidised price. This is the foremost support the Bangladesh government gives to the agricultural sector every year. For the fiscal year (FY) 2016-17 budget allocation was proposed of Tk. 90 billion which is approximately 2.6% of the total budget (MoF, 2016). However, in terms of budget allocation, the Ministry of Agriculture is in eight position among all ministries, with 4.01% (Tk. 136.76 billion) of the total budget allocation for FY 2016-17. Moreover, the share of the Agricultural Ministry in the Annual Development Programme (ADP) was only 1.7%.

[1] The mission of DAE is "to provide efficient and effective needs based extension services to all categories of farmer, to enable them to optimise their use of resources, in order to promote sustainable agricultural and socio-economic development" (DAE, 1999 : 1).

Overall, it can be said that although agriculture is the base of Bangladesh economy it is of relatively low importance to government in the budget.

2.6 Natural Disasters and their Effects on the Economy

Bangladesh is widely recognised as one of the most disaster prone countries in the world. Almost every year it suffers from a range of disasters, some of which are large-scale national disasters and others are local or low intensity disasters. The occurrence of natural disasters causes loss of life, damage to infrastructure and property, and have other adverse effects on lives and livelihoods. The value of economic damage caused by different disasters for the period of 1980-2016 is estimated at around 488 million US dollars per year (Table 2.5). In terms of preparedness and vulnerability of living conditions, through the World Risk Index it is ranked 5th among 171 countries in the world (World Risk Report, 2016).

Table 2.5 : Natural disasters and its effect in Bangladesh from 1980-2016

No. and years of severe drought years	5 (1981, 1982, 1989, 1994, 1995)
No. and years of big floods years	10 (1987, 1988, 1989, 1993, 1998, 2000, 2007, 2014, 2015, 2016)
No. and years of major cyclones/storm years	5 (1985, 1991, 1997, 2007, 2009, 2013, 2015, 2016)
Total	
No. of events	263
No. of people killed	192,768
Average killed per year	5210
No. of people affected	342,725,993
Average affected (per year)	9,262,865
Economic Damage (US $ X 1000)	18,086,500
Economic Damage (US $ X 1000) per year	488,824

Source: BBS (2016a) & EM-DAT (n. d.); Up to 2010 the source is BBS. Data from EM-DAT on different disasters and their effect in the economy for the period of 2011-2016 are added to make it up-to-date.

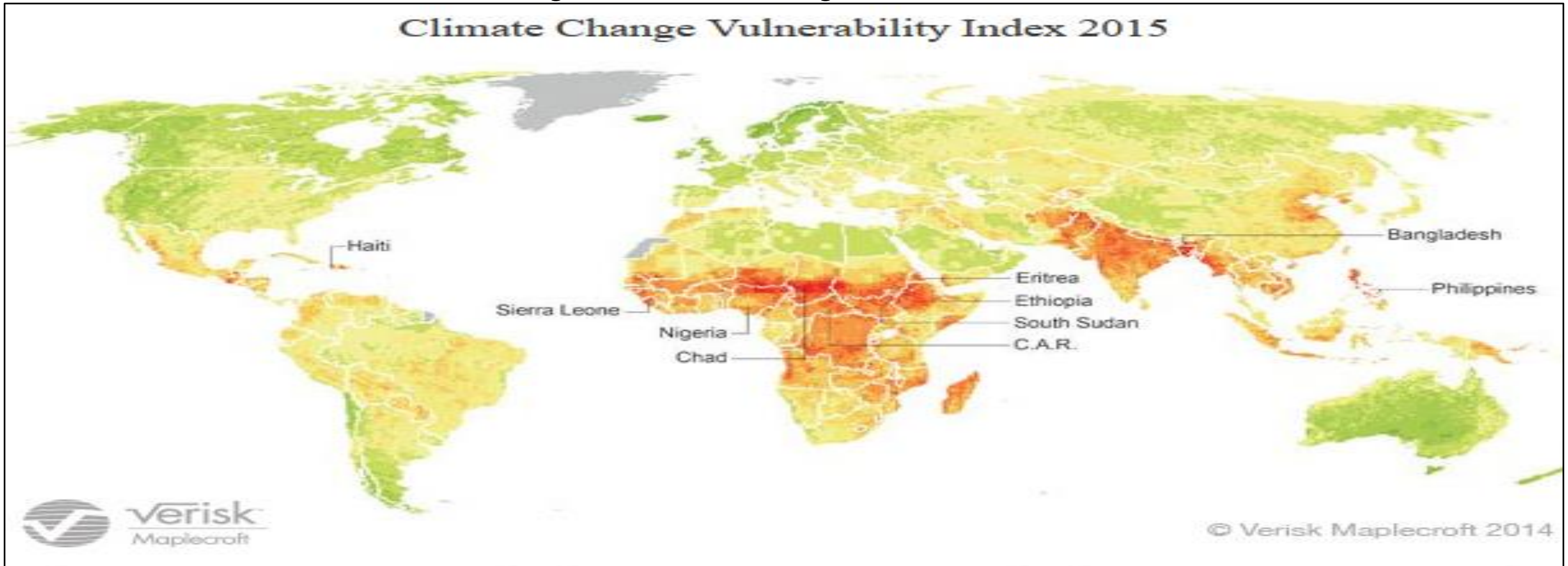
In the face of climate change, the country would likely experience further climatic hazards like drought, floods and cyclones. Current predictions of climate change suggests that drought, floods and cyclones may become more frequent and more severe during the 21st century and cause widespread impacts on the economy (NAPA, 2009). The national adaptation programme of action of Bangladesh government has identified several hazards and their impacted sectors in the face of climate change (Table 2.6). This would seriously affect the country's future food production and poverty situation. According to the *Climate Change Vulnerability Index* (CCVI, 2015), evaluating the sensitivity of populations, the physical exposure of a country and government capacity to adapt to climate change over the next 30 years, Bangladesh is ranked as the most 'at risk' country among 198 countries in the world (shown in Figure 2.5).

Table 2.6 : Hazard impacts, vulnerable areas and impacted sectors

Climate and Related Elements	Critical Vulnerable Areas	Most Impacted Sectors
Temperature rise and drought	• North-west	• Agriculture • Water • Energy • Health
Sea Level Rise and Salinity Intrusion	• Coastal Area • Inland	• Agriculture • Water • Human settlement • Energy • Health
Floods	• Central Region • North East Region • Char land	• Agriculture • Water • Infrastructure • Human settlement • Health • Disaster • Energy
Cyclone and Storm Surge	• Coastal and Marine Zone	• Marine Fishing • Infrastructure • Human settlement • Life and property
Drainage congestion	• Coastal Area	• Water • Agriculture

Source : NAPA (2009)

Figure 2.5 : Climate Change Vulnerable Atlas



Rank	Country	Category
1	Bangladesh	Extreme
2	Sierra Leone	Extreme
3	South Sudan	Extreme
3	Nigeria	Extreme
5	Chad	Extreme

Rank	Country	Category
6	Haiti	Extreme
7	Ethiopia	Extreme
8	Phillippines	Extreme
9	C.A.R.	Extreme
9	Entrea	Extreme

Legend
Extreme Risk
High Risk
Medium Risk
Low Risk
No data

Source: CCVI (2015); The Climate Change Vulnerable Index evaluates the sensitivity of populations, the physical exposure of countries, and government capacity to adapt to climate change over the next 30 years.

2.7 Climate Change and Weather Variability in Bangladesh

Bangladesh generally has a subtropical monsoon climate. Three seasons, namely summer, winter and rainy season, are prominent. Summer begins in March and ends in June, then comes the rainy season from July to October followed by the winter season from November to February (BBS, 2016a). In climatology, long-term precipitation and temperature are used to define climate characteristics of a place (Bunkers et al., 1996). Therefore, climate change can be seen by investigating changes of those variables over a long time.

There are seven climatic zones in Bangladesh (shown in Appendix 1 indicating A-G zones). Weather station data on monthly maximum and minimum temperatures, and total rainfall for those climatic zones was obtained from the Bangladesh Meteorological Department for 50 years (1966-2015). One weather station[2] situated in each zone was carefully selected to capture the maximum variability among the zones as well as to have an average for the country. There is no climate station for zone C, so the data from a nearby weather station was included. The climate change situation in Bangladesh as a whole as well as across the zones are investigated in the next three sections. Several statistics - mean, standard deviation (SD) and coefficient of variation (CV) - are used to identify the change and variability of temperature and rainfall over the period 1966-2015.

2.7.1 Climate Change in Bangladesh

Climate change in Bangladesh is assessed first using the average annual maximum temperature, average annual minimum temperature and average total rainfall. As total 50 years data is there, therefore two periods, 1966-1990 and 1991-2015 (25 years in each), are considered to see the changes in climate. Table 2.7 shows that the mean for both the average annual maximum and minimum temperature has increased over the two periods. Although for both the absolute variability (SD) decreased, the decrease in relative variability (CV) is more for the minimum temperature. The increase in temperature with a decline in variability suggests a more stable, warming climate. In contrast, the mean for average annual total rainfall has declined with both the absolute variability and relative

[2] The weather stations associated with zones are: for A (South-eastern zone) Noakhali, for B (North-eastern zone) Sylhet, for C (Northern part of the northern zone) Rangpur, for D (North-western zone) Bogra, for E (Western zone) Rajshahi, for F (South-western zone) Jessor, and for G (South-central zone) Dhaka.

variability in rainfall over those two periods. All this evidence suggests that there has been a change in the climate of Bangladesh over the last 50 years.

Table 2.7 : Climate change in Bangladesh over 1966-2015

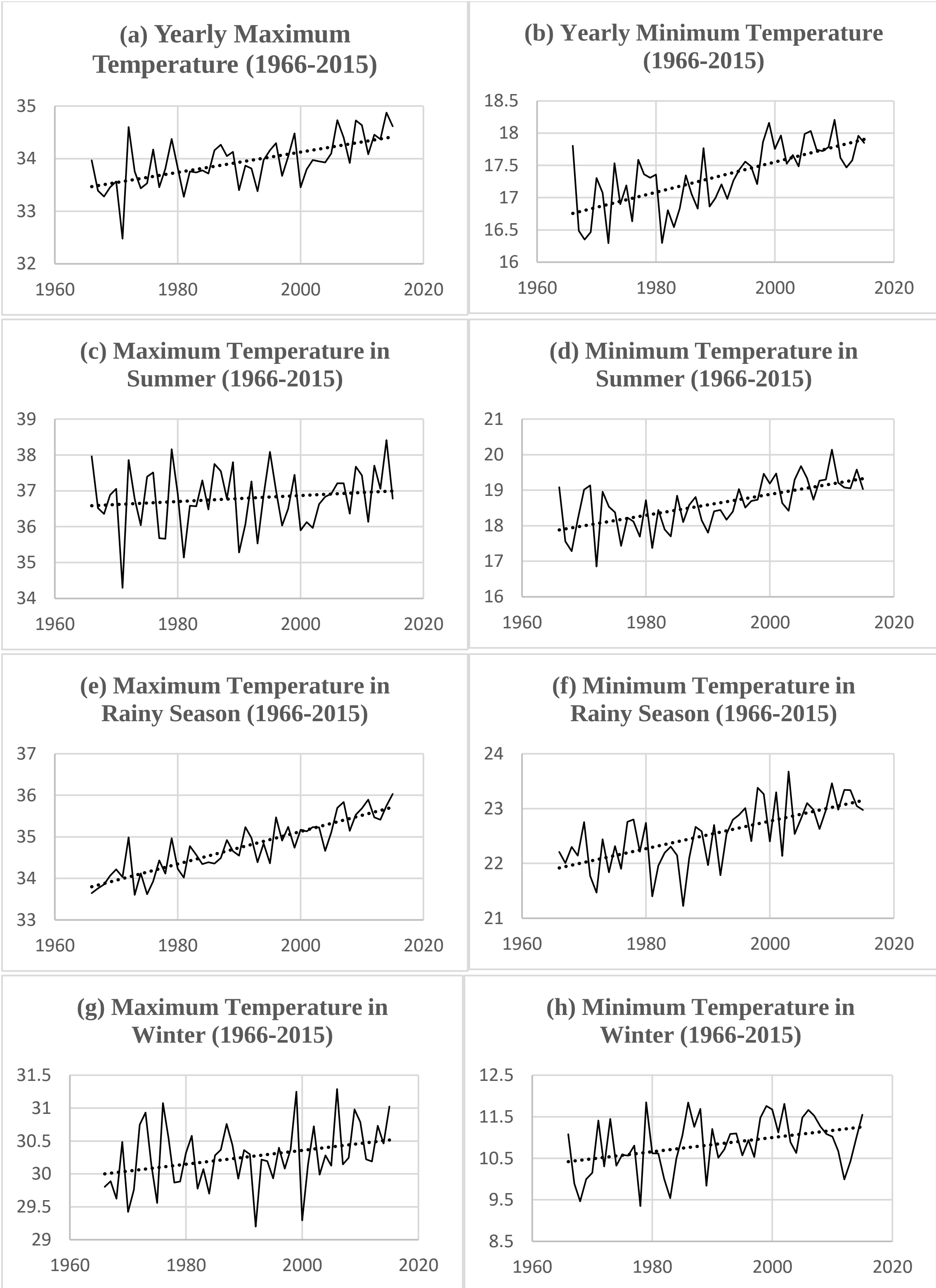
Major climate variable	Statistical tool	1966-1990	1991-2015
Average annual maximum temperature (^{0}C)	Mean	33.73	34.15
	Standard Deviation (SD)	0.44	0.40
	Coefficient of Variation (CV) (%)	1.31	1.17
Average annual minimum temperature (^{0}C)	Mean	16.99	17.66
	Standard Deviation (SD)	0.45	0.31
	Coefficient of Variation (CV) (%)	2.66	1.75
Annual total rainfall (Millimetre)	Mean	2360	2264.16
	Standard Deviation (SD)	255.75	262.91
	Coefficient of Variation (CV) (%)	10.83	11.61

Source: Author's calculation.

Turning to the seasonal characteristics of the climate, these are shown graphically with the seasonal maximum (or minimum) temperature. Seasonal refers to the overall mean of those months that constitute the season. The maximum and minimum temperature of overall Bangladesh in different seasons and their trend are shown in Figure 2.6. It is seen that both yearly maximum and yearly minimum temperatures have an increasing trend over the period 1966-2015 for the country as a whole (a and b in Figure 2.6). Although both yearly maximum and yearly minimum temperatures show an increasing trend, the increase in minimum temperature is a little steeper than that of the maximum. Consequently, it may produce an increase in average yearly temperature.

Like the annual temperature, for all three seasons, maximum and minimum temperatures also have an increasing trend for the country (c-h in Figure 2.6). It is also seen that, although all three seasons have an increasing trend in both temperatures, but in case of the summer season, the minimum temperature rises more sharply than the maximum one. This means that the rise in summer temperature is less variable (stable and warm). Even in the rainy season, it can be seen that the maximum temperature rises more than the minimum temperature. In the rainy season, rainfall usually causes temperature to fall but here it shows the opposite effect. Moreover, it seems that in the rainy season both maximum and minimum temperature has a faster rate than the other two seasons. Overall, although there is considerable variation from year to year in both maximum and minimum temperature but the evidence suggests an increasing average temperature for the country.

Figure 2.6 : Maximum and minimum temperature over 1966-2015



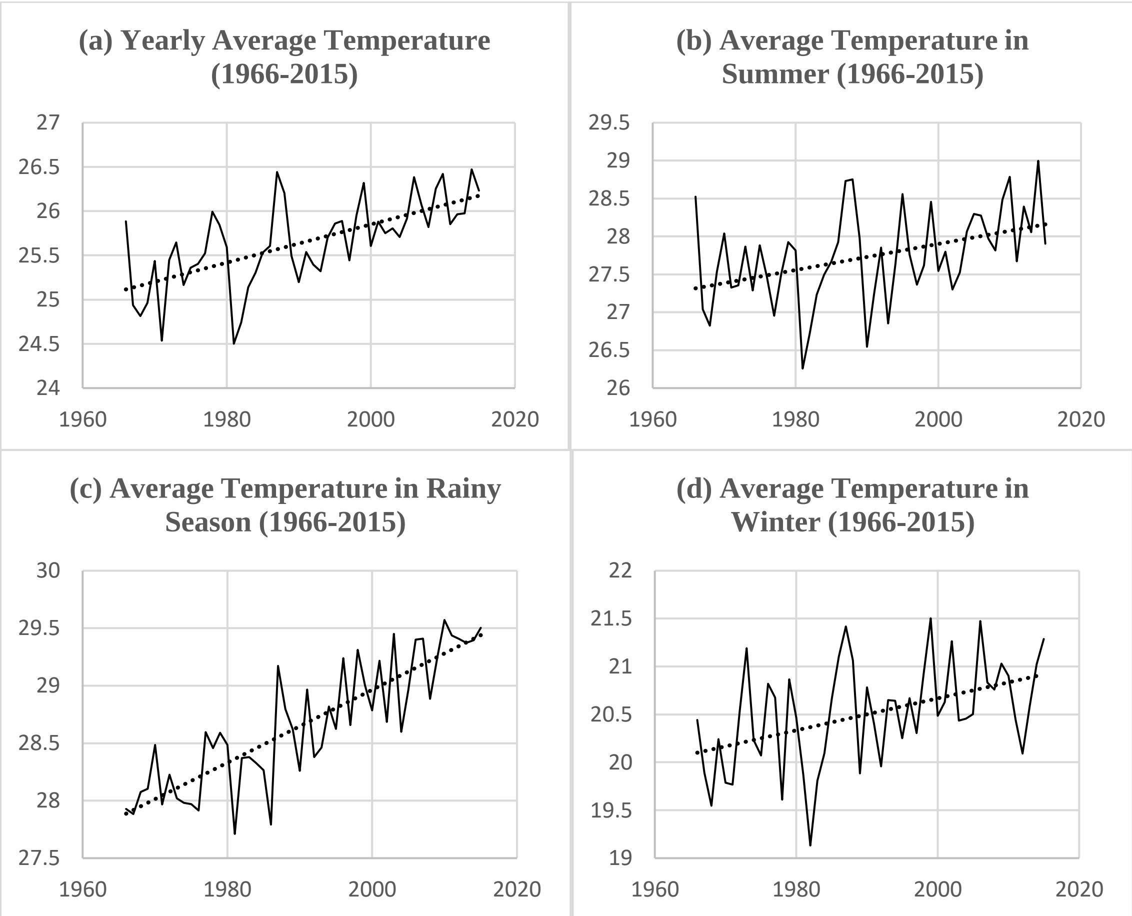
Source: Author's calculation.

Note: These are based on country level maximum and minimum calculated by taking the average of 7 meteorological station data taking each from seven climatic zones in Bangladesh. Figure (a) and (b) is for yearly average whereas (c)-(h) are for seasonal average. For the three seasons the months are considered as: Summer (March-June), Rainy (July-October), Winter (November-February). With some variation, all of these are showing an increasing trend for Bangladesh.

In Figure 2.7, the trends and variability in mean seasonal temperature over the period of 1966-2015 are shown. Monthly mean temperature is calculated from the maximum and minimum temperature. Then the average of this mean over the months that constitute the season is considered as the mean seasonal temperature for that particular season. It is seen that overall, the yearly average temperature has an upward trend (a in Figure 2.7). Although there is a considerable variation over the years, it seems that the variability has decreased over the last 20 years.

It is also evidenced here that although there is a considerable variation in the mean temperature for all three seasons, they have an increasing trend over those periods (b-d in Figure 2.7). This is because the maximum as well as minimum temperature (shown in Figure 2.6) are increasing. It can also be noticed that, although the average temperature has as increasing trend for all three seasons, in the rainy season it is rising at a faster rate than the other two seasons.

Figure 2.7 : Seasonal mean temperature in Bangladesh over 1966-2015

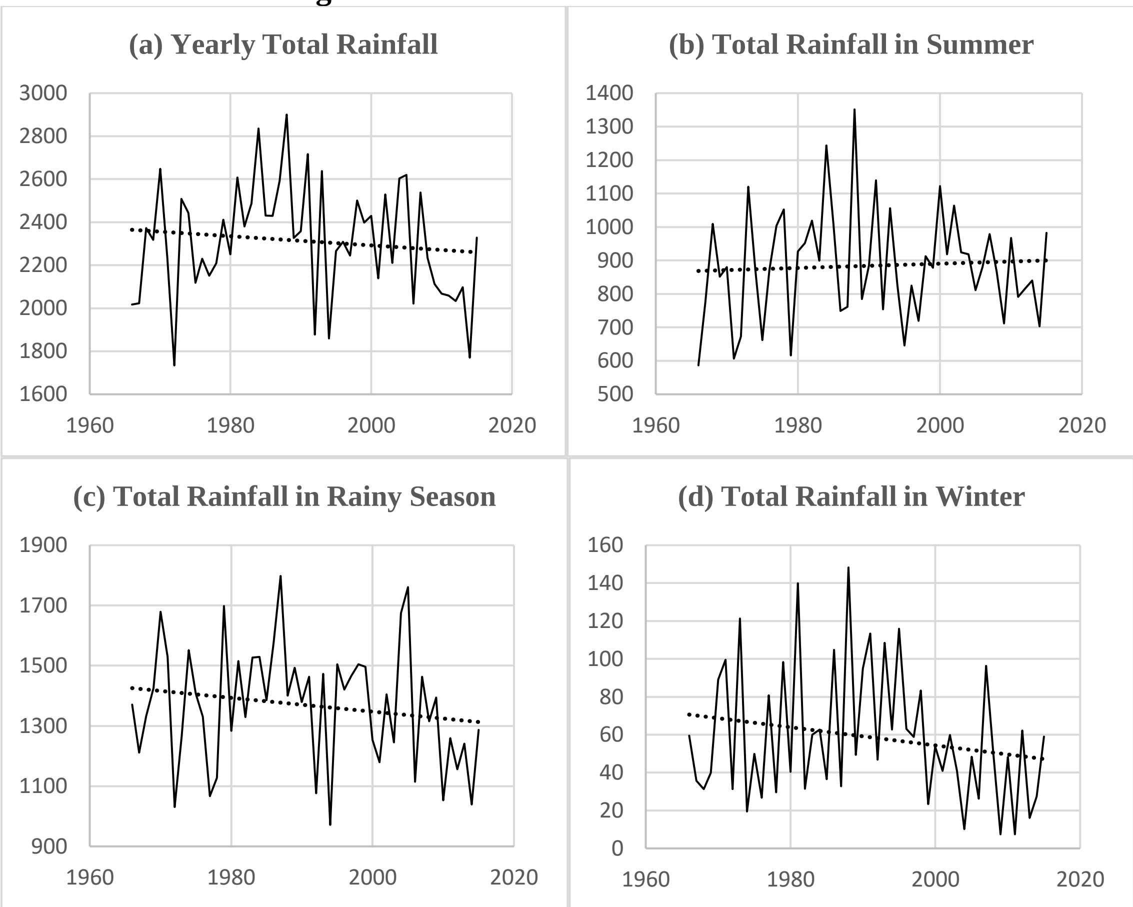


Source: Author's calculation.

Note: These are based on country level average calculated by taking the average of seven meteorological station data taking each from seven climatic zones in Bangladesh. Monthly average is calculated first from monthly maximum and minimum. Then yearly average is calculated from those monthly averages and seasonal average is by considering months of those seasons; for summer (March-June), rainy season (July-October), and winter (November-February). All of these shown an increasing trend over the last fifty years.

The total rainfall situation over the 1966-2015 period is shown in Figure 2.8 from yearly as well as different seasonal perspectives. The yearly total is the aggregation of all month’s total rainfall in that year. Similarly, the seasonal total is the aggregation of all the months that constitute that particular season. It is observed that the total rainfall in both rainy season and winter have a decreasing trend, whereas in summer it shows a slight increasing trend. Although there is again, considerable variability in the rainfall over those periods, overall, the yearly total rainfall shows a declining trend (a in Figure 2.8).

Figure 2.8 : Total rainfall over 1966-2015



Source: Author’s calculation.

Note: These are based on country level average calculated by taking the average of seven meteorological station data taking each from seven climatic zones in Bangladesh. For each station yearly total as well as seasonal total is calculated first. Yearly total is calculated by adding total rainfall of all 12 months of that year. Similarly, seasonal total is the total rainfall of those months that constitute a season (for Summer March-June, for Rainy season July-October, and for Winter November-February. Overall, the rainfall situation shows a decreasing trend over the last fifty years.

2.7.2 Climate Variability at Different Climatic Zones in Bangladesh

Climate variability is analysed here for each climatic zone, again using simple mean, standard deviation (SD) and the coefficient of variation (CV) in maximum and minimum temperatures, and total rainfall among the different climatic zones in Bangladesh. The yearly variability for the zones in terms of both temperature and rainfall are shown. Then for each climate variable, the variability among the individual zones is analysed.

Table 2.8 : Inter-zone climate variability for the period 1966-2015

Climatic zone	Yearly mean maximum temperature (^{0}C)			Yearly mean minimum temperature (^{0}C)			Yearly total rainfall (Millimetre)		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
A: South-eastern	33.24	0.68	2.03	18.37	0.71	3.88	3080	508	16
B: North-eastern	33.54	0.77	2.28	17.24	0.93	5.40	4068	636	16
C: Northern part of North	33.19	0.56	1.70	16.56	1.11	6.68	2175	483	22
D: North-western	34.19	0.61	1.77	17.35	0.99	5.73	1734	377	22
E: Western	34.73	0.87	2.50	16.71	0.76	4.53	1482	325	22
F: South-western	34.90	0.69	1.98	17.04	0.80	4.71	1643	328	20
G: South-central	33.78	0.61	1.80	18.03	0.81	4.49	2046	410	20

Source: Author's calculation.

Table 2.8 shows the variation among the descriptive statistics for different climate variables across the different regions. The Western and South-Western zones have the highest mean maximum temperatures. The absolute variability (SD as 0.87) as well as relative variability (CV as 2.5) in western zone are also high. In contrast, the northern part of the north zone has the lowest maximum temperature as well as lowest absolute variability (SD as 0.56) and relative variability (CV as 1.70). Again, the Northern part of the North zone has the lowest mean minimum temperature as well as the highest variability. In terms of yearly average total rainfall, the Western zone is the driest one, whereas the North-Eastern zone is the wet zone. The mean of yearly average rainfall is more than double in the North-Eastern zone compared to the dry western zone. Although rainfall variability is highest in the north-eastern zone, it is lowest in the Western zone.

It is observed in Table 2.9 that the Western and South-Western zones have experience highest maximum temperature in summer, whereas the North-Eastern zone has the lowest. Similarly, both of them have the highest and lowest absolute variability respectively. The variation of maximum temperature among the zones is less in the winter season than the rainy season. In the rainy season, the Western and South-Western zones have high mean yearly maximum temperature. Although the South-Eastern zone has the lowest mean in maximum temperature in rainy season, its absolute and relative variability are higher.

Table 2.9 : Inter-zone seasonal maximum temperature variability 1966-2015

Climatic zone	Yearly mean maximum temperature (^{0}C)								
	Summer			Winter			Rainy season		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
A. South-eastern	35.26	0.88	2.5	30.33	0.71	2.34	33.99	0.86	2.52
B. North-eastern	35.16	0.91	2.59	30.33	0.90	2.97	35.06	0.86	2.46
C. Northern part of North	36.04	1.16	3.22	28.82	0.66	2.34	34.76	0.62	1.79
D. North-western	37.27	1.23	3.31	30.30	0.74	2.43	35.01	0.86	2.45
E. Western	39.18	1.48	3.78	30.15	0.69	2.30	35.03	0.85	2.44
F. South-western	38.24	1.42	3.71	31.24	0.77	2.46	35.17	0.72	2.04
G. South-central	36.39	1.19	3.27	30.47	0.75	2.46	34.43	0.75	2.18

Source: Author's calculation.

From Table 2.10, it is observed that the variation in mean minimum temperature among zones is more in summer and winter than in the rainy season. The South-Central zone experiences the highest minimum temperature in summer, whereas in winter it is among the lowest. The relative variability in mean minimum temperature is highest in the northern part of North zone in summer, but in the South-Western zone in winter.

Table 2.10 : Inter-zone seasonal minimum temperature variability 1966-2015

Climatic zone	Yearly mean minimum temperature (^{0}C)								
	Summer			Winter			Rainy season		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
A. South-eastern	19.16	1.31	6.58	12.91	0.98	7.62	22.94	0.92	4.01
B. North-eastern	18.03	0.84	4.63	11.57	0.99	8.59	22.15	0.75	3.38
C. Northern part of North	17.69	1.30	7.35	10.02	0.69	6.93	22.18	1.07	4.82
D. North-western	18.59	1.24	6.70	10.48	1.06	10.09	22.68	0.81	3.57
E. Western	18.35	0.89	4.83	9.53	0.92	9.61	22.43	0.95	4.24
F. South-western	19.02	1.11	5.86	9.67	1.22	12.66	22.44	0.70	3.12
G. South-central	19.35	0.84	4.32	11.78	1.07	9.12	22.93	0.70	3.05

Source: Author's calculation.

From the viewpoint of average total rainfall, the north-eastern zone has highest and the western zone has the least rainfall in both summer and the rainy season (Table 2.11). Although in the winter season there is not much rain in Bangladesh, still there is some variability among the zones in mean total rainfall in winter. Among all the zones, the northern part of North zone has the lowest average total rainfall and the South-Eastern zone has the highest rainfall in the rainy season.

Table 2.11 : Inter-zone seasonal rainfall variability 1966-2015

Climatic zone	Yearly average total rainfall (Millimetre)								
	Summer			Winter			Rainy season		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
A. South-eastern	1076.6	303.0	28.1	84.1	73.9	87.9	1919.5	412.5	21.4
B. North-eastern	1837.4	375.9	20.4	75.1	54.9	73.1	2155.9	460.1	21.3
C. Northern part of North	814.7	264.8	32.5	33.5	25.4	76.1	1326.4	357.3	26.9
D. North-western	615.48	224.4	36.4	40.3	36.1	89.5	1078.3	295.0	27.3
E. Western	471.0	169.4	35.9	45.3	40.3	88.9	966.0	263.5	27.3
F. South-western	568.8	196.5	34.5	70.8	62.1	87.7	1003.6	287.6	28.6
G. South-central	815.8	252.5	30.9	64.7	55.4	85.7	1165.5	308.3	26.4

Source: Author's calculation.

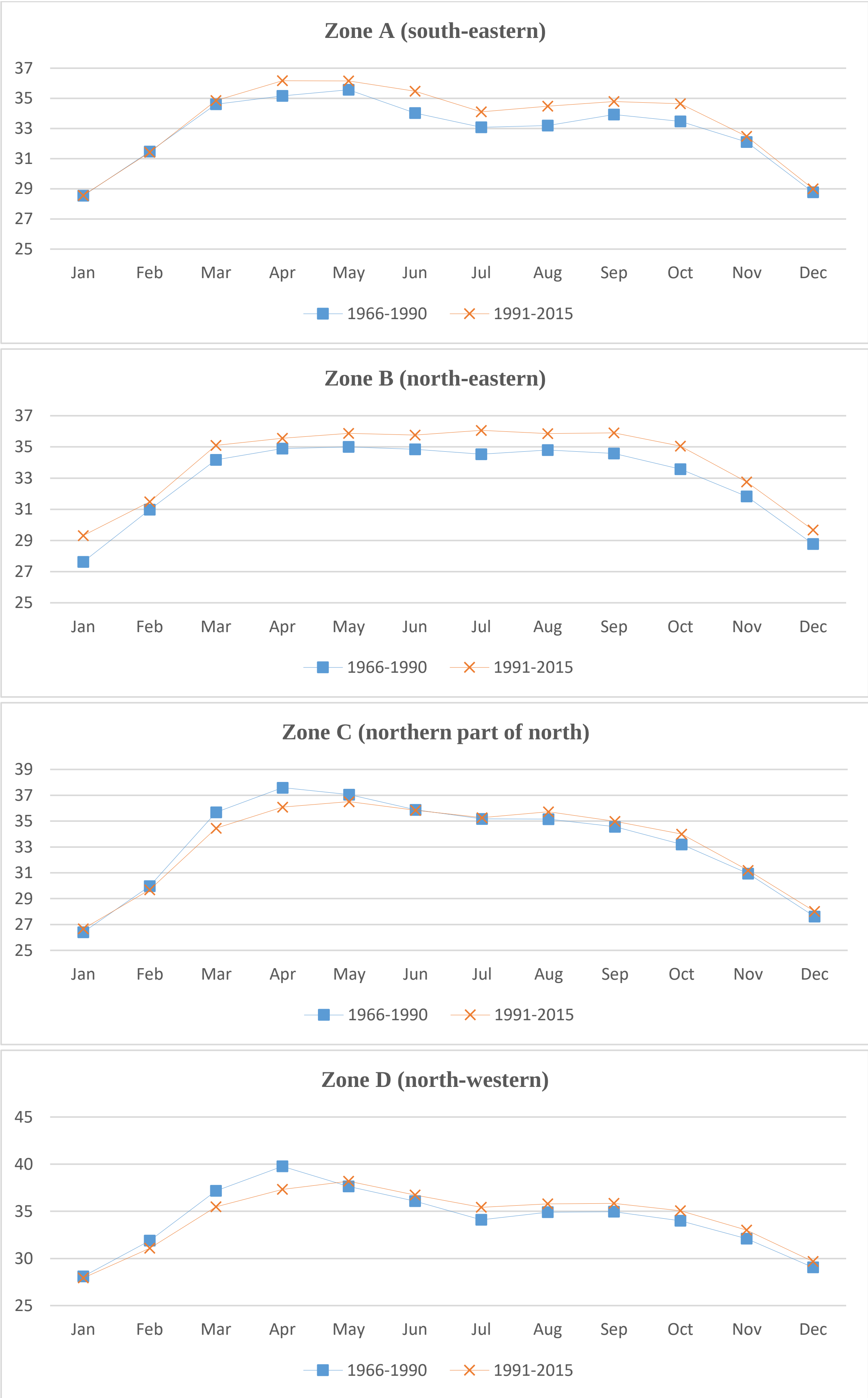
Overall, it is seen that the south-eastern and north-eastern zone are the rainiest, whereas the western and south-western ones have less rainfall, and the rest have moderate rainfall. In terms of temperature, the south-eastern and north-eastern zones are less hot, the western and south-western zones are hot, and the other zones are moderately hot in Bangladesh.

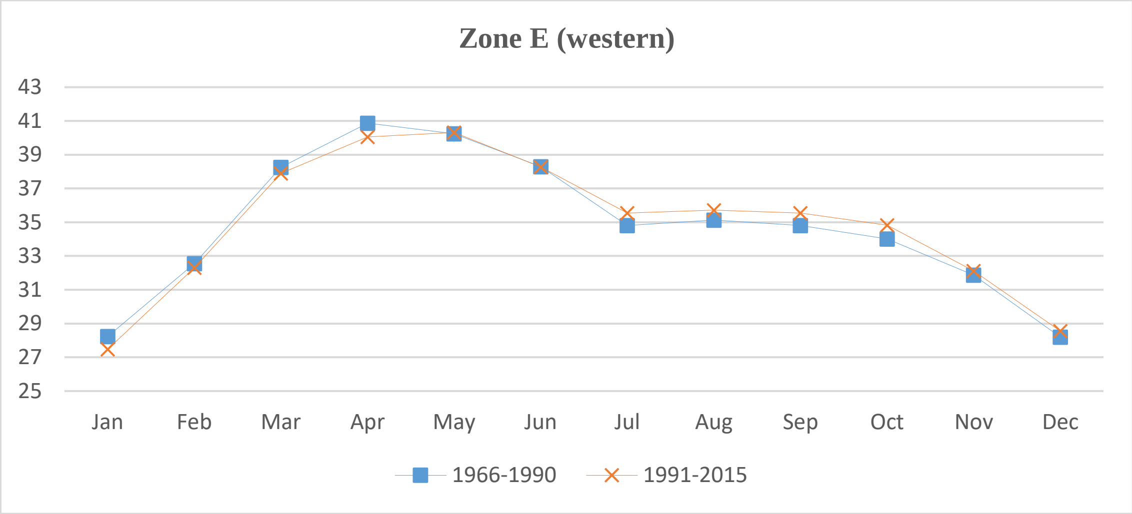
2.7.3 Monthly Changes in Climate in Different Climatic Zones

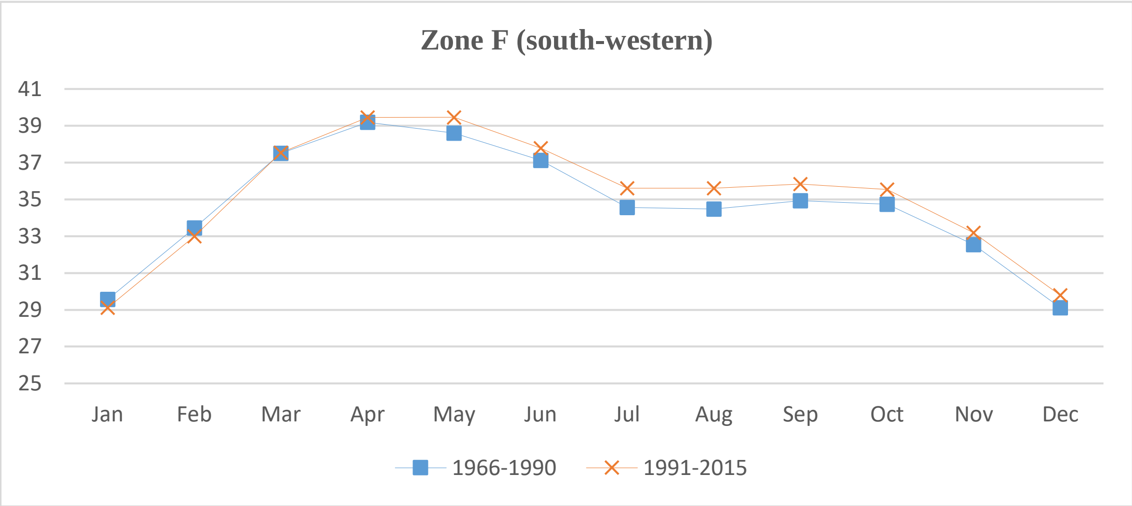
The changes in climatic conditions are analysed here from temporal changes in rainfall, maximum and minimum temperature over the years. The available total 50 years data dividing into two periods (1966-1990 and 1991-2015, 25 years each), average figures across the months for those two periods, changes in the climate across all the zones are analysed here. For the convenience of understanding, a graphical presentation is given for those two periods separately for each climate variable (maximum temperature, minimum temperature and rainfall situation, shown in Figure 2.9, Figure 2.10 and Figure 2.11 respectively).

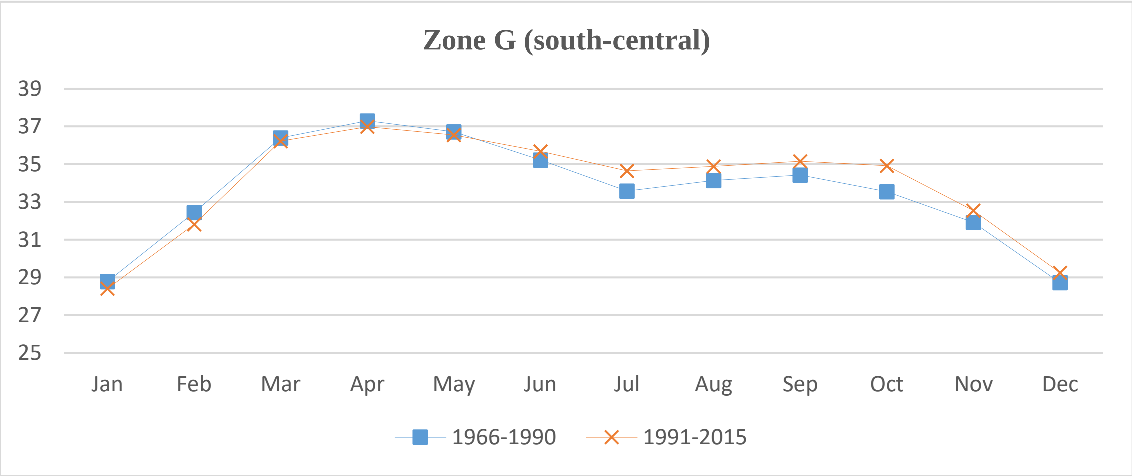
It can be seen from Figures 2.9, 2.10 and 2.11 that the condition of all three climate variables in all the zones have changed over those two periods. The magnitude of changes differs from zone to zone. Moreover, the changes are also different in different months; some months have more changes and some have less. Maximum temperature has increased for almost every month and the increase is more during summer (March-June) and the rainy season (July-October), as shown in Figure 2.9. Minimum temperature has also increased (Figure 2.10). On the contrary, the monthly rainfall has declined and the highest decline is noticeable during the rainy season (July-October), shown in Figure 2.11. Overall, it is seen that temperature has increased, whereas rainfall has decreased from one period to the next.

Figure 2.9 : Changes in monthly average maximum temperature (^0C)





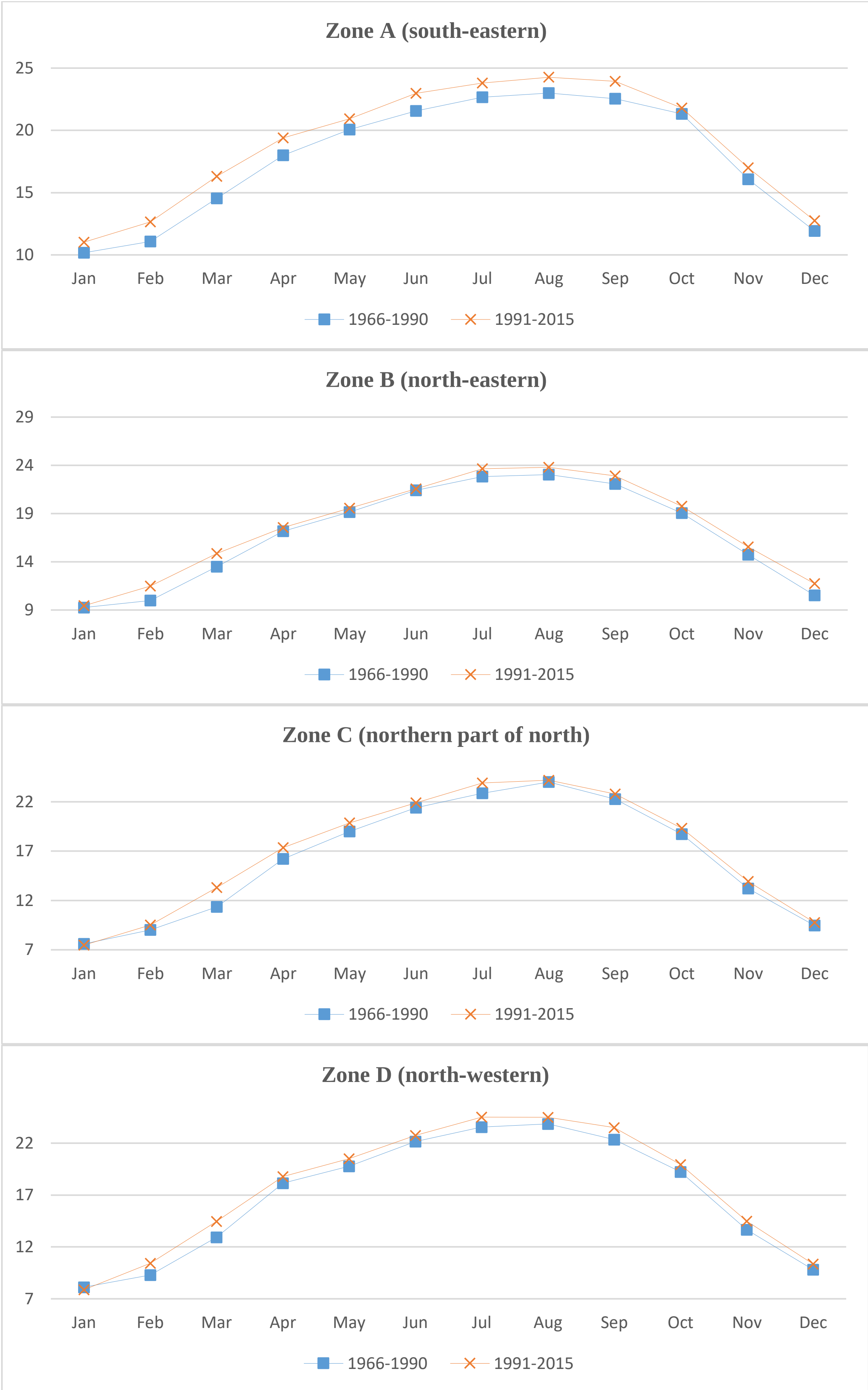


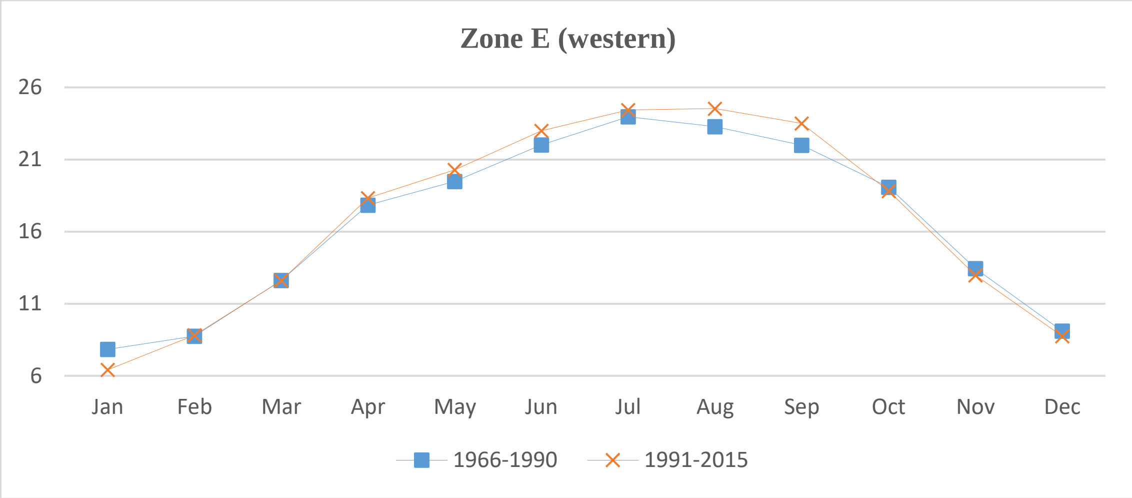


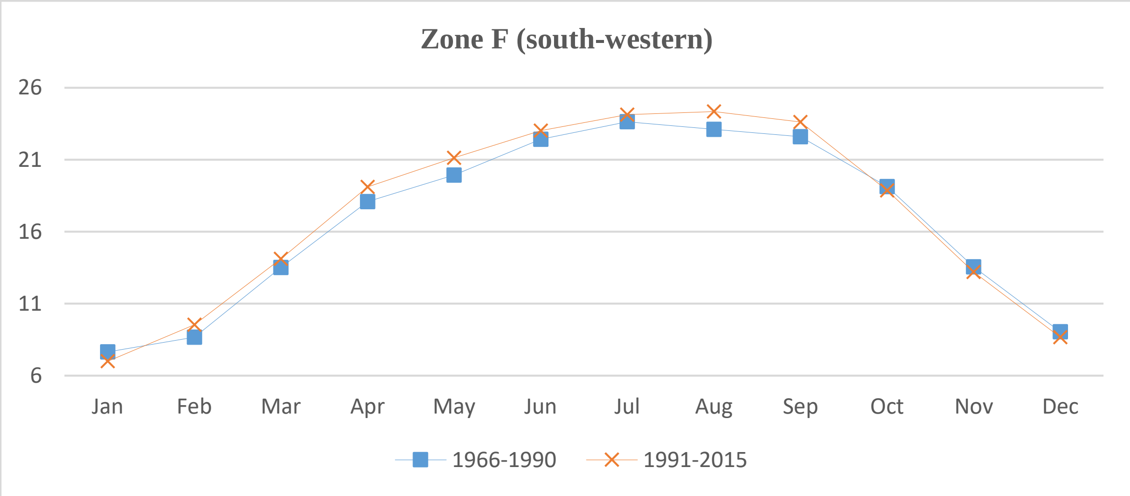
Source: Author's calculation.

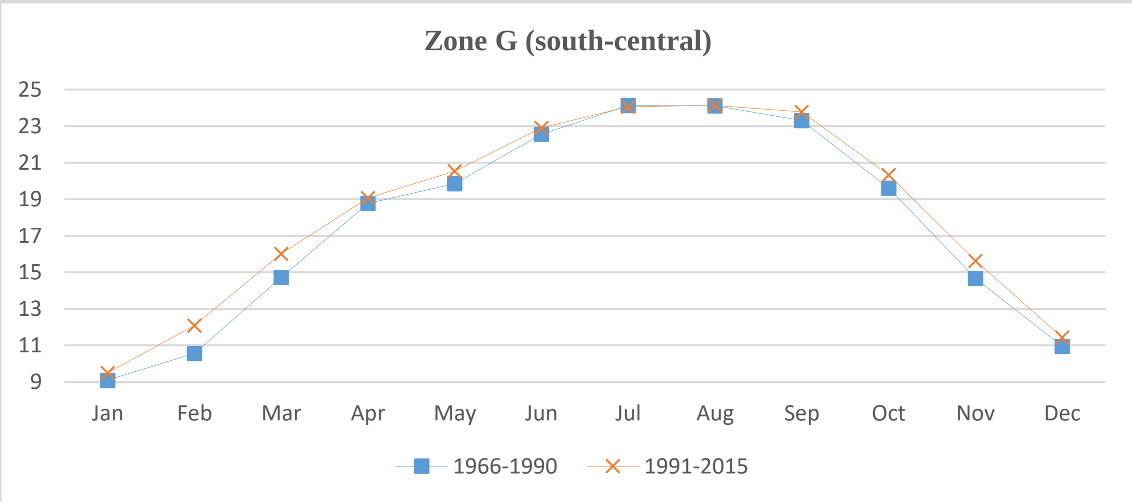
Note: Changes in monthly maximum temperature across seven climatic zones in Bangladesh are shown here. Monthly maximum temperature is averaged for two periods, 1966-1990 and 1991-2015 to see the changes. The magnitude of changes differs from zone to zone. The changes are also different in different months. It can be seen that maximum temperature has increased for almost every month and the increase is more during summer (March-June) and the rainy season (July-October).

Figure 2.10 : Changes in monthly average minimum temperature (^0C)





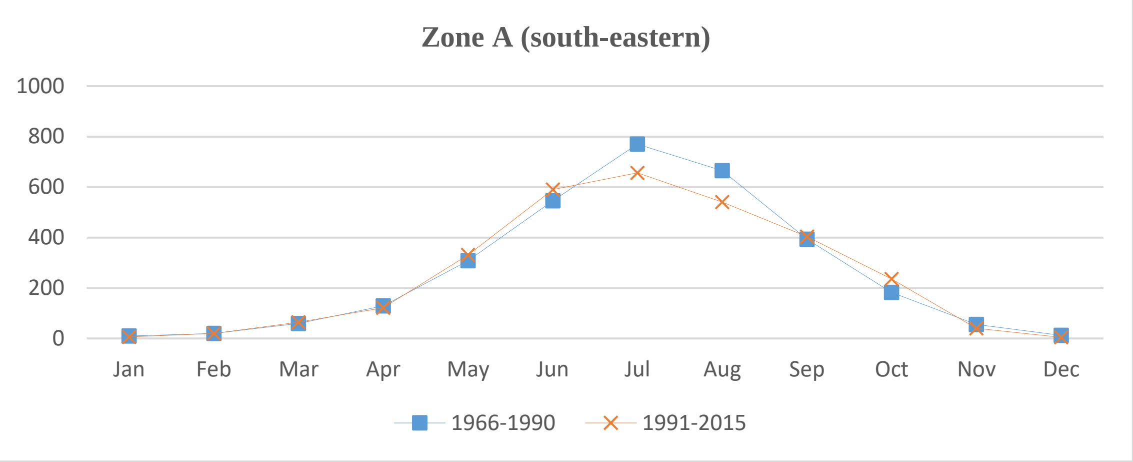


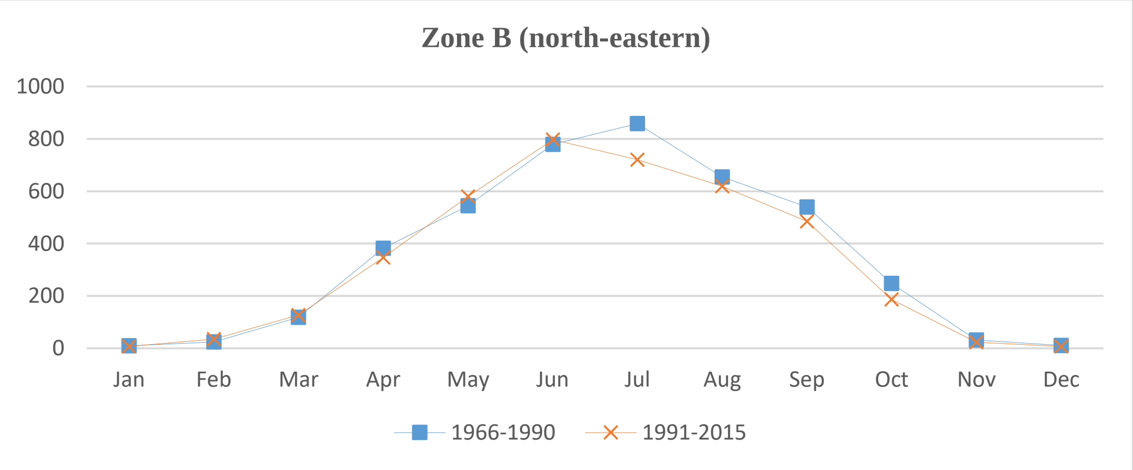


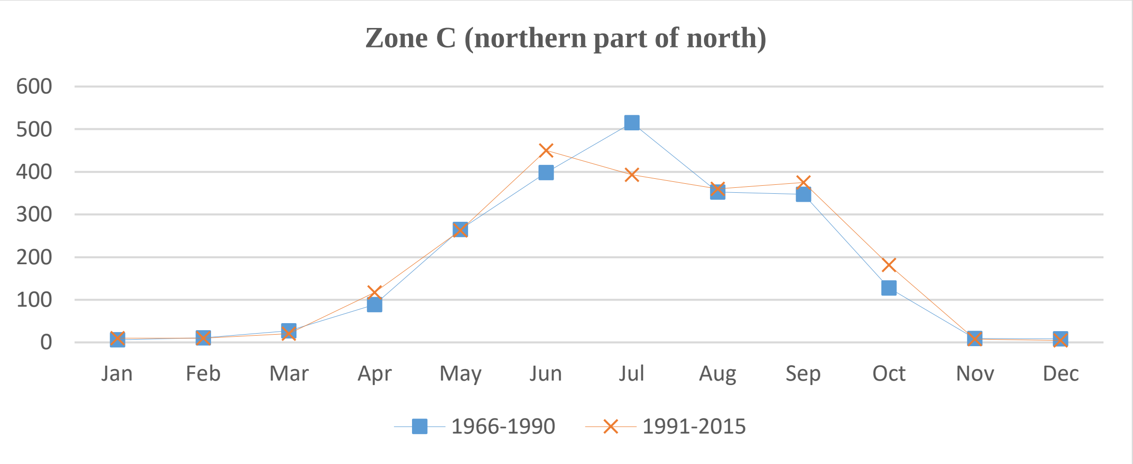
Source: Author's calculation.

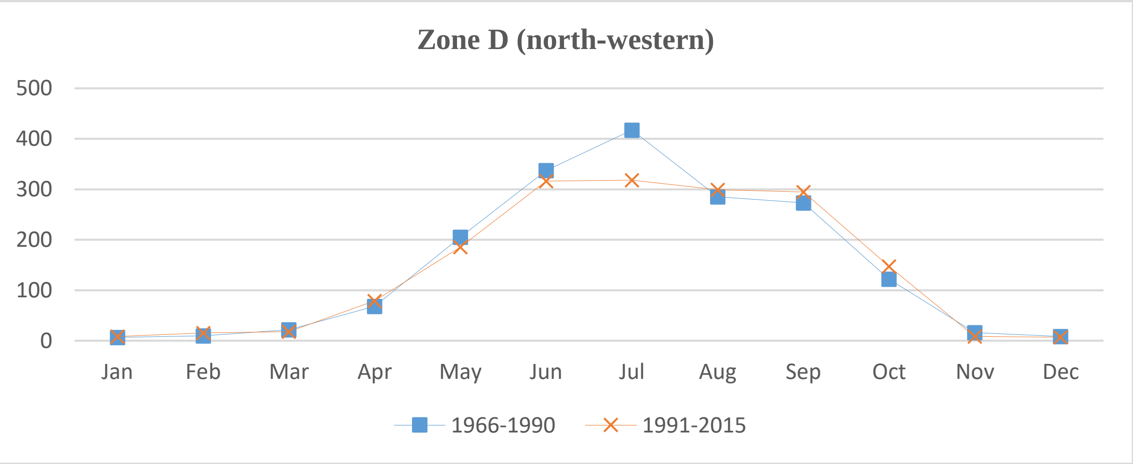
Note: Changes in monthly minimum temperature across seven climatic zones in Bangladesh are shown here. Monthly minimum temperature is averaged for two periods, 1966-1990 and 1991-2015 to see the changes. The magnitude of changes differs from zone to zone. The changes are also different in different months. It can be seen that minimum temperature has increased for almost every month and is more during summer (March-June) and the rainy season (July-October).

Figure 2.11 : Changes in monthly average total rainfall (Millimetre)









Source: Author's calculation.

Note: Changes in monthly total rainfall across seven climatic zones in Bangladesh are shown here. Monthly total rainfall is averaged for two periods, 1966-1990 and 1991-2015 to see the changes. It can be seen that total rainfall has decreased for most month from one period to the next. Moreover, the highest decline is noticeable during the rainy season (July-October).

It is seen from the above analysis that climate has changed considerably over the period of 1966-2015 in Bangladesh. More specifically the temperature has increased whereas the rainfall has decreased considerably in all three seasons. Because of these changes it is expected that production of rice crops as well as other crops grown in Bangladesh would experience some effect, especially, Aman rice, which is mainly a rain-fed crop grown in the rainy season all over Bangladesh. It is found that the rainfall has decreased during the rainy season and the temperature has increased. Therefore, it is expected that both this increase in temperature and decrease in rainfall would have some effect on the production of Aman rice in Bangladesh. Reviewing spatial and temporal vulnerabilities of different rice production systems Wassmann et al. (2009b) has also argued that Bangladesh is one of the countries in Asia where climate change would affect rice production system because of increasing heat stress approaching beyond critical level of rice plant.

2.8 Conclusion

The purpose of this chapter was to provide a brief introduction of Bangladesh. A limited literature review as well as the researcher's own analysis was used to provide an understanding of the importance of agriculture to the national economy, the proneness of the country to natural disasters that affect life, livelihood and the overall development of the country; and the characteristics of Bangladesh's climate which is markedly seasonal and varies across the country. On the last point, it is seen that the climate of Bangladesh has changed considerably over the last fifty years, and these changes are expected to have effects on the agricultural sector and the wider economy.

Chapter 3: Survey Design, Data Collection and Some Descriptive Statistics

3.1 Introduction

Data is of vital importance to the research undertaken in this thesis and the quality of the research findings depends upon the quality of data. The nature and objective of this research required farm level data for the analysis. Therefore, for this research data was collected using a farm level survey undertaken in Bangladesh. In this chapter, a detailed description of the survey and associated questionnaire is provided and basic descriptive statistics about the survey data are discussed.

The chapter is structured in the following way: Section 3.2 outlines the survey and questionnaire design, which includes all the steps taken before the final survey relating to the questionnaire design and sampling procedure. Section 3.3 describes the study area and how the data was collected in the field. Section 3.4 then provides some descriptive statistics for the collected data. It also considers the representativeness of the data for Bangladesh by cross-checking against national statistics where available. Different statistics, including number, mean, standard deviation, range and percentage distribution, are used to describe the different variables related to the collected data. In Section 3.5, the implication of the findings from the simple descriptive statistics are discussed. Lastly, the chapter ends with a concluding section.

3.2 Survey and Questionnaire Design

3.2.1 Survey Data

A survey is a particular technique for collecting data in a systematic and structured way (de Vaus, 2014). Two distinguishing features of survey data are the nature of the data and the advantages of analysis using that data. Accordingly, de Vaus (2014) argued that the required information about the same variables or characteristics are collected here from more than one unit of analysis (which represent a case). As the information collected for each case is comparable, the whole set of collected data takes a structured or rectangular form. With this structured data, it is then easy to analyse from different perspectives in accordance with the research objectives.

This research is about the impact of climate change on rice farms in Bangladesh as well as the farmers' adaptation to climate change. Hence, physical and financial information regarding production, cost and adaptation strategies taken are a vital part of this research. Although data from household surveys is available, they are designed as multipurpose surveys, broadly focused on a set of demographic and socioeconomic matters. Thus, primary data collection is necessary to address the specific research questions posed in this thesis, and the survey method of data collection is the most effective way to obtain the required data from rice farm-households in Bangladesh. However, before conducting a survey as part of a research project, a number of questions relating to the questionnaire and survey design needed to be addressed, including: What would be the questions contained in the questionnaire? How can a representative sample be identified? In addition, how will the survey be administered? (Murray, 2014)

3.2.2 Preliminary Questionnaire

Survey research often builds on similar past attempts to increase the comparability as well as generalisability of the result. For that reason, the researcher of this study identified some similar types of survey research and requested the corresponding lead researcher for a copy of their questionnaire if possible. After email requests to the corresponding researchers, two questionnaires were collected, from Deressa and Hassan (2009) and Sarker et al. (2013), whose surveys were conducted in Ethiopia and Bangladesh respectively. The research focus was about the impact of climate change in the first study and about adaptation in the second study. These two questionnaires were very helpful in developing the structure as well as the wording of this research questionnaire. Apart from that, questions were constructed in accordance with the requirements of this research.

As the survey would be undertaken in Bangladesh, the researcher obtained opinions from experts in Bangladesh who are involved in agriculture or agricultural research, to make further improvement in the questionnaire. For that purpose, discussion about the questionnaire was held with several academics involved in agricultural research and officers from the Department of Agricultural Extension in Bangladesh. Detailed description on the survey in the filed is also given in Appendix 2. The questionnaire was amended at this stage to incorporate their suggestions, to make it clear for the respondents.

3.2.3 Pilot Survey

A pilot survey is an important part of a survey research. It determines whether the questionnaire works properly (Czaja & Blair, 1996). It provides a better understanding of the survey questionnaire and provides insight into respondents' understanding of the questionnaire. It can identify problems faced by those responding relating to misunderstanding questions, their unwillingness to answer questions, and their not knowing how to answer (Blair et al., 2014). It can also assess the respondents' ability to provide answers that are valid and reliable. According to Czaja and Blair (1996) validity of answers requires two things. First, the questions measure the dimension or construct of interest. Second, respondents interpret the questions as intended. So, through pilot survey problems with the wording of the draft questionnaire can be corrected before the final survey (May, 2011).

Regarding the sampling methods and size of a pilot survey, there is no fixed methodology and sample size (Czaja & Blair, 1996). Although it is possible to follow the same procedure as the final survey, it is often not advisable from a convenience point of view (Blair et al., 2014). Moreover, as it is only about the questionnaire design, not about the research findings, it relies on the researcher's own judgment and is also based on researchers' resource availability (Czaja & Blair, 1996). McNeill (1990) suggested that the researcher should try the questionnaire on a number of people similar to those involved in the actual research. The sample size for a pilot survey is typically small compared to the final survey and sometimes may just a few respondents (Blair et al., 2014). Czaja and Blair (1996) suggested to interview a sample of between 20 and 30 as part of the pilot.

In this research, the draft questionnaire was tested during a pilot survey, face-to-face interview undertaken by researcher himself, involving a total of 20 farmers interviewed at two stages which allowed an initial round of amendments to be made and tested; each stage involved interviewing 10 farmers. The farmers were selected randomly from four different villages randomly selected in Bangladesh. In this case, no specific sampling technique was used, unlike the final survey which was based on random selection as discussed below. After conducting the first round of interviews of 10 respondents the questionnaire was also amended. In this stage, mainly some wording and the ordering of the questions were changed. With this amended questionnaire, the second round pilot survey on another 10 farmers was undertaken and it was found that the questionnaire worked successfully. The responses from this pilot survey are not included in the final survey. Finally, through the pilot survey, the questionnaire for this research was finalised.

3.2.4 Final Questionnaire

The final questionnaire was of a structured form and mostly closed ended (see Appendix 10). The advantages of this type of standardized questionnaire are that it is uniformly administered to all the respondents and is suitable for analysis by computer (Casley & Kumar, 1990; Brace, 2008). In the questionnaire, several sections were included to assist the elicitation of the information required for this research.

Broadly, there were six main sections in the final questionnaire. It started with a section on socio-economic and demographic characteristics. Questions related to the household head's age, gender, and education, household size and so on. Questions in the next section related to farm characteristics, like farm size, land fertility, tenure status, livestock ownership, household's agricultural labour availability and so on. Information related to institutional accessibility were in the following section, which included questions relating to access to extension advice, credit, advance weather forecasts, irrigation, market and so forth. Then the next two sections were about farmers' perceptions about changes in climate and the adaptation to climate undertaken by them. Information about the farm's production and costs for rice production for the production year 2014-15, which is the latest year coincide with the survey schedule, is in the last section.

3.2.5 Sampling Procedure

Sampling deals with selecting and observing a part of the population in order to make inferences about the whole population. Before conducting a survey, appropriate sampling techniques have to be identified. In this respect the population in terms of its content, extent, and units has to be defined first (Kish, 1965). In this study, the population was all rice farms situated in different district in Bangladesh. To cover all climatic zones of the country, a representative district is purposely selected based on climate data availability and major rice producing district (detailed description is given in section 3.3). Then the sample units were the selected rice farm-households from that district, following a well-defined sampling procedure.

The sampling procedure is very important for the precision of estimates (Blair et al., 2014). Theoretically, the sampling distribution of an estimate is approximately normally distributed. However, this approximation improves with the sample design. Although the approximation improves with increasing sample size, that is not always achievable because of funding and time constraints. This suggests some rational decision function that will enable a reasonable degree of precision. A complete and formal statement of this function is often very difficult (Kish, 1965). Instead, we may be able to fix a reasonable sample size within the time and fund constraints and then determine the sample design

(Groves & Heeringa, 2006). Moreover, a good sample design can achieve a desired approximation even with a smaller sample size (Leedy & Ormrod, 2014).

As the population for this study was the all rice farms in a district, the geographical area as well as the numbers were quite big. Moreover, a sampling frame of the ultimate observational units (one list covering all farm-households in the district) was not readily available. Singh and Mangat (1996) argued that in a number of practical situations where a satisfactory sampling frame for ultimate observational units is not readily available and the cost of obtaining such a frame is considerable, then multistage[3] sampling is the only feasible procedure.

In multi-stage sampling, the materials are regarded as made up of a number of first stage sampling units, each of which is made up of a number of second stage units. Each of these second stage units are made up of a number of third stage units and so on. The sampling process is carried out in stages using random or stratified sampling at subsequent stages, considering their existing natural divisions and sub-divisions (Yates, 1949). For example, the construction of the second stage frame need only be carried out for those first stage units which are actually included in the sample. Hence, it become more flexible compared to simple random sampling.

The selected units of samples in the first stage are called the *first stage units,* or *primary stage units (PSU)*. Then the units from the subsequent stages are *second stage units (SSU)*, *third stage units (TSU)* and so on. Because of its advantages, it is particularly useful in surveys of underdeveloped countries where no sufficient and accurate frame exists (Yates, 1949). Moreover, using this sampling technique, research on a large area can be covered very easily (Cochran, 1977).

The aim of this research is to cover the whole country, Bangladesh, which needed consideration of a large number of districts. Moreover, district level farm-household lists as a sampling frame were not readily available. Because of these reasons, as well as the advantages of the technique, this research employed the multi-stage random sampling to select samples in the field survey. In the area of economic research in developing countries (Fan et al., 2013; Olusola & Olusola, 2013; Akerele et al., 2014), especially related to agriculture in which the survey was involved (Goyal et al., 2006; Bäckman et

[3] As an example, Sing and Mungat (1996) explains a four-stage sampling procedure for surveys for estimating yield of a crop in a particular state. Here, the development blocks may be considered as first stage units, villages within blocks the second stage units, fields within villages the third stage units and small plots within fields which would be harvested to record yield as the fourth stage units.

al., 2011; Adunga, 2013; Chisasa, 2014), this technique is well established because of its advantages as well as suitability.

3.2.6 Validity and Reliability of the Data

Validity and reliability are two important issues regarding data collected by survey methods (de Vaus, 2014). Validity refers to the proper measurement of the concept that the research intends to measure. For example, if a research uses an IQ test to measure intelligence, then it has to be sure that it does in fact measure intelligence. In this research, variables were included in the questionnaire are based on the literature related to the research issues. Moreover, questionnaires from previous similar types of research (Deressa & Hassan, 2009; Sarker et al., 2013) were also considered while constructing the questionnaire for this research. Therefore, the validity of the content and measurement for the data in this research can be supported.

In this respect measurement of several aspects of the farm (including farm size, quantity produce, farm income and value of the assets) related to the data collected need to be discussed further. Farm size is the important component of any agricultural statistics and failure to adequately measure agricultural land of the farm would lead to the biased estimates which in turn lead to questionable conclusions (Carletto et al., 2015). In the context of agricultural data collection for the measurement of land area three main methods are available: 1) compass and rope (CR), also known as traversing, 2) respondent self-reported (SR) areas, and 3) GPS-based measurement (Carletto et al., 2016). Although different methods present different challenges in terms of their implementation, a potentially accurate method can become highly inaccurate if poorly implemented in the field, or it may simply not be feasible on the scale of the survey. The CR method is considered the 'gold standard' of land area measurement and gives precise measurement but the method is more cumbersome and time-consuming (Carletto et al., 2016). Moreover, to implement this approach in data collection needs trained personnel. In case of GPS based measurement, this approach is costly and requires special training as well as special devices (Carletto et al., 2015). The GPS technology also creates measurement errors because of the satellite position, signal propagation and receivers. Moreover, this approach cannot measure properly when the plot size is very small. As the researcher himself in this research is conducting the survey so, CR and GPS based approach become very impractical because of time, fund and training constraints.

In this research, farmer self-reported (SR) areas is used to get the farm size data. In household surveys, this approach is widely used as the information can be derived by incorporating questions related to land areas into the questionnaire with little additional time and money (Carletto et al., 2015; Carletto et al., 2016). However, land measures taken from farmers SR areas suffers from errors (Carletto et al., 2013). Farmers may intentionally over-state or under-state their land size if they perceive that this information may be used for property taxes or access to a particular programme (Carletto et al., 2015). In this research, the researcher explained this issue to the respondent very clearly before starting the interview. The researcher reassured the respondent that the interview was related to independent research, and the data will be made anonymous and will not be available to any agencies, and therefore as consequence of the information provided there would be no possibilities to have direct personal benefit or harm in future.

Carletto et al. (2015) also argued that unintentional reporting errors can occur in SR approach from natural tendency to round off numbers and approximations of land areas. The land record system in Bangladesh is well structured through traverse surveying (i.e. CR method), mapping of plots, registration of deeds during transfer of land and updating of ownership records (Nahrin & Rahman, 2009). The Directorate of Land Record and Survey (DLRS) under the Ministry of Land (MoL) is responsible to carry out surveys and upgrading of Record-of Rights (ROR). Farmer's land size is documented and transfer of any parcel of land is registered through a deed with stamp registered in Registration Office at the Upozilla (sub-district) level. Therefore, farmers land size is well documented and they know the exact size of their land under their farm in Bangladesh. During the interview the researcher also sought confirmation from the farmer regarding the accuracy of their knowledge regarding their land size and the farmers confirmed this from their own documentation. Therefore, in this research farmers SR farm size are not likely to suffer from unintentional reporting problem.Reliability refers to the consistency of responses. A question that gets inconsistent answers from the same person on different occasions is unreliable. Ambiguous or vague question wording is mainly responsible for unreliable responses, as respondents may understand a question differently on different occasions (de Vaus, 2014). In this research, such wording problem were addressed through the pilot survey before finalizing the questionnaire. Moreover, the researcher investigated consistency in responses by asking questions to the respondents in different ways during interviews.

Regarding the reliability of the some other data (like total quantity produce, income and value of assets) were also been considered cautiously during the interview. In the case of quantity produced, most of the farmers acknowledged that they do not measure their production using the standard scale like kg or ton. However, they do use local units and scales to measure the output. Thus, all farmers confirmed that output was measured by using either standard scale or local scale. Those who did not use a standard scale to measure their output use a basket made of bamboo/crane (locally known as 'Jhuri' or 'Dhama') or a jute sack (locally known as 'Bosta') after the harvest. The size of the baskets and sacks conform to a standard associated with a known weight, through which they measure their quantity produce. They use 'maund' (which is equal to 40 kg) as the local unit of measure for output weight; 2 basket is equal to 1 maund and 1 sack contains 2 maund and 7 kg.

In the case of income, to obtain an accurate figure disaggregation of sources are used in the questionnaire (shown in Appendix 10). For example, for agricultural income information of net revenue from rice, other crops, livestock and poultry, and fishery are obtained from the farmers. The reliability of their answers are checked through deriving the quantity produced, selling prices and costs incurred for production. Similarly, different sources for non-agricultural income are considered, such as income from services provided, business owned, pensions, and remittances. In case of the value of household assets, different items such as a television, radio, mobile phone, motor cycle, bicycle, and refrigerator are considered. If they could not remember the value of an asset that they have then the brand name of the asset is recorded and the market value obtained. A similar technique was considered in the case of farm assets, such as tractors, power tillers, threshers, swallow tube-wells, bulls and carts. Therefore, although the information is obtained through respondents self-reporting, the validity and reliability of the data was considered.

3.3 Study Sites and Administering the Survey

An aim of the survey was to cover all climatic zones of the country. The whole country is divided into seven climatic zones based on climatic variation (Rashid, 1991; shown in Appendix 1). The different climate zones with the major districts in each zone along with their net cropped area, net rice cropped area and major climate characteristics are shown in Table 3.2**Error! Reference source not found.**. As the districts in the same climatic zone are assumed to have the same climate situation, any district in the region can represent that climate region. Hence, if one district is selected from each of the seven climatic zones, then these seven districts should be representative of the whole of Bangladesh. For that reason, one district from each climatic zone was selected.

The districts from each region were purposely selected mainly on the basis of climate data availability as well as being a major rice producing district in that climatic zone. In the case of region C there was no weather station, so a nearby district which has a weather station was selected. In the case of region G, again the major rice producing district was selected but it too does not have a weather station, so a nearby weather station was considered here also. The selected districts from each regions and the weather station associated with them are shown in Table 3.3.

Following the procedures of multi-stage sampling, in each selected district the following four stage procedure was adopted: (1) two *upozila* (sub-districts) from each district were selected; (2) one block[4] from each *upozilla* was selected; (3) two villages in each selected block was selected, and (4) the sample households from those villages were randomly selected. So, in this study the PSUs are the sub-districts in a district. Then the blocks within the sub-district and then villages in each block are the SSUs and TSUs respectively. Finally, the farm households in each village are the fourth stage units (FSUs) or ultimate observational units for our study. The sampling units for the final stage of a multistage sampling design are also called enumeration units or listing units. It is necessary to specify the characteristics of interest along with the attributes of enumeration units which they share in common while defining sampling frame (Levy & Lemeshow, 2008). In this research, the purpose the survey is to take information regarding the quantity of rice produced, the cost of production, income, the farmers' perception of climate change and adaptations made by farm-households. It was assumed that farmers producing rice experienced the same climatic, socio-economic and institutional accessibility environment in their farming activity if they were located in the same zone/district. The sampling frame for this research for the multi-stage sampling is shown in Table 3.1. The details of all these units are shown in Appendix 3.

[4] The agricultural extension office divides the sub-district into several blocks for their working convenience. Each Sub-Assistant Agricultural Officer look after 4 blocks. There are several villages in each block.

Table 3.1 : Sampling frame and summery of the sample

	Sampling Frame					
	PSU	SSU	TSU	FSU		
Zone/District	Number of Sub-district in each district from where SSU is drawn	Number of Blocks in the selected sub-district (2 sub-district drawn from each PSU)	Number of Villages in the selected block (1 block drawn from each SSU)	Total farm-households in the selected village (2 village drawn each from TSU)	Sample taken from each FSU (15% of farm-households are drawn from each FSU)	Relevant attributes which they share in common
A/Noakhali	9	25	6	109 107	16 16	Farmers producing rice experiencing same climatic, socio-economic and institutional accessibility environment in their farming activity in the same zone/district.
		14	5	96 92	14 14	
B/Sylhet	12	27	7	111 110	17 17	
		28	6	103 97	15 15	
C/Kurigram	9	33	4	93 90	14 14	
		30	5	102 98	15 15	
D/Bogra	12	22	4	136 130	20 20	
		20	4	132 135	20 20	
E/Rajshahi	9	29	5	116 112	17 17	
		23	4	107 105	16 16	
F/Jessor	8	25	4	105 104	16 16	
		28	6	107 104	16 16	
G/Gagipur	5	33	8	67 66	10 10	
		32	7	65 67	10 10	
Total					432	

Note: PSU=Primary Sample Unit, SSU=Secondary Sample Unit, TSU=Tertiary Sample Unit, FSU=Forth/Final Sample Unit.

The local offices of the Department of Agriculture at the *upozilla* maintain lists of rice farms for each village. This list includes the farmer's name, address and farm size. From that list, using a table of random numbers, following the remainder method[5] (Singh, 2003), the sample farm households from each village was selected. In this way, following the multi-stage random sampling procedure in the sampling, this study ensured randomness in the data collection process (Blaikie, 2000). Moreover, as the study followed this well established probability sampling procedure, the representativeness of the population can be claimed for the samples obtained (de Vaus, 2014).

A large sample size derived from a standard statistical formula is quite unattainable for an individual researcher with limited resources. Casley and Kumar (1990) argued that a sample does not necessarily have to be large to meet specified inferential requirements. They also argued that the sample can be drawn from a narrowly defined group and the size of the sample depends mainly on the variation within a population of the variable being tested, not on the population size. Bryman (2016) also argued that if population is relatively homogeneous and the variation is low, then even a smaller sample can be representative of a larger population.

[5] In this procedure first any starting point in the table of random numbers considering the same column size equal to the number of digit that total population size (N) has is selected. Suppose if we have a population of N=115 farm-household in a village and we want to select a sample size of n=15 from it. To pick a random sample of 15 out of this 115 population, first have to select randomly any three columns from the random number table, it could be column 1 to 3, 4 to 6, or any three columns. Then following the starting point we have to take note of all the numbers less than or equal to N. If any number is greater than 115 then that have to be divided by 115 to get the remainder which is the required number. When the remainder is zero then the 115 would be the number to note. In this way, a total of 15 numbers will be noted as the required size of sample is 15. From the numbered farm-households list, these numbers will be our sample for interview.

Table 3.2 : Climatic zones and their characteristics in Bangladesh

Climate Zone	Major districts in the zone	% of total area of Bangladesh	% of total net cropped area of Bangladesh	% of Rice production of Bangladesh	Major climate and soil characteristics with respect to Bangladesh average
A. South-eastern zone	Chittagong, Bandarban, Cox's Bazar, Noakhali, Potuakhali	24.19	19.01	20.8	Climate: mild summer and winter, high rainfall Soil type: silty clay loam, grey silt loam and friable
B. North-eastern zone	Shylhet, Muolvi-Bazar, Sunamgonj, Hobiganj	10.38	7.25	7.91	Climate: mild summer but relatively cold winter, highest average rainfall Soil type: silty clay loams, grey silt loam and grey clay
C. Northern part of the northern region	Panchagarh, Nilphamary, Lalmonirhat, Kurigram	8.63	7.85	7.4	Climate: relatively hot in summer but coldest in winter, above average rainfall Soil type: brown silt loam and sandy loam
D. North-western zone	Bogra, Dinajpur, Rangpur, Kustia	10.62	11.05	17.44	Climate: relatively hot in summer and cold in winter, medium rainfall Soil type: brown sandy loam and sandy clay loam
E. Western Zone	Naogaon Nawabganj, Rajshahi,	8.18	17.05	9.35	Climate: relatively high temperature in summer and low in winter, lowest rainfall Soil type: clay loam, silty clay loam and clay
F. South-western zone	Jessore, Magura, Rajbari, Khulna	10.94	13.43	11.57	Climate: above average hot in summer, average cold in winter, and above average rainfall Soil type: silty clay loam and clay loam
G. South-central zone	Mymensingh, Tangail, Gagipur, Dhaka, Comilla, Barishal	27.06	24.36	25.53	Climate: average summer and average winter, above average rainfall Soil type: grey silty clay, clay loam and friable

Source: Author's calculation based on Rashid (1991) and BBS (2016)

In this research, assumption is that all the farmers living in villages of the same district experienced the same socio-climatic environment in their farming activities. As a result, they were mostly a homogeneous group in a particular district. Therefore, a small sample size can be representative of the large population in our study (Casley & Kumar, 1990). For this reason, due to resource constraints, this research selected approximately 15% of the total number of farm households in each selected village. A total of 432 farm households became the sample size for this research and were surveyed by the researcher.

The sample size for each district is shown in Table 3.3 and further details of these are given in Appendix 3.

Table 3.3 : Zone-wise selected district, associated weather station and sample size

Climatic Zone	District selected	Weather station	Total number of farm holding in the selected villages	Sample size
A. South-eastern zone	Noakhali	Noakhali	404	60
B. North-eastern zone	Sylhet	Sylhet	421	64
C. Northern part of the northern region	Kurigram	Rangpur	383	58
D. North-western zone	Bogra	Bogra	533	80
E. Western Zone	Rajshahi	Rajshahi	440	66
F. South-western zone	Jessor	Jessor	420	64
G. South-central zone	Gagipur	Dhaka	265	40
Total			2866	432

The construction of the draft questionnaire, piloting, and finalizing the questionnaire were carried out between April 2015 and October 2015. The final survey was administered between October 2015 and February 2016, scheduled to coincide with the farming season for Aman rice in 2015. Farmers in Bangladesh are not very educated, and the telephone or mail survey method is not a viable approach. Therefore, to undertake face to face interviews was the only viable way to gather information from them. For this research the researcher thus personally visited each of the selected farm households and personally interviewed the farmers. A detailed account of the data collection in the field is given in Appendix 2.

3.4 General Characteristics of Survey Data

3.4.1 Socio-Economic Characteristics

The number of total sample households was 432 and all of the respondent were the heads of their household. In Bangladesh, households, especially farm households, are mostly headed by a male member of the family (BBS, 2013). This study found this to be true with 99% of the sample households being headed by a male. The average family size of the sample households was around six, with an average of two income-earning members. Thus, in general, two-thirds of the family members are considered dependants in the sample households. Bangladesh’s total dependency ratio is 63% in rural areas (BBS, 2015), which is similar to the sample data.

Most of the respondent farmers were middle aged (31-55 years), around 74%. In terms of education, around 17% of the respondent farmers were illiterate. Apart from this, 40%

had primary (1-5 years of schooling), 33% had secondary (6-10 years of schooling) and 10% had above secondary level of education. National statistics for specifically farmers' education level is not available but the closest statistics available is the educational levels for rural male population. It shows that 53%, 30% and 9% of rural male population in Bangladesh has primary, secondary and above secondary level of education respectively (BBS, 2016a).

Agriculture is the major occupation for 97% of respondent households. Other occupational activities in which farm households engage are services, day labour, trading and running a small business. On average 84% of total income comes from agricultural sources in our survey data. Around 29% of the households did not have any electricity facility of their own, corresponding national statistics is 32% (BBS, 2016a). Membership of any agricultural society, co-operative or club was found to be very limited among the farmers, with 11 percent of the farmers having membership of a group formed by either the agriculture Extension Office or micro-credit organizations. The existence of any other grouping among farmers was not found.

3.4.2 Farm Characteristics

The average farm size of the households was 2.35 acres with the largest farm size being 13.6 acres and the smallest being 0.22 acres. To compare this farm size data with the national situation, sample farmers were categorized into different sub-groups based on their farm size. For that purpose, three sub-groups were considered as used by the Agricultural Census 2008 in Bangladesh: small farms having up to 2.49 acres of land, which includes both marginal and landless farmers; medium size farms having 2.5-7.49 acres of land; and large farms that have 7.5 acres and more of farmland (BBS, 2010). According to this classification, in the sample data 76% were small, 17% are medium and 6% were large farmers. Corresponding national statistics for these are 77%, 18%, and 5% respectively (BBS, 2016a).

It was also found that 56% of our sample households were owner-occupiers, that is farmers who owned the whole or the majority of their farm land, and the remaining 44% were tenant farmers who either had no farm land or the majority of their farm land was rented. According to the Agricultural Census 2008, 65% of farm holdings are owner-occupier in Bangladesh (BBS, 2016b).

To get the information about the household's own work force employed in the farming activity, farmers' were asked about how many of their family members work in farming activities. A study by Cain (1977) in Bangladesh found that in rural households children begin to perform useful household and productive task related to agricultural operations by age 6. That is why in this study, farmers' responses were recorded in respect of number of children as well as adult members. As the productivity is different for child and adult, so following Cain's (1977) findings[6] the total family labour is calculated here by considering 3 child equal to 1 adult. It is found that on an average each household has 3 agricultural worker of its own.

In the survey questionnaire, farmers were asked about the fertility of their land, using four categories: low fertility, medium fertility, fertile and very fertile. The argument is that a farmer who can best judge the fertility of his land. Around 45% of the respondents indicated that the fertility of their farm land was medium fertility.

It was also found that around 86% of farm households owned poultry and/or livestock (e.g. chickens, ducks, cows, buffalos, goats and sheep).

[6] Cain (1977) found that children at different age and sex have different productivity. Examining the amount of time children spend at work and comparing work pattern with adult, their results indicate that child's total work is around one third of an adult's work in rural Bangladesh.

Table 3.4 : Sample farmers and farm households characteristics

Characteristics	Categories	Number	Min	Max	Mean	Standard Deviation
Age	Young (up to 30)	8 (1.85)	26	73	49.56	8.74
	Middle aged (31- 55)	319 (73.84)				
	Old aged (55+)	105 (24.31)				
	Total	432 (100)				
Level of Education	No Education (0 year of schooling)	72 (16.67)	0	18	5.46	4.10
	Primary (1-5 years of schooling)	173 (40.05)				
	Secondary (6-10 years of schooling)	143 (33.1)				
	Above secondary (10+ years of education)	44 (10.19)				
	Total	432 (100)				
Family Size	Small (up to 4 members)	75 (17.36)	2	19	6.29	2.45
	Medium (5-7 members)	272 (62.96)				
	Large (7+ members)	85 (19.68)				
	Total	432 (100)				
Households Own Agricultural Labour	Adult		1	8	2.59	1.12
	Child		0	4	0.64	0.74
	Total**		1	9.33	2.80	1.19
Literate Member			0	12	3.19	1.56
Earning Member			1	5	1.69	0.83
Electricity	Yes	308 (71.30)				
	No	124 (28.70)				
Membership to any Society	Yes	48 (11.11)				
	No	384 (88.89)				

Note: *Figures in parentheses indicate percentage; ** Calculated considering 3 child equal to 1 adult;
Source: Author's Field Survey, 2015/16

Table 3.5 : Characteristics of the farm

Characteristics	Categories	Number	Min	Max	Mean	Standard Deviation
Farm size	Small (Up to 2.49 acres)	330 (76.39)	0.22	13.6	2.35	2.16
	Medium (2.50 - 7.49 acres)	75 (17.36)				
	Large (7.5+ acres)	27 (6.25)				
	Total	432 (100)				
Tenure Status	Owner farmer	243 (56.25)				
	Tenant farmer	189 (43.75)				
	Total	432 (100)				
Farming Experience			4	58	31.49	8.91
Land Fertility	Low	74 (17.44)				
	Medium	193 (44.68)				
	Fertile	111 (25.69)				
	High	74 (12.50)				
	Total	432 (100)				
Livestock and/or poultry owned	Yes	370 (85.65)				
	No	62 (14.35)				
	Total	432 (100)				

*Figures in parentheses indicate percentage; Source: Author's Field Survey, 2015/16

3.4.3 Institutional Accessibility

Farmers' institutional accessibility is very important for the development of the agricultural sector of a country. From the survey data it was found that around 30% of the farmers did not have access to formal agricultural extension advice. Government agricultural extension advice is the main advice provider in the country. Apart from government advice, other sources of extension advice are from microcredit institutions and the different input (especially seed and pesticide) companies' sales personnel.

Along with formal agricultural extension advice noted above, farmers in Bangladesh also try to take advice from other more informal sources. From this survey evidence, it was found that other sources of advice are the media (radio/television/newspaper), discussion with neighbouring farmers and discussion with input sellers (i.e. the owner of shop who sells fertilizer, pesticides and other inputs). Among these sources, the advice from other farmers and the advice from the input sellers were very significant in numbers. Around 62% and 48% of the respondents admitted obtaining advice from these two sources respectively. Although these sources are not mutually exclusive among themselves or with formal sources.

Table 3.6 : Intuitional accessibility

Characteristics	Accessibility		Number	Sources	
				Names	%
Formal Extension Advice	Yes		301 (69.68)	Govt.	98.67
				Other	1.33
	No		131 (30.32)		
Other sources of advice (not mutually exclusive)	Yes*		432	Other farmers	61.81
				Input seller	48.15
				tv/newspaper	6.94
	No		0		
Advance weather information	Yes		147 (34.03)	Media	77.55
				Farmer	22.45
	No		285 (65.97)		
Credit	Yes		253 (58.56)	Com. Banks	29.63
				NGOs	29.63
				Friends	29.10
				Others	11.64
	No		179 (41.44)		
Irrigation facilities	No	0% of land	20 (4.63)		
	Yes	Up to 25% of land	5 (1.16)	Govt.	28.88
		26-50% of land	32 (7.41)		
		51-75% of land	29 (6.71)	Private	38.35
		76-100% of land	346 (80.09)	Own	32.77

*Multiple responses; Figures in parentheses indicate percentage; Source: Author's Field Survey, 2015/16

Regarding advance weather forecasts and the availability of that information to farmers, it was found that only 34% of the farm households had regular access to advance weather information. The source of such weather information in all cases was the media, i.e. weather reports from radio, television and newspapers.

It was also found that around 41% of the farm households of our sample were not able to access agricultural credit from any source. Those who had accessed agricultural credit over the last one year shows that no single sources dominated the provision of credit to rice farmers in Bangladesh. Commercial Banks (mainly nationalised local banks), NGOs (for example Grameen Bank, and BRAC), and friends and relatives each are providing agricultural credit to around 29% of farm households. Rest of the households are taking credit from input sellers and traders of agricultural products.

Most of the farms, that is around 95% of the sample, had access to irrigation facilities, but the percentage of land with irrigation facilities varied markedly. Moreover, in terms of service providers, the majority with irrigation were privately owned. In terms of market accessibility, the average distance to both input and output markets was about 3.56 kilometres, with the largest distance reported being 8 kilometres and the shortest distance close to zero kilometres.

3.5 Discussion

It is argued that the provision of electricity supplies to rural areas will have a positive impact on income and overall well-being of farm households in developing countries (Elias & Bower, 2015). However, in the sample, more than one third of the farm households do not have electricity. The literature on climate change adaptation also provides evidence that electricity facilities influences farmers to take adaptation strategies (Nhemachena & Hassan, 2007; Seo et al., 2009). Therefore, to create a conducive environment for adaptation, electricity availability might be improved in Bangladesh.

Regarding access to agricultural extension advice, it was found that more than one fourth of the farmers lacked such support. Even those who claimed to have access to this facility also showed dis-satisfaction about its availability as well as the quality of government agricultural extension advice. Although it was not the information the researcher was requesting in the survey, while giving answers on extension advice accessibility farmers did tend to complain about its provision. In this respect, informal discussions with the sub-assistant agricultural officer, suggested that sometimes it is quite difficult for the government officers to provide a service of the quality demanded by farmers because of the large area allocated to those officers, the number of farms they have to cover, as well as the transport limitations.

Apart from formal extension advice, farmers also take advice from other sources such as discussions with neighbouring farmers. Such advice is referred to as farmer to farmer extension and is always considered in the literature to be an important source of knowledge dissemination and a way to promote technology adoption in developing countries (Sinja et al., 2004; Kiptot et al., 2006). Shah et al. (2016) found that this source was the third most important source in the diffusion of agricultural technology in Bangladesh. In this respect, farmer’s clubs or societies can play an important role in disseminating knowledge and promoting climate change adaptation. However, the existence of this farmer’s club/society/group was found to be insignificant in numbers in this survey. Creating farmers’ clubs/societies/groups can facilitate appropriate adaptation to reduce the climate change impact in Bangladesh.

The role of input sellers as another source of extension advice was an important finding from the survey data. Two types of input sellers exist. The first category is the big shop owners, locally known as dealers, as well as distributional agents of seed companies, pesticides companies and other input companies. The other type of input seller is small shop owners selling agricultural inputs like fertilizer, seeds, and pesticides. These small shop owners often interact with farmers and work as an information dissemination hub for farmers. Shah et al. (2016) found that these dealers are the most important source for diffusion of knowledge, other than the government extension advice. However, the quality of their advice can be questioned because of their business motives as well as their own knowledge limitations. Dissemination of knowledge as well as adoption of climate change adaptation can also be increased through these agents.

Advance weather forecasts and availability of that information to farmers are important to reduce vulnerability (Ziervogel & Calder, 2003). It helps farmers in management decisions relating to planting, harvesting, application of fertilizer and irrigation, to increase profitability of the farm business, and to reduce risk in the production system (Britt et al., 2002). From the survey data it was found that around two thirds of the farmers sampled did not get weather information. Moreover, the farmers complained that this information was general to the whole country or, at best, to the whole region; they did not get information specific to their particular district or area. Moreover, they said in most cases the information is not accurate. For example, some respondents said that when they waited for rain, as forecast, no rain happened, and when they irrigated the land, as no rain forecast, the heavy rain occurred.

Inaccuracy about the weather forecast, as well as the lack of appropriate information among the farmers, were found during the survey. It was also found that farmers used their own knowledge and understanding based on their experience to inform their weather outlook. Again, in this respect, most of the farmers’ acknowledged that the general trend has changed now. Weather has become very unpredictable to them. This may have an impact on the cost of production or misallocation of resources, for example, when rainfall occurs after irrigation has been applied by the farmer. If the farmer had had more accurate information on the weather, then more efficient decisions might be made regarding, in the example given, the use of the irrigation, thus avoiding the cost of irrigation provision.

Credit is always considered as an important factor to increase productivity and raise farm incomes in developing countries (Liqiu & Yanqiu, 2011; Donkoh et al., 2016). This is true for rice farms and especially for small farms (Njeru et al., 2016). Moreover, in relation to climate change, smallholder farmer's ability to adapt to reduce the negative impacts of climate change is hindered by lack of access to credit (Ringler, 2010). From the current survey data it was found that a considerable portion (around 41%) of the farm households were not able to access agricultural credit from any source. Moreover, the majority of the farms in Bangladesh are small in size. Therefore, to increase adaptation and to reduce the climate change impact, or even to have an opportunity, this issue needs to be addressed.

A considerable portion of the land of farm households was not under irrigation, which is an important issue in the face of climate change. Although government is undertaking the major infrastructural development related to infrastructure, the majority of services such as selling of irrigation water and maintaining the pumps are in private ownership. Again, although it was not related to this research issue directly, the farmers complained about the availability as well as the price of irrigation. Climate change is likely to exacerbate these problems in the near future.

3.6 Conclusion

This chapter described the survey procedure, study sites and the conduct of the survey in Bangladesh, which was undertaken to collect data on the farm household for to support the research in this thesis. Simple descriptive statistics were also presented here to provide some insight into some important characteristics of the sample farms. While presenting the descriptive statistics here, whenever national statistics were available, comparison was made to demonstrate the quality of the data; it was found that the farm-household characteristics of our data were quite similar to the national level statistics, which supports the suitability of the sampling procedure used as well as the representativeness of the data. Using the sample data, the sensitivity of rice farming to climate will be investigated empirically in the next chapter.

Chapter 4: Estimating the Impact of Climate Change on Aman Rice Production in Bangladesh

4.1 Introduction

A growing body of scientific literature suggests that climate change would affect the agricultural sector, leading to serious implications for food production across the world. Agricultural production is very much dependent on climate variables like temperature and rainfall. The changes in temperature and rainfall are particularly challenging for developing countries where the adaptive capacity is very low (IPCC, 2007). However, the majority of the available studies on the potential impact of climate change to agriculture are case studies relating to developed countries (Fernandez & Blanco, 2015). Moreover, impact analysis studies considering a particular crop, especially rice, are very few in number.

Rice is one of the major staple food crops of the global population; more than half of the world's population, especially in developing countries in Asia, depend on it for their daily calorie intake (Gnanamanickam, 2009). Because of its importance, not only as a staple for more than half of the world's population but also in providing food security and eradicating poverty, the UN declared the year 2004 to be the International Year of Rice (FAO, 2004; Gnanamanickam, 2009). In a number of developing countries agriculture mainly consists of rice farming. There have been few attempts to analyse the impact of climate change on the rice crop in developing countries.

The main aim of this study is to see the impact of climate change on the rice crop in Bangladesh. For that purpose, a specific rice crop variety, Aman, is chosen here. The rationale for choosing this rice is that it is the crop grown in all regions of the country, it covers the majority of the cultivated area. Aman rice is grown in July-December in Bangladesh and, in that period, the rainy season normally occurs in July-October. Although irrigation is sometimes used when there are delays in the rainfall or the quantities of rain are too little, the production of Aman rice mainly depends on rainwater. That is why it is considered to be a rain-fed crop. Therefore, the specific objectives of this research presented in this chapter are as follows:

- to estimate the impact of climate change on net revenue of Aman rice;
- to estimate the effects of climate change on yield of Aman rice; and
- to estimate the impact of climate change on the cost of production of Aman rice.

The chapter is structured in the following way. Section 04.2 provides a summary of relevant literature. Section 04.3 describes the data used in the analysis. The analytical and econometric estimation methodology, including important considerations related to the estimation procedure, are described in the Section 4.4. Section 4.5 reports the findings of the analysis, and is followed by the conclusion and recommendations.

4.2 Literature Review

Empirical studies suggest that climate change will impact on the agricultural sector (Cline, 2007; Stern, 2007). Although the degree of impact would vary because of the magnitude of change and the degree of vulnerability, it is expected to have more effect on the developing countries than on developed countries (World Bank, 2013). Temperature increase is likely to have more adverse effects in developing countries, since they are predominantly located at lower latitudes, and temperature is already close or beyond the thresholds for agricultural production in such locations (Cline, 2007). Further warming, changes in rainfall and other extreme weather events are likely to impact crops, both directly by affecting plant physiology and indirectly through pests and diseases (Porter et al., 2014; Newbery et al., 2016).

In order to assess the impacts of climate change on agriculture, two approaches have been widely used in literature. The first one is known as the Ricardian approach (Mendelsohn et al., 1994) and the second one is known as the production function approach (Adams, 1989; Chang, 2002).

Mendelsohn et al. (1994) proposed the Ricardian approach in their study to measure the climate change impact in US agriculture. It is based on the classical economist David Ricardo’s theory that in a competitive market the value of the land is reflected from its productivity (Fezzi et al., 2014). Similarly, if the productivity is affected because of climate change then that would be reflected through the land value. Mendelsohn et al. (1994) in their seminal paper argued that relating land values to climate differences could capture the effect of climate. Thus, using statistical regression of climate variables on land values, they estimated the effect of climate change on US agriculture.

The original Ricardian approach proposed by Mendelsohn et al. (1994) used land values as the dependant variable in their regression model. However, in most developing countries land prices do not reflect the real value of land because of imperfection in the market. Even in some countries, because of imperfections in the market statistics on land value are largely absent (Wang et al., 2009). In this respect, Kumar and Parikh (1998) argued that the land prices depend upon the expected future net revenue[7] and current net revenue can be considered as a proxy for expected future net revenue. Therefore, the Ricardian approach can be used in the developing countries context using the net revenue instead of land value.

Estimations using the Ricardian approach are available for the USA (Mendelsohn et al., 1994; Deschenes & Greenstone, 2007), Canada (Reinsborough, 2003), many countries in Africa (Kurukulasuriya & Mendelsohn, 2006; Mano & Nhemachena, 2007; Deressa & Hassan, 2009; Kabubo-Mariara, 2009; Wood & Mendelsohn, 2015), India (Kumar, 2011), Sri Lanka (Seo et al., 2005) and China (Wang et al., 2014).

Proposing the Ricardian approach, Mendelsohn et al. (1994) measured the impact of climate change on US agriculture using cross-sectional data on climate, farmland prices, and other economic and geophysical data for almost 3,000 counties. From their estimates they found that higher temperatures in all seasons except autumn reduce average farm values, while more precipitation outside of autumn increases farm values. In contrast, Deschenes and Greenstone (2007) found the positive effect of both temperature and precipitation changes on US agriculture, but used time series data instead of cross sectional data and estimated the effect of random year-to-year variation in temperature and precipitation on agricultural profits. Reinsborough (2003) also used the Ricardian approach proposed by Mendelsohn et al. (1994) and found the similar positive effect on agriculture from climate change in Canada.

Kurukulasuriya and Mendelsohn (2007; 2008b) examined the impact of climate change on cropland based on a survey of over 9000 farmers in 11 countries in Africa using the Ricardian cross-sectional approach. In this research, the net revenue from growing crops is regressed on climate, water flow, soils and other economic variables like access to electricity, irrigation access and regional dummies. They found the negative effect on net revenue from the increase in temperature and deceasing precipitation. They concluded that 10% increase in temperature and 10% decrease in precipitation would lead to a 13% and 4% decrease in net revenue respectively. Following the same approach similar results were also found by Mano and Nhemachena (2007) in Zimbabwe, and by Deressa and Hassan (2009) in Ethiopia. However, recently Wood and Mendelsohn (2015) found that higher temperatures and precipitation lower agricultural revenues in the more important

[7] Net revenue refers to gross return from the land minus the cost involved to earn that return.

rainy season but increase revenues in the less important cool, dry season in northern Guinea and southern Senegal.

Some studies examined the impact of climate change on agriculture by focusing particularly on livestock. Kabubo-Mariara (2009) estimated a Ricardian model of net livestock incomes in Kenya based on a sample of 722 households. The marginal impacts from this study suggest gains from rising temperatures and losses from increased precipitation. In another study, based on surveys of almost 5000 livestock farmers across ten countries in Africa, Seo and Mendelsohn (2008b) found that the livestock net revenues of large farms in Africa are more sensitive to temperature than those of small farms. Using the Ricardian results this study also predicted that the net revenues of small farms would increase as much as 120% (+USD6 billion) but those of large farms would fall by 20% (-USD12 billion) by 2060.

Apart from the African case studies, a few studies also estimated the relationship between farm level net-revenue and climate variables in other developing countries, for example, India (Kumar & Parikh, 2001), Sri Lankan (Seo et al., 2005) and China (Wang et al., 2014) using the Ricardian approach. Using both time-series and cross-section (district level) data, Kumar and Parikh (2001) found that temperature in October has a positive effect, whereas the temperatures in the remaining seasons have negative effects on Indian agriculture. On the contrary, Seo et al. (2005)found a mixed results for Sri Lankan agriculture. Applying the estimated regression result from the Ricardian approach to different climate scenarios, they estimate a range of effects from 20 percent loss to a gain of 72 percent. Although they found the increase in rainfall impact is beneficial to the whole country, Kumar and Parikh (2001) found a significant seasonal variation on net revenue. However, both study found that the precipitation effect is lower in comparison to the temperature effects.

Wang et al. (2014) explored the impacts of climate change on agriculture by region in China. Applying the Ricardian Approach they estimated the climate sensitivities for North and South China separately. In their model, instead of average seasonal temperature and precipitation variable they used deviation of temperature and precipitation between current year (2001) and average values in the long run (1951-2001). Although they found that effect on farm net revenue varies (to different degree) in the north and the south, rise in temperature has adverse effect whereas benefiting effect from increase in rainfall. They also found that for both north and south China, increasing temperature is beneficial to irrigated farms, while for rain-fed farms, higher temperature will result in a reduction in net revenues.

According to Seo et al. (2005), agronomic studies show that a particular range of temperature and precipitation is required for optimal crop production and deviation from that range would reduce the crop productivity. Later on, Schlenker and Roberts (2008; 2009) also found that there is a highly mon-linear and asymmetric relationship between temperature and yields. Overall, in agriculture the effect of climate on production is expected to be nonlinear as productivity first increases and then decreases with warmer temperature and precipitation, meaning tends to a hill-shaped relationship (Mendelsohn, 2012). Because of that all studies use the nonlinear specification of climate variables (temperature and rainfall) in their empirical model (Kumar & Parikh, 2001; Seo et al., 2005; Kurukulasuriya & Mendelsohn, 2008b; Wang et al., 2014; Wood & Mendelsohn, 2015). Although most studies concluded the non-linear specification of climate variables, some studies did not found any evidence (Wood & Mendelsohn, 2015) or a weak quadratic relation (Roberts et al., 2012).

In the production function approach, the effect of climate change on crop yields is estimated. Generally, in the field of agricultural economics the production function approach is widely used to identify important variables and their effect on crop yields. In case of estimating the impact of climate change, statistical regressions relating yields to climate variables are used to capture the impact of climate on agricultural productivity using this approach. Climate change impact has been estimated using this approach for the USA (Chen et al., 2004), Nigeria (Eregha et al., 2014), Taiwan (Chang, 2002; Chen & Chang, 2005), India (Guiteras, 2009; Barnwal & Kotani, 2010) and China (Wei et al., 2014).

Roberts et al. (2012) explored the link between climate change and corn yield in U.S. using time series data of Illinois corn yields from 1950-2010. As climate data they use growing degree days and extreme heat degree days along with precipitation in the regression. They found that shifting 24 hours of temperature from 29^0C to 39^0C decreases corn yield by approximately 6.2%. Although this study found a positive link between precipitation and corn yield, evidence suggested that high temperature can be damaging to corn yield even when precipitation is greater than or much less than mean value. In a similar study conducted by Schlenker and Roberts (2009) also found the similar strong causal negative link between extreme heat and corn yield in U.S..

Wei et al. (2014) estimated climate change impact on three crop yields, wheat, rice and maize, considering provincial panel data from 1980 to 2008 in China. Their estimates showed that temperature increase had a positive impact on yield growth of wheat and rice by 1.3% and 0.4% respectively, but the opposite impact for maize by 12%. Their study also concluded that although precipitation effect is positive, the main impact on crop yield is from temperature rise in China. In a similar study, Chang (2002) estimated the potential impact of climate change on Taiwan's agricultural sector considering yield of 60 crops from 15 sub-regions in Taiwan for the years 1977-1996. This study found that the impact of climate variables affect significantly on crop yield, but are different on different crops. From the estimated results, Chang (2002) concluded that overall Taiwan's agricultural sector would not suffer from temperature increase, but would have serious deteriorative effect from precipitation increase. The conclusion drew from this study differs completely from Wei et al.'s (2014) study. Wei et al. (2014) found that impact of temperature and rainfall is positive on rice yield, but Chang (2002) found it opposite. Moreover, rainfall effect is marginal on crop yield in Wei et al.'s (2014) study, whereas it is very devastating in Chang's (2002) study.

Chen et al. (2004) examined the potential effects of climate change on major crop yield in U.S. agriculture using the panel data technique developed along the line of the stochastic production function approach suggested by Just and Pope (1978; 1979). Their estimated results suggested that although temperature and rainfall increase have a positive impact on yield for sorghum, they have opposite effect individually on corn yield. Guiteras (2009) and Barnwal and Kotani (2010) have estimated the impact of climate change on Indian agriculture using same methodology but the former did it on the whole country but the later did it for only a state named Andra Pradesh. Using the panel data both study regressed yearly district-level yield of major crops (rice, wheat, sorghum, and maize) on yearly weather (temperature and precipitation) data and district fixed effect. Both of this study concluded that an increase in average temperature has an adverse effect on crop yield in India, which is opposite of findings from Chen et al.'s (2004) study in U.S.

The advantage of the Ricardian approach is that, as it uses the net revenue of the farm, so it incorporates all adaptations that the farm could take to use the land in response to climate change (Schlenker et al., 2005). However, this approach has also been criticised for not considering some other unobserved variables of cross sectional units, not giving production information, and ignoring price differences (Cline, 1996; Deschenes &

Greenstone, 2007). On the other hand, the advantage of the production function approach is that it analyses the crop-specific impacts from climate variables. However, this approach has also been criticised because it does not take into consideration the substitution, adaptation and new activities that farmer could take in response to climate change.

This study seeks to estimate the impact of climate change on both net revenue and yield for a rice crop, specifically Aman rice, and also investigates the impact of climate change on the cost of production of that crop. While there are a few studies on rice crops but all of them use the production function approach (Kim & Pang, 2009; Karn, 2014). Sarker et al. (2014) undertook a study, using production function approach, considering rice yield using panel data for Bangladesh. The novelty of this present study compared to the previous one is that the analysis here is based on survey data conducted at the farm household level. Moreover, this is the first time any study has tried to see the climate impact from the cost of production perspective. Therefore, this study will contribute to the expanding literature on climate change impact on agriculture by examining the effect of key climate variables on net revenue (i.e. the Ricardian approach), yield (i.e. the Production function approach) and cost of production (new area completely missing in the literature) of a rice crop in a developing country.

4.3 The Data

Cross sectional data collected by the researcher from rural household level survey in Bangladesh, as described in Chapter 3, is the source of evidence used here for this analysis. The sample size is 432 farm-households which were randomly selected from all climatic zones (total 7 climatic zone in Bangladesh) and are believed to be representative of such farm-households across the country. Aman rice is the only rain-fed rice crop in Bangladesh, and the analysis here is based on that rice crop alone. Using a structured questionnaire, detailed data on the costs of production were collected for different stages of Aman rice production (i.e. land preparation, transplanting, weeding and harvesting stages) for the 2015 season. Moreover, the survey was undertaken between October 2015 to February 2016, just at the end of Aman rice production. Collecting cost information related to different stages of rice production at the end of production season reduced the cognitive burden on the respondents and increased the likelihood of retrieving better retrospective data. The quantity of Aman rice produced on the farm and the farm-gate selling price were also collected. Data on farmers' socio-economic and demographic characteristics were collected as these help to explain differences in observations between farm-households.

Using the collected data net revenue, yield and cost of production per acre of Aman rice crop for each farm-household is calculated. Net revenue is the gross revenue (quantity produced multiplied by the farm-gate selling price) minus total cost of production. In the total cost, all monetized cost that farmers had incurred was included, but not included the rent for land and value of household's own labour.The focus is on costs of purchased variable inputs. Therefore, the net revenue is the measure of returns of land and family labour from Aman rice production. The yield is the total quantity produced of Aman rice. The net revenue, yield and cost of production per acre are then calculated by dividing total cultivated land area of each household (measured in terms of acres).

For climate data temperature and rainfall data on each zone are also considered in this study. Data for climate in the form of daily maximum temperature, daily minimum temperature, and daily rainfall were collected from Bangladesh Meteorological Department (BMD) for each district related to our study for the period of 1966-2015. Maximum and minimum temperature are first averaged for daily average temperature and then this daily average temperature is averaged to give the monthly average. In the same way, the daily rainfall is totalled to get the monthly rainfall for each year. These climate variables are then averaged over the 50 years to get the normal climate values for each month.

The collected information comprise a primary data set with farm-household-specific information on yield, cost and net revenue. Climate data is of limited availability in most developing countries, where typically one weather station covers a wide geographical area. Bangladesh is not exception to that and a wide geographical area is covered by one weather station in there. Therefore, in this study, although all data used are farm-household-specific, the climate data is district specific and not farm-household-specific.

4.3.1 Matching Climate Data with Aman Rice Growth Phases

Every crop has three main growth phases in its total growing period: establishment, flowering and ripening. Based on relevant weather variables, farmers maintain a crop calendar and accordingly each crop has its established sowing and harvesting dates. In Bangladesh the growing period of Aman rice in any one calendar year is July to December (BBS, 2016b) so in this study, the three growth phases are considered as the sowing period (July-August), the flowering and grain formation period (September-October) and the ripening period (November-December). During the data collection process, this information was verified by the farmers and the divisions considered here found to be appropriate. This study considered that it would be useful to analyse the effect of climate on the complete growing period as well as in the three growth phases for Aman rice. Thus, temperature and rainfall corresponding to the whole growth period as well as the three growth stages are obtained by taking the mean values of those months' climate values.

4.3.2 Some Descriptive Statistics of Data

Some basic statistics for the data used in the empirical analysis are shown in Table 4.2. The district level variability in net revenue, yield, cost, temperature and rainfall in the three different stages of rice growth is shown in Table 4.1 also. Per acre average net revenue, yield and cost of the Aman rice across the different districts are Taka 28200±7547, 55±16 maund[8] and Taka 10654±4271 respectively. The long-term (1966-2015) average temperature during the sowing, flowering and ripening phases of Aman rice are respectively 28.9±0.41, 28.1±0.33 and 21.9±0.54 ^{0}C. Similarly, the total rainfall during the sowing, flowering and ripening phases of Aman rice are respectively 869±327, 499±121 and 31±13 millimetre.

Table 4.1 : District level average net revenue, yield, cost and climate data

Climatic Zone/District	Net Revenue (Tk)	Yield (Maund)	Cost (Tk)	Temperature (^{0}C)			Rainfall (mm)		
				Sow	Flow	Ripe	Sow	Flow	Ripe
A.Noakhali	38086.2	80.9	12155.8	28.2	28.2	22.8	1310.8	608.6	55.8
	(3072.2)	(8.8)	(3711.8)						
B.Sylhet	35938.3	62.2	6224.4	28.4	27.5	22.2	1426.1	729.8	36.9
	(3344.6)	(8.7)	(3971.3)						
C Kurigram	30684.1	53.3	7348.7	29.1	27.6	21.0	810.5	515.9	14.7
	(3820.1)	(7.7)	(1895.7)						
D.Bogra	25298.8	51.3	11878.3	29.1	28.2	21.9	659.9	418.4	19.9
	(2336.4)	(5.8)	(2036.4)						
E.Rajshahi	19197.5	38.4	9352.1	29.3	28.2	21.3	581.9	384.1	22.5
	(2529.6)	(6.6)	(2185.5)						
F.Jessor	23438.4	51.7	16671.3	29.2	28.4	21.7	614.8	388.8	35.9
	(7277.4)	(11.9)	(2739.9)						
G.Gagipur	25659.6	44.7	10349.9	29.0	28.3	22.3	699.1	466.4	39.3
	(3531.4)	(16.9)	(2031.6)						
Overall	28199.7	54.76	10653.7	28.9	28.1	21.9	869.1	498.9	31.3
	(7547.1)	(15.7)	(4270.7)	(0.41)	(0.33)	(0.54)	(326.7)	(121.4)	(13.1)

Note: Figures in parentheses are standard deviations. Sow, flow and ripe denoted the sowing, flowering and ripening phases of Aman rice.

Farmers in Bangladesh also have access to irrigational facility. Apart from Aman rice which is grown in the rainy season, if the same farmland has access to groundwater

[8] In Bangladesh, the maund is used to measure the weight of crops in rural areas. 1 maund = 40 kg

irrigation then it can also be used to produce another rice[9] crop in the dry season. Aman rice is considered to be a rain-fed crop because of its main dependence on rainwater falling during the rainy season. However, sometimes farmers need to use supplementary irrigation when required. Therefore, this Aman rice is both a rain-fed and irrigated crop, not simply a rain-fed crop. On an average 86% of the land of the respondent farm-households have the access to irrigational facility (shown in Table 4.2).

Table 4.2 : Basic descriptive statistics of sampled farm households

Variables	Mean	SD	Min.	Max.
Household/Head Characteristics				
Farming experience of household head (years)	31.49	8.9	4	58
Education of household heads (years)	5.46	4.1	0	18
Household Agricultural labour (numbers)	2.8	1.19	1	9.33
Farm Characteristics				
Fertility of land (1=low fertile, 2= medium fertile, 3= fertile, 4=highly fertile)	2.33	0.9	1	4
Tenure status (1=tenant farmer, 0=owner farmer)	0.44	0.5	0	1
Institutional accessibility				
Formal extension advice (1=yes)	0.67	0.46	0	1
Advance weather information (1=yes)	0.34	0.47	0	1
Access to credit facility (1=yes)	0.44	0.5	0	1
Accessed to irrigation facility (% of land)	86.42	26.68	0	100
Climatic factors				
Average temperature (^{0}C) in whole period	28.47	0.312	27.94	28.79
Total rainfall (mm) in whole period	1367.95	445.64	966	2155.9
Average temperature (^{0}C) in sowing period	28.9	0.41	28.16	29.33
Average temperature (^{0}C) in flowering period	28.05	0.33	27.51	28.41
Average temperature (^{0}C) in ripening period	21.87	0.54	21	22.75
Total rainfall (mm) in sowing period	869.08	326.71	581.86	1426.14
Total rainfall (mm) in flowering period	498.87	121.44	384.14	729.76
Total rainfall (mm) in ripening period	31.25	13.05	14.68	55.77
Revenue, production and cost				
Net Revenues (In Bangladeshi Taka)	28199.72	7547.135	9825.758	76875
Output per acre (in Bangladeshi maund[10])	54.76	15.69	18.73	130.30
Cost per acre (In Bangladeshi Taka)	10653.69	4270.65	903.23	25333.33

[9] Boro rice is produced in those lands which have an irrigation facility during the dry season after the Aman rice production period. The Boro period (November-March) is the winter season. In winter, rain is much less in Bangladesh and so the Boro crop mainly depends upon groundwater irrigation as considered as irrigated crop.

[10] In Bangladesh, the maund is used to measure the weight of crops in rural areas. 1 maund = 40 kg

The average temperature and total rainfall during different growth phases (sowing flowering and ripening) of Aman rice by zone/district, which is presented in Figure 4.1 and Figure 4.2 respectively, shows a clear pattern of spatial variation across the study areas, although the variation is relatively small.

Figure 4.1 : Temperature across zone/district and growth phase

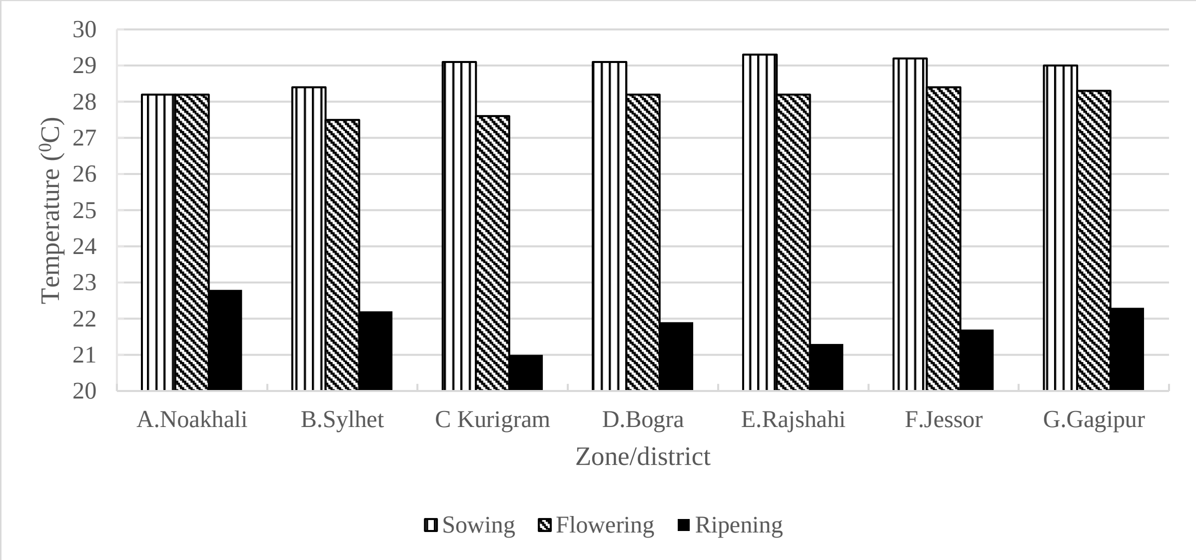
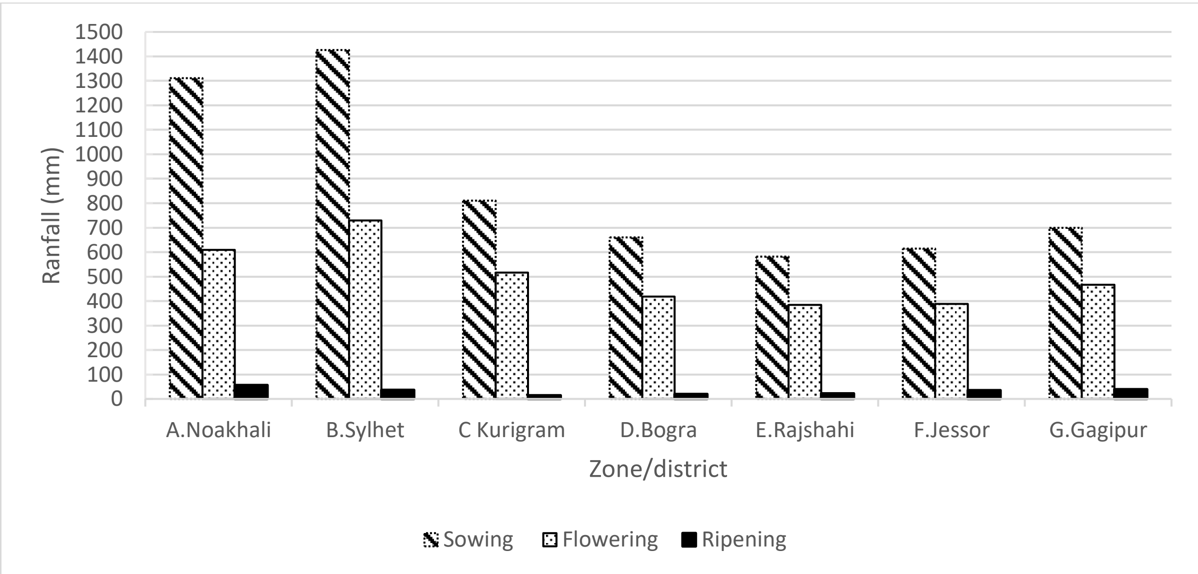


Figure 4.2 : Rainfall across zone/district and growth phase



4.4 Methods

The main research focus of this study is to determine how sensitive the current Aman rice production is in Bangladesh to different climate variables. To answer this question, this study uses both the Ricardian and the production function approaches to see the effect of climate on Aman rice production. In addition, this study extended its investigation exploring another model where the cost of production of Aman rice is considered as a dependent variable, which is missing in the literature. Therefore, this study estimates multiple regression models using net revenue, yield and cost of Aman rice as dependent variables. It is expected that altogether this may give a better picture regarding the effect of climate change on agriculture.

4.4.1 Analytical Model

Following Mendelsohn et al. (1996) let us assume a well-behaved production function of the form:

$$Q_a = Q_a(X, C, FH) \tag{4.1}$$

where Q_a is the quantity produced of Aman rice, *X* is a vector of purchased inputs other than land, *C* is a vector of climate variables, and *FH* is a vector of other farm-household level variables like soil fertility, and the socio-economic characteristics that may influence production. With a given set of input price P_X, output price P_a, output quantity Q_a, climate variables *C*, and farm-household level different characteristics *FH*, a farmer's net revenue can be expressed as:

$$NR_a = P_a Q_a - \sum P_X X \tag{4.2}$$

where NR_a is the net revenue of the farm arising from Aman rice production.

A profit maximizing farmer will choose inputs *X* to maximize the net revenue within the given climate, soil and socio-economic condition. Therefore, the reduced form of maximizing net revenue subject to given inputs will be a function of exogenous variables *C* and *FH*. The general form of the reduced form of this will be:

$$NR_a = f(C, FH) \tag{4.3}$$

Following the same principle, the reduced form of yield and cost function can be written respectively as:

$$Q_a = f(C, FH) \tag{4.4}$$

$$TC_a = f(C, FH) \tag{4.5}$$

where Q_a is the quantity produced of Aman rice and TC_a is the cost to incur for producing the Aman rice.

4.4.2 Empirical Model

To examine the impact of climate change on Aman rice, this study uses the semi-log functional form because of its superior interpretation. We know that because of its functional form the estimated coefficient of each of the explanatory variables will show us the relative change in the dependent variable from a one unit change in that explanatory variables (Wooldridge, 2006). Following the standard literature in climate change studies (Gbetibouo & Hassan, 2005; Deressa & Hassan, 2009; Kabubo-Mariara, 2009) the general form of the regression model that this study uses is:

$$\log(X) = \alpha + \sum\beta C + \sum\gamma_{FH} FH + \mathcal{E} \tag{4.6}$$

It can be written as:

$$\log(X_{ij}) = \alpha + \beta_1 T + \beta_2 R + \sum\gamma_{FH} FH_{ij} + \mathcal{E}_{ij} \tag{4.7}$$

and

$$\log(X_{ij}) = \alpha + \sum\beta_{1s} T_s + \sum\beta_{2s} R_s + \sum\gamma_{FH} FH_{ij} + \mathcal{E}_{ij} \tag{4.8}$$

where,

X_{ij} = net revenue (NR) / yield (Q) / Cost of production (TC) of farm *i* in j climatic zone

T_s and R_s = temperature and rainfall respectively

FH_{ij} = farm-household level socio-economic and other control variables

Therefore, here three types of dependent variable are used to estimate the climate sensitivity and all these dependent variables NR, Q and TC are in per acre units. *FH* includes a vector of household characteristics (such as experience, education, and household agricultural labour), a vector of farm characteristics (such as farm size, fertility of land and tenure status), a vector of institutional accessibility (such as extension advice, climate information, credit facility and irrigation facility) and a vector of district dummies. All these control variables are identified based on economic literature and earlier empirical studies. β's the vector of parameters which we are interested in, and $\mathcal{E}$ is a household-specific error term. Subscript *i* represents the individual farmer, *j* is as climatic zones and *s* indicates sowing, flowering and ripening periods for Aman rice. Without the *s* subscript in the temperature and rainfall it represents the whole Aman rice growing period. The parameters to be estimated are α, β and γ.

The net revenue (NR) is calculated by deducting production costs from gross revenue. The production cost includes all expenses related to seed, fertilizer, pesticides, irrigation, machinery, cost of hired labour and other costs related to production of Aman rice in that production year. Neither family labour nor the household's rent for land is included in the cost expenses (TC). Therefore, the NR is the measure of returns of land and family labour from Aman rice production and TC is the cost that farmers need to spend on the different inputs for Aman rice production. Based on the total cultivated land area of each household (measured in terms of acres), the net revenue, yield and cost of production per acre are calculated for each household.

As this is a cross sectional study, therefore while running the regression unobserved regional (zone/district in our study) factors that could confound the climate effects is considered. In STATA the 'areg' command is used to absorb zone/district dummies for this analysis. As the climate data (temperature and rainfall) is district specific, therefore temperature and rainfall variables in the regression are not identified due to correlation with district fixed effect. This research is to see the effect of temperature and rainfall, whereas they are not identified in the regression results. Therefore, to overcome this problem, with the climate variables this study also included climate variables multiplied with farm size (i.e. climate*farm size). Thus the general form of regression model for this study shown in equation 4.6 become

$$\log(X) = \alpha + \sum\beta_1 C + \sum\beta_2 Cf + \sum\gamma_{FH} FH + \mathcal{E} \quad (4.9)$$

More elaborately with temperature (T) and rainfall (R) variables shown in 4.7 and 4.8 become

$$\log(X_{ij}) = \alpha + \beta_1 T + \beta_2 R + \beta_3 T f_{ij} + \beta_4 R f_{ij} + \sum\gamma_{FH} FH_{ij} + \mathcal{E}_{ij} \quad (4.10)$$

and

$$\log(X_{ij}) = \alpha + \sum\beta_{1s} T_s + \sum\beta_{2s} R_s + \sum\beta_{3s}(T_s f_{is}) + \sum\beta_{4s}(R_s f_{ij}) + \sum\gamma_{FH} FH_{ij} + \mathcal{E}_{ij} \quad (4.11)$$

Where f_{ij} is the farm size of farmer *i* in climatic zone *j*. The argument is that the temperature and rainfall apply to an area of land. The bigger the area, the bigger its exposure. Empirical study also confirms that large farms are more sensitive to climate variables than small (Seo & Mendelsohn, 2008b). Moreover, even if β_1 and β_2 are not identified with district fixed effects, β_3 and β_4 could still identified and able to capture the effect of temperature and rainfall respectively on X (i.e., net revenue, yield, and cost) depends on farm size.

In this study, the semi-log functional form is used as the estimation model. The justification for the use of this form are several. First, strictly positive variables often have conditional distributions that are heteroskedastic or skewed which can be mitigated by taking their log (Wooldridge, 2013 :185). Wooldridge (2013) argued that using the log of a positive dependant variable often satisfies the Classical Linear Model assumptions more closely than models using dependant variable without log. He also argued that another potential benefit of taking the log of a variable is to narrow its range. This is particularly true of variables that can take large values. Narrowing the range of the dependant variable can make ordinary least square estimation less sensitive to outliers. Although it is acknowledged that using logarithmic transformations may create extreme values, that occur when the variable takes a value between 0 and 1 (Wooldridge, 2013). In this research, the three dependant variables, (net revenue, yield and cost of production) are all positive and take large values (range is shown in Table 4.2).

In applied economic research, this is also quite standard rules of thumb the log is taken when the dependant variable takes positive and large integer values, (such as in the case of a firm's annual sales, population, and wages/salaries) (Wooldridge, 2013: 185). However, there is no set pattern seen in the climate change impact studies. In their estimations, some studies on climate change impact analysis have used the semi-log form (Gbetibouo & Hassan, 2005; Sanghi & Mendelsohn, 2008) while others have used the simple linear form (Deressa & Hassan, 2009; Wang et al., 2014). In the absence of a strong theoretical argument it becomes an empirical question (Gujarati & Porter, 2010: 138). In such cases to select the functional form the Box-Cox test can be used (Maddala & Lahiri, 2009: 229).

The Box-Cox test results are shown in Table 4.3. In both net revenue and yield as dependant variable, the preferred model suggested by the test result is to use the log of the dependant variable (Maddala & Lahiri, 2009: 230; Stata, n. d.). However, in the case of cost of production the test result suggests choosing either the linear specification or the log of the dependant variable. As the net revenue and yield cases suggest the superiority of the log form, to make the result consistent and comparable this research takes the log of all three-dependant variables (net revenue, yield and cost of production) in the estimation of the models. The independent variables could also be taken in the log form. The climate variables are in multiplicative form with farm size. If their log form taken then it will create complications in calculating their marginal impact as well as in their interpretation. To avoid this unnecessary complications in their estimation, in this research the semi-log functional for is taken in the estimation model.

Table 4.3 : The Box-Cox test results

Dependant variable	Specification of climate variables	Test H_O	P-values (Prob. > chi^2
Net Revenue	Whole growth period	theta = 1 theta = 0	0.000 0.075
	3 growth stages	theta = 1 theta = 0	0.000 0.736
Yield	Whole growth period	theta = 1 theta = 0	0.000 0.050
	3 growth stages	theta = 1 theta = 0	0.000 0.077
Cost of Production	Whole growth period	theta = 1 theta = 0	0.000 0.000
	3 growth stages	theta = 1 theta = 0	0.000 0.000

Note: The Box-Cox test provides a comparison of the log versus the linear specification of dependant variable. If the test hypothesis theta = 0 is accepted then use log of dependant variable and if theta = 1 is accepted then use untransformed linear specification (Maddala & Lahiri, 2009: :230; Stata, n. d.).

The interpretation of the semi-log model is also appealing. The coefficient of the semi-log model provide the relative change in the given variable. Simply using the coefficient multiplied by 100 gives us an estimate of the exact percentage change for absolute change in the independent variable (Wooldridge, 2013: 185). In this research, as the semi-log form is used, the interpretation of the coefficient (beta) is a one-unit change in independent variable resulting change in dependant variable 100beta percent. For example, if coefficient of an independent variable is 0.29 then the interpretation would be, the dependant variable would increase 29 percent following a one unit change in that independent variable. This percentage change will give us a clear sense regarding the intensity of change in the dependant variable (i.e. net revenue, yield and cost of production) following a one unit change in climate variables (i.e. temperature and rainfall). In each case (i.e., net revenue, yield, and cost), this study estimates two different specifications for climate variables, the total Aman growth period and the different phases of the growth period. For each of these cases (i.e., the whole period and different phases of growth period) three models having different specifications are used to examine the robustness of the estimates; these are (1) considering temperature only, (2) considering rainfall only, and (3) considering both temperature and rainfall. Therefore, for net revenue, there are six specifications for climate variables, three considering the whole growth period and three considering the different stages of rice growth phase. Then all six models are considered using linear and quadratic term for climate variables. Thus, there are 12 specifications (6×2) for net revenue. In the same way, 12 models are estimated for yield and cost of production.

Following the standard literature on the Ricardian approach, when NR is the dependent variable then the explanatory variables are temperature, rainfall and relevant control variables, which are exogenous (Deressa & Hassan, 2009; Wang et al., 2009). However, in the case of Q as the dependent variable, this study intentionally avoids the use of farm inputs that are under the farmers' control, which might be endogenous to the model (Karn, 2014). Therefore, the model used here for the analysis is free from any likely endogeneity problem. That is why input variables are excluded from the production function which ensures to capture the full effect of climate variables and ensures capturing the short-run adaptation inclusively (Welch et al., 2010; Karn, 2014). The same argument is also applicable to the model where TC is the dependent variable.

Regarding any potential endogeneity problem, although input variables are omitted partly to avoid this problem, variable like farmer's self-reported land fertility may be endogenous. Farmers who have experienced good yields that year might report higher land fertility. During the data collection, the researcher was particularly concerned to minimize this possibility. While asking for the fertility of their land, farmers were adviced not to consider yield of current year only, but to base their opinion on their experience on yields over a longer period and without considering the influence of different factors like fertilizer use and climate. However, there might be endogeneity caused by unobserved variables. Given our small cross-sectional data, it is difficult to solve this problem completely, though the use of control variables, like farm size and the experience of farmer, would minimize endogeneity (Neven et al., 2009).

The reduced form estimation model, like the models used in this research, are criticised because of its implicit assumptions that may not hold in the context of research. Assumptions regarding on profit maximising farmers, the technical and allocative efficiency of farms, and proper functioning of markets are always in question especially in developing countries. However, research on technical, allocative, and scale efficiency of rice farms found a high level of efficiency[11] in Bangladesh (Wadud & White, 2000; Coelli et al., 2002; Rahman, 2003b; Wadud, 2003; Bäckman et al., 2011). Moreover, these researches also identified that experience and education of the household head, household labour, non-agricultural income, access to a credit facility, extension advice, irrigational infrastructure and regional variations are the major factors that caused efficiency differences among the farm households. In this research, all these variables are included in the models. Therefore, although the reduced form model here omits the data on purchased inputs, including several farm household variables (shown in Table 4.2) in the model to some extent compensates for the limitations of dropping information. Regional dummies as well as clustered standard errors around the zone are also considered here to control unobserved factors that are unique to zones that could influence the climate effects.

Thus, to examine the impact of climate change on Aman rice this study estimated multiple regression models using net revenue, yield and cost as dependant variables in three separate estimates with climate and some other relevant control variables. Altogether 36 (12×3) specifications are used here for the estimation. These models explore the likely range of functional relationships between our dependent variable of interest and climate. A number of models are used here because there is no strong theory to guide the specification of a model of the impact of climate change on rice crop. Therefore, the selected way to proceed is to explore different possibilities in empirical specification and then judge them using statistical criteria.

Cross-sectional studies usually suffer from the problems of heteroscedasticity and multicollinearity problems. The heteroscedasticity problem is tackled by considering the farm household level control variables in the regression. Unobserved regional factors that could confound the climate effects are also considered during the regression analysis. To tackle the multicollinearity problem, correlations among different farm-household control variables are tested at the beginning of the estimation procedure. In case of high and significance correlation some variables are dropped from the estimation model. Correlation among different variables are shown in Appendix 11.

In this study, climate variables are multiplied by farm size, as in the regression analysis temperature and rainfall variables are not identified due to correlation with district fixed

[11] The average score for technical efficiency found 0.83 (Bäckman et al., 2011) and 0.91 (Wadud, 2003), for allocative efficiency found 0.91 (Wadud, 2003), and scale efficiency found 0.933 (Coelli et al., 2002) and 0.921 (Wadud & White, 2000). The range for different efficiency score is 0-1, efficiency score 1 means fully efficient and 0 means completely inefficient.

effect. Therefore, a particular concern is how farm size relates to the dependant variables across zones, especially with the yield. Two simple approaches, correlation coefficient and non-parametric regression, are employed here to see whether there exists any relationship (Barrett et al., 2010). The statistic is calculated with dependent variables (net revenue, yield and cost) in levels as well as in logarithm specifications. The coefficient of correlations for the full sample as well as across zones/district are shown in Table 4.4. It can be seen that the coefficient of correlation between yield and farm size is positive but not statistically significant, and is equal to 0.0231 when computed in levels and 0.11 when measured in logarithms. Moreover, there exist no fixed pattern of relation between farm size and yield across zones, as the statistic is positive in some zones and negative in others, and none of the estimated values are statistically significant.

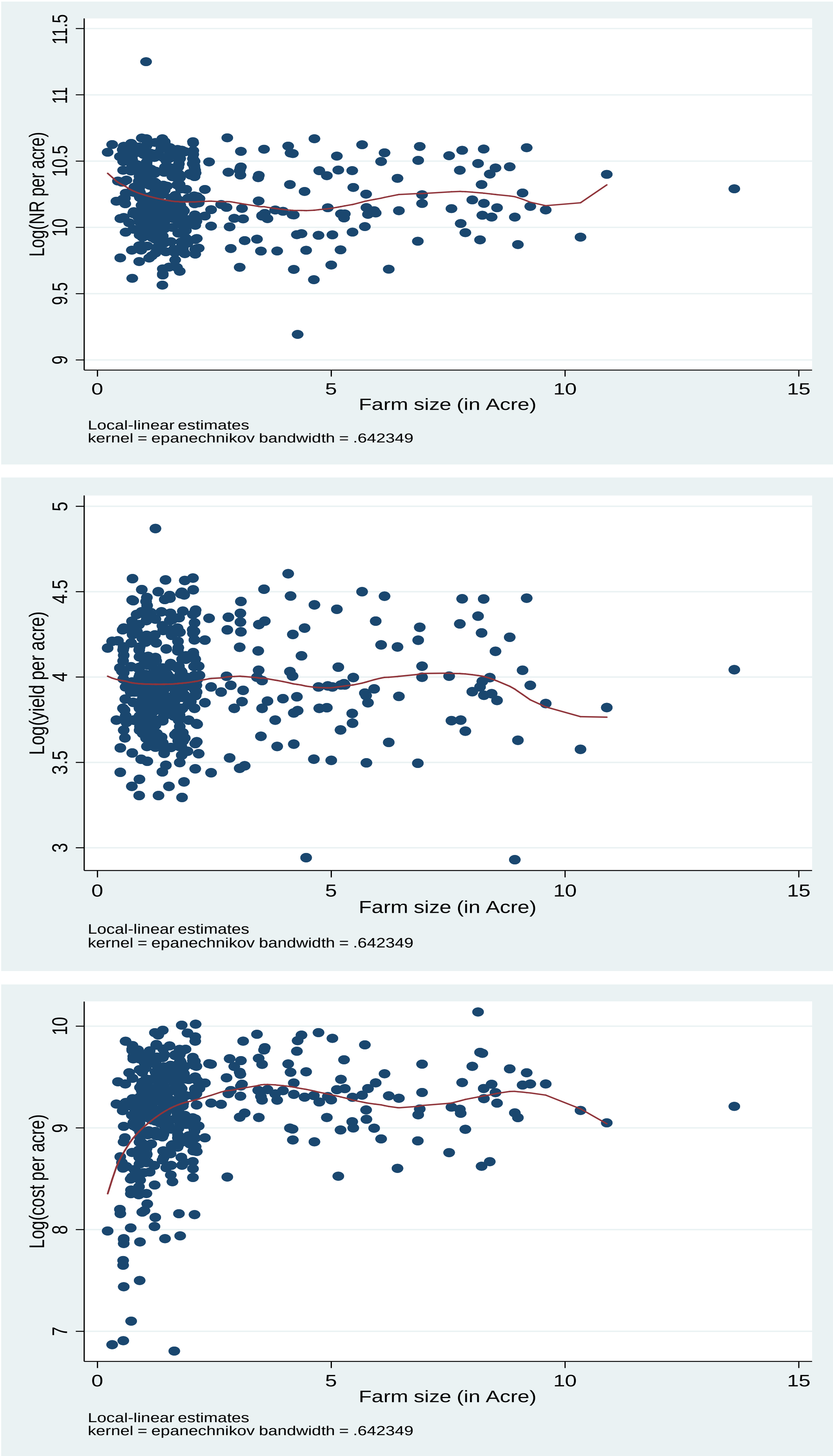
Table 4.4 : Correlation coefficient between farm size and NR, yield and cost

	Zone/District							
	A	B	C	D	E	F	G	Full sample
NR	0.0267	-0.1813	-0.0521	-0.0087	-0.0504	-0.0516	-0.2632	-0.332
Yield	0.1868	0.1431	-0.1077	0.0818	0.0529	0.1037	-0.2040	0.0231
Cost	0.2067	0.3661*	0.4867*	0.1593	0.1288	0.2254	0.0742	0.1479*
Log(NR)	0.0321	-0.1762	-0.382	0.0022	-0.0682	-0.0217	-0.2600	-0.0287
Log(Yield)	0.1939	0.1505	-0.1042	0.0787	0.0670	0.1398	-0.3237	0.110
Log(Cost)	0.1858	0.4152*	0.4532*	0.1727	0.1303	0.2333	0.0977	0.1827*

Note: NR denotes the net revenue; NR, yield and cost are in per acre; *Indicates statistical significance at the 5% level.

The results of non-parametric regression of the logarithm of net revenue, yield and cost of production on farm size is shown in Figure 4.3. The slope of the regression lines also does not show any particular pattern. By either of these simple methods, there is ample evidence that multiplication of farm size with the climate variables would not create a particular pattern of effect on the interested dependant variables (NR, yield and cost) in the estimation and is good solution to the problem of omitting of climate variables.

Figure 4.3 : Nonparametric regression of Log(NR/yield/cost) on farm size



4.4.3 Marginal Impact Analysis

As the semi-log functional form is used in the regression model (i.e. the dependent variable is only in log form), the marginal impact analysis will show the effect of a marginal change in temperature and rainfall variable on the relative change in dependant variable. Following Deressa and Hassan (2009), for the equation 4.9 the marginal impact of the climate variable (C_i) on the dependent variable evaluated at the mean of that variable is expressed as:

$$E\left[\frac{dlog(X)}{dC_i}\right] = \beta_1 + \beta_2\, E(f_i) \qquad (4.12)$$

where *i* represent temperature and rainfall.

To be specific, for example, in case of temperature, the marginal impact of temperature on the dependent variable would be (from equation 4.10):

$$E\left[\frac{dlog(X)}{dT}\right] = \beta_1 + \beta_3\, E(f) \qquad (4.13)$$

The derivation of equation 4.13 is given in the Appendix 7.

In the same way, the marginal impact of rainfall is also calculated. Moreover, the calculation is the same for each dependant variable (net revenue, yield and cost of production).

4.5 Results and Discussion

4.5.1 Regression Results for Net Revenue

The impact of climate variables on net revenue from Aman rice is examined here using multiple regression analysis. Climate variables[12] on two sets of rice growth periods (the complete growing period and three growth phases), two functional forms (linear and quadratic) and three different specifications are considered here. Overall, this gives a total of 12 models that include some combination of temperature and rainfall variables as independent variables. This approach is adopted because all these models collectively cover the possible forms of functional relationship between net revenue and climate.

The results of the analysis are reported in Table 4.5 and Table 4.6. Among all these models performance of the models is judged from the overview of the results considering the AIC, BIC, R^2, adjusted R^2 and the significance of the independent variables. From the overview of the results, it is found that models considering the three stages ofclimate variables are preferable in terms of number of significant climate variables. There is nosingle model in which climate variables (temperature and rainfall) are significant when the climate variables are considered for the whole Aman rice growth period (shown in Table 4.5). As our main interest is to see the impact of climate variables, the significance of those variables are important, and for the analysis we need choose a model from Table 4.4 with climate variables.

From the models, and considering the different stages of climate variables, R^2 and adjusted R^2 estimates favours model 4, 5, and 6 shown in Table 4.6. Model 4 considered only rainfall variables, whereas model 5 and 6 considered both temperature and rainfall variables with linear and quadratic specification respectively. Among these three, R^2 and adjusted R^2 estimates favours both model 5 and 6. No sign of superiority of quadratic specification (column 6 in Table 4.6) is evident from these statistics. However, the AIC and BIC support the linear specification of climate variables shown in column 5. Moreover, in this model, the number of significant climate variables are also more when compared to the other two. Therefore, the linear specification in column 5 is taken here as the base model to explain the effect of climate on net revenue. Thus, in the rest of this section, the effect of climate variables on net revenue is examined considering the climate variables for the three different stages, sowing, flowering and ripening (shown in column

[12] In addition to these models, estimation using alternative definitions of temperature (representative month's average, maximum and minimum) were also done, but the result does not vary too much.

5 of Table 4.6).Specification 5 in Table 4.6 indicates that all temperature variables are significant in explaining the variations of net revenue of aman rice across farm households. It is seen that temperature at the sowing and ripening period has a positive and significant effect on Aman rice net revenue. In contrast, temperature at the flowering stage has a negative impact on net revenue. To some extent this result is consistent with the other studies from African countries. Although previous studies using the Recardian approach were undertaken with a focus on net revenue of the farm, these considered several crops rather than a particular crop, and they also found the negative relationship between crop revenue and temperature (Kabubo-Mariara & Karanja, 2007; Deressa & Hassan, 2009). Moreover, previous studies considered the temperature variables from seasonal perspectives and not from the perspective of different growth stages of crops. Therefore, from this study it can be argued that for the Aman rice crop the net revenue decreases because of an increase in temperature in flowering stage in Bangladesh.

The results for rainfall are also showing a similar pattern, with sowing and ripening stages having a positive impact on net revenue whereas the flowering stage having negative impact on net revenue. The positive impact of a rainfall increase on the sowing and ripening stage is can be explained by Aman rice growing in the rainy season and requiring plenty of water at the sowing stage for land preparation and for plant physiology. This is also to some extent consistent with the other studies in African countries; although with these studies the net revenue of farms was associated with several crops, and the rainfall variable was considered from only a seasonal perspective (Gbetibouo & Hassan, 2005; Kabubo-Mariara & Karanja, 2007; Deressa & Hassan, 2009). However, the negative impact of rainfall in the flowering stage found here is slightly different from those studies in African countries as the rainfall variable is focused on particular stages of the crop's growth here compared to the seasonal perspective in the case of the African studies. Another possible explanation could be linked to the particular rice crop as during the flowering stage the Aman rice in Bangladesh may be experiencing optimal levels of rainfall. Therefore, any increase in rainfall might have a negative impact on crop growth and consequently have a negative impact on net revenue. This result also indicates that crop specific as well as place specific studies are required to examine the specific effect of climate change on agriculture.

In this study, the dependant variable (net revenue) is in log form so the estimated coefficient shows the relative change in net revenue. It is not wise to calculate the magnitude of total change in net revenue using these estimated coefficients directly because the climate variables have a multiplicative coefficient with farm size. Therefore, it is interpreted from the view point of its marginal impact, which has explained later.

Among all the farm household level control variables, only the farm size and fertility of the land have a significant value, and both have a positive impact on the net revenue, which is consistent in all the models in terms of their sign and significant. This also showed the robustness of our estimates. Apart from these two variables, although other variables are not significant, their signs are consistent with the usual economic meaning. In the case of the long established debate of an inverse relationship between farm size and productivity, the literature now supports a positive relationship (Wattanutchariya & Jitsanguan, 1992; Ram et al., 1999). Moreover, Chand et al. (2011) found that despite superior production performance, small farms in India are weak in terms of generating adequate income and sustaining livelihoods. Rahman and Rahman (2009) found that farm size is positively related to productivity and efficiency in rice production in Bangladesh. Therefore, positive farm size and productivity as well as efficiency might be the possible explanation for the result found in this study that there is a positive impact of farm size on net revenue.

Table 4.5 : Models considering the climate variables for whole Aman rice growth period (Dependant variable: log of Aman rice net revenue)

VARIABLES	1	2	3	4	5	6
Temp*fsize	-0.00169	0.00139			-0.0142	-0.00162
	(0.00587)	(0.00597)			(0.0138)	(0.0356)
Temp sq. * fsize		-5.52e-05				8.84e-06
		(0.000208)				(0.00116)
Rain * fsize			4.90e-07	5.02e-05	-8.95e-06	4.78e-05
			(3.77e-06)	(3.02e-05)	(9.86e-06)	(9.27e-05)
Rain sq. * fsize				-1.59e-08		-1.54e-08
				(9.62e-09)		(2.35e-08)
Experience	0.00142	0.00142	0.00141	0.00144	0.00144	0.00144
	(0.000989)	(0.000989)	(0.000980)	(0.000985)	(0.00101)	(0.00101)
Education	0.000544	0.000544	0.000537	0.000451	0.000515	0.000453
	(0.00203)	(0.00203)	(0.00203)	(0.00202)	(0.00201)	(0.00203)
HH agri. Labour	0.0108	0.0108	0.0108	0.0109	0.0108	0.0109
	(0.00646)	(0.00646)	(0.00647)	(0.00649)	(0.00645)	(0.00650)
Farm size	0.0430	-	-0.00572	-0.0410*	0.412	-
	(0.168)		(0.00458)	(0.0204)	(0.403)	
Fertility of land	0.0269***	0.0269***	0.0269***	0.0270***	0.0269***	0.0270***
	(0.00342)	(0.00342)	(0.00342)	(0.00343)	(0.00342)	(0.00345)
Tenure status	-0.00879	-0.00879	-0.00874	-0.00884	-0.00864	-0.00883
	(0.0169)	(0.0169)	(0.0169)	(0.0168)	(0.0169)	(0.0168)
Ext. advice	0.00931	0.00931	0.00935	0.00914	0.00896	0.00912
	(0.0163)	(0.0163)	(0.0163)	(0.0164)	(0.0165)	(0.0164)
Climate info.	0.00160	0.00160	0.00155	0.00142	0.00185	0.00144
	(0.0162)	(0.0162)	(0.0162)	(0.0163)	(0.0163)	(0.0161)
Credit facility	0.00661	0.00661	0.00667	0.00597	0.00641	0.00597
	(0.0133)	(0.0133)	(0.0132)	(0.0136)	(0.0135)	(0.0136)
Irrigation facility	-0.000193	-0.000193	-0.000193	-0.000204	-0.000195	-0.000204
	(0.000234)	(0.000234)	(0.000233)	(0.000236)	(0.000236)	(0.000237)
Constant	10.09***	10.09***	10.09***	10.09***	10.09***	10.09***
	(0.0349)	(0.0349)	(0.0350)	(0.0347)	(0.0351)	(0.0350)
Model Summary						
Observations	432	432	432	432	432	432
R-squared	0.777	0.777	0.777	0.777	0.777	0.777
Adj. R-squared	0.7680	0.7681	0.7680	0.7677	0.7676	0.7671
AIC	-557.4953	-557.4971	-557.4671	-557.8581	-557.6385	-557.8584
BIC	-533.0847	-533.0866	-533.0565	-533.4475	-533.2279	-533.4478

Note: "-" denotes as omitted because of collinearity. Standard errors are in parentheses; *** p<0.01, ** p<0.05, * p<0.1; Regression results for log of net revenue of Aman rice is shown here. Climate variables are temperature and rainfall for the Aman rice complete growing period. Different columns show the different possible combinations of climate variables to cover all possible functional relationships between net revenue and climate. In columns 1 & 2 only the temperature variable is considered but they use linear and quadratic form respectively. Column 3 & 4 are like the previous two but here, instead of temperature only the rainfall variable is also considered. In columns 5 & 6 the temperature and rainfall variables are both considered with linear and quadratic forms respectively. Some of the variables (Temp, temp sq,, rain, and rain sq.) are not reported here as they are omitted because of collinearity. The full table is shown in Appendix 4.

Table 4.6 : Models considering the climate variables for three phases of Aman rice growth period (Dependant variable: log of Aman rice net revenue)

VARIABLES	1	2	3	4	5	6
Temp: sow * fsize	-0.0159	-1.141			0.0441*	-4.346***
	(0.0140)	(1.117)			(0.0195)	(0.443)
Temp: sow sq. * fsize		0.0197				0.0717***
		(0.0194)				(0.00742)
Temp: flower * fsize	0.0110	1.229			-0.127***	3.068***
	(0.00830)	(0.972)			(0.0255)	(0.324)
Temp: flower sq. * fsize		-0.0220				-0.0556***
		(0.0175)				(0.00586)
Temp: ripe * fsize	-0.0111	-0.0589			0.0247**	2.202***
	(0.00980)	(0.301)			(0.00697)	(0.212)
Temp: ripe sq. * fsize		0.00122				-0.0514***
		(0.00705)				(0.00492)
Rain: sow * fsize			8.55e-05***	0.000456***	0.000161***	-0.000232***
			(1.40e-05)	(4.05e-05)	(2.85e-05)	(1.94e-05)
Rain: sow sq. * fsize				-2.01e-07***		-
				(2.84e-08)		
Rain: flower * fsize			-0.000199***	-0.00119***	-0.000662***	-
			(4.15e-05)	(0.000226)	(9.98e-05)	
Rain: Flower sq. * fsize				9.60e-07**		-
				(2.68e-07)		
Rain: ripe * fsize			-0.000476***	-0.00185*	0.00128**	-
			(8.67e-05)	(0.000839)	(0.000380)	
Rain: ripe sq. * fsize				2.58e-05		-
				(1.49e-05)		
Experience	0.00143	0.00143	0.00139	0.00142	0.00142	0.00142
	(0.00102)	(0.00101)	(0.000999)	(0.00101)	(0.00101)	(0.00101)
Education	0.000567	0.000542	0.000468	0.000362	0.000362	0.000362
	(0.00205)	(0.00204)	(0.00204)	(0.00203)	(0.00203)	(0.00203)
HH agri. Labour	0.0111	0.0114	0.0113	0.0114	0.0114	0.0114
	(0.00627)	(0.00638)	(0.00639)	(0.00638)	(0.00638)	(0.00638)
Farm Size	0.387	-	0.0348***	0.141**	1.884***	-
	(0.420)		(0.00898)	(0.0552)	(0.186)	
Fertility of land	0.0268***	0.0266***	0.0260***	0.0260***	0.0260***	0.0260***
	(0.00327)	(0.00312)	(0.00318)	(0.00319)	(0.00319)	(0.00319)
Tenure status	-0.00916	-0.00885	-0.00846	-0.00876	-0.00876	-0.00876
	(0.0168)	(0.0169)	(0.0170)	(0.0169)	(0.0169)	(0.0169)
Ext. advice	0.00887	0.00891	0.00993	0.00971	0.00971	0.00971
	(0.0165)	(0.0167)	(0.0167)	(0.0168)	(0.0168)	(0.0168)

Climate info.	0.00187	0.00152	0.00166	0.00184	0.00184	0.00184
	(0.0164)	(0.0163)	(0.0162)	(0.0163)	(0.0163)	(0.0163)
Credit facility	0.00618	0.00682	0.00795	0.00693	0.00693	0.00693
	(0.0134)	(0.0138)	(0.0133)	(0.0138)	(0.0138)	(0.0138)
Irrigation facility	-0.000203	-0.000222	-0.000218	-0.000228	-0.000228	-0.000228
	(0.000230)	(0.000239)	(0.000240)	(0.000241)	(0.000241)	(0.000241)
Constant	10.09***	10.10***	10.10***	10.10***	10.10***	10.10***
	(0.0353)	(0.0345)	(0.0357)	(0.0363)	(0.0363)	(0.0363)
Model Summary						
Observations	432	432	432	432	432	432
R-squared	0.778	0.778	0.778	0.779	0.779	0.779
Adj. R-squared	0.7673	0.7665	0.7681	0.7668	0.7668	0.7668
AIC	-558.1745	-554.8641	-559.7295	-560.4795	-560.4796	-560.4783
BIC	-533.7639	-522.3167	-535.3190	-536.0690	-536.0690	-536.0677

Note: "-" denotes as omitted because of collinearity. Standard errors are in parentheses; *** p<0.01, ** p<0.05, * p<0.1; This table is like Table 4.5 but here the climate variable is for three growth phases of Aman rice. See the explanation in the note for Table 4.5. Some of the variables (Temp sow, Temp sow sq, Temp flow, Temp flow sq, Temp ripe, Temp ripe sq, rain sow, rain sow sq, rain flow, rain flow sq, rain ripe, and rain ripe sq,) are not reported here as they are omitted because of collinearity. The full table is shown in Appendix 4.

4.5.1.1 Marginal Impact analysis for Net Revenue

The marginal impact of temperature and rainfall on net revenue from Aman rice is shown in Table 4.7. Here the linear specification for the climate variable with all three stages of growth is considered (from column 5 of table 4.6). It is found that each 1^0C increase in average temperature in the sowing and ripening stage would increase the net revenue per acre by around 10 percent and 6 percent respectively. In contrast, such a change will reduce the yield by around 29 percent in the case of flowering phase.

Table 4.7 : Marginal impact of climate change on net revenue

Variables	Stages	% change in NR
Temperature	Sowing	10.36
	Flowering	-28.85
	Ripening	5.80
Rainfall	Sowing	0.04
	Flowering	-0.16
	Ripening	0.3

It is also found that the effect of temperature is much more than that of rainfall on the net revenue (NR) of Aman rice. Moreover, although warmer conditions in the sowing and ripening stages will have a positive effect, the negative effect from flowering stage will cause greater damage to the NR. As a result, the overall effect of climate change in NR of Aman rice in Bangladesh would be negative. The negative effect on farm net revenue from the previous studies in African countries (Gbetibouo & Hassan, 2005; Kabubo-Mariara & Karanja, 2007; Deressa & Hassan, 2009) cannot identify the exact stages where the effects lie. From this study, it is found that it is during the flowering stage that the negative effect of climate change causes the decrease in NR.

Overall, it is seen that an increase in climate variables in the sowing and ripening stage is associated with an increase in net revenue, whereas increase in these variables lowers the net revenue during the flowering stage. Further research could be undertaken to see the effect by zone. For example, what are the climate variables' effect on net revenue in zones that have higher or lower temperature and rainfall variables in different stages of rice growth? Or, what are net revenue affects in zones that have higher (or lower) sowing (or flowering) temperatures because of zone differences in, say, soil quality or input intensity? Because of data limitations, answering such questions was beyond the scope of this research. Future research in these areas could provide interesting findings as well as more focused policy advice.

4.5.2 Regression Results for Yield

Like the previous analysis, to examine the effect of climate variables on Aman rice yields, this study estimated the multiple regressions for two sets of rice growth periods (one is for the complete growing period and the other is for the three stages of the growth period) and six different specifications of independent variables[13]. Therefore, initially the analysis starts with 12 models with different combinations of temperature and rainfall variables as independent variables. It is assumed that collectively all these models will cover the possible forms of functional relationship between Aman rice yield and climate.

The results are reported in Table 4.8 and Table 4.9. The preferred model is based on the statistics contained in the tables, including the AIC, BIC, R^2, adjusted R^2 and the significance of the independent variables. The results support the following findings: (1) Like the previous analysis for net revenue, here models considering the three stages of climate variables are preferable to those for the whole period in terms of number of significant climate variables. (2) Unlike the net revenue analysis, here the quadratic specifications are superior to the linear ones. (3) Like the net revenue, here also the models with both temperature and rainfall variables are better than those containing either one only.

Of the specifications which have climate variables for different growth periods (shown in Table 4.9), the preferred specification is chosen by examining the AIC, BIC, R^2 and adjusted R^2. Although the adjusted R^2 favour both the linear and quadratic specifications in column 5 and 6 respectively, the AIC and BIC is in favour of linear specification in column 5. Moreover, the quadratic specification (in column 6) has omitted rainfall variables. Therefore, the linear specification in column 5 is taken here as the base model to explain the effect of climate on yield. Thus, in the rest of this section the effect of climate variables on yield is examined considering the climate variables for three different stages, sowing, flowering and ripening (Specification in column 5 of Table 4.9).

The specification in column 5 of Table 4.9 indicates that all the temperature variables are significant in explaining the variations of yield across farm households. The average temperature in the sowing phases has a positive and significant effect on Aman rice yield in Bangladesh. Knowledge of crop science suggest that crop yields are most likely to suffer from high temperature at the seedling stage (Rosenzweig et al., 2001), which is

[13] In addition to these models, estimated models with alternative definitions of temperature (representative month's average, maximum and minimum) were also tried, but the result showed little difference.

quite opposite to this study found. The possible explanation could be related to rice crop as well as the country of study.

It is also found that temperature increase in ripening stage also has a positive effect on Aman rice yield. The findings is consistent with that shown in column 6 associated with the quadratic specification which indicates that temperature in the ripening period will increase yield at an decreasing rate. In terms of consistency with the literature, Welch et al. (2010) found the same positive correlation between rice yield and temperature at the ripening phase.

The findings above suggested that present mean sowing and mean ripening temperature might be in the optimum temperature range for Aman rice production in Bangladesh. Therefore, an increasing trend in sowing and ripening stage could increase rice yield. Science of rice production supports the validity of this argument as the maximum optimum temperature for rice sowing time is 25-35^{0}C (Datta, 1981; Wassmann et al., 2009a) whereas, the average temperature for that time in different zones in Bangladesh ranges from 28.2^{0}C to 29.3^{0}C (shown in Table 4.1) that do not exceed the threshold level. Consistent with this study, Welch et al. (2010) also found a positive impact of maximum temperature on rice yield during the vegetative and ripening phase. Some recent empirical researches on rice yield also found that increase in mean temperature is associated with increase in rice yield (Zhang et al., 2010; Chao et al., 2014).

In contrast, it is also found that temperature in the flowering phase has a negative effect on yield. This is consistent with the knowledge of crop science that higher temperature at the reproductive stage of rice plant causes pollen to lose viability in grain (Rosenzweig et al., 2001) and reduces spikelet fertility from 90 to less than 20% (Wassmann et al., 2009a). Moreover, many studies show that pests become more active in warmer weather (Estay et al., 2009). From the coefficient of temperature for all growth phase, it is also seen that the degree of sensitivity is greater in the flowering stage than that of the sowing and ripening stages. Therefore, although temperature increase in the sowing and ripening phases may have a positive effect on rice yield, temperature increases in the flowering stage causes greater damage. This may be why empirical research found a negative impact of temperature increase on rice yield (Sarker et al., 2014; Le, 2016; Wang et al., 2017).

Rainfall in all three phases has a significant effect on Aman rice yield and most of them are consistent with both linear and quadratic specifications considering rainfall only (specifications in 3 and 4 of Table 4.9). Rainfall during the sowing and ripening stages has a positive impact on yield, whereas the effect is negative during the flowering stage. Aman rice is grown in rainy season in Bangladesh and during the sowing season it requires more water. Therefore, intuitively it is logical that an increase in rainfall in that period would increase production. In contrast, an increase in rainfall has a negative impact during the flowering stage. Cloudiness caused by rainfall depresses solar radiation, which reduces pollination and grain formation at his stage. Moreover, wet conditions increase fungi and bacteria (Rosenzweig et al., 2001). However, the negative effect from rainfall increase in flowering stage is less than the positive effect from sowing and ripening stages, caused to have overall positive effect on rice yield from rainfall increase. This positive effect of rainfall on yield is also consistent with some empirical studies (Felkner et al., 2009; Chao et al., 2014; Sarker et al., 2014).

However, the degree of the effect may vary from zone to zone. As the sowing and flowering stage temperatures are associated with an increase in yield, the intensity of that increase may vary from zone to zone. Investigating this issue could be a research area warranting further attention where it could be explored the yield trend in zones. Investigation would be how the benefit trend in yield varies among zones with lower/higher sowing and ripening stage temperature. Or how zone differences such as soil quality may affect yield trend in zones with higher (or lower) sowing (or flowering) temperature. As the soil quality data is limited here, therefore it is beyond the scope of this research but future research can be explored those also.Overall, this study finds that both temperature and rainfall variables at each stage can be significant in explaining the variation of Aman rice yield across farm households. Although the mechanisms of climate change impact on rice yield is inconclusive as some studies found positive impact whereas some found the opposite, the results from this study could provide an explanation channel how temperature and rainfall of different stage of rice plant growth affect rice yield. Among all the farm household level control variables the experience and education of household head, farm size and fertility of the land have a significant value. All of them also have a positive impact on the yield. Although other variables are not significant, their signs are consistent with the economic reasoning.

Table 4.8 : Models considering the climate variables for whole Aman rice growth period (Dependant variable: log of Aman rice yield)

VARIABLES	1	2	3	4	5	6
Temp*fsize	-0.0132	0.0127			0.0392	0.0371
	(0.0135)	(0.0133)			(0.0376)	(0.108)
Temp sq. * fsize		-0.000453				-0.00109
		(0.000472)				(0.00351)
Rain * fsize			1.14e-05	-0.000185*	3.73e-05*	-0.000240
			(7.40e-06)	(9.22e-05)	(1.87e-05)	(0.000272)
Rain sq. * fsize				6.26e-08*		7.50e-08
				(3.03e-08)		(6.93e-08)
Experience	0.00326*	0.00326*	0.00325**	0.00313**	0.00317*	0.00316*
	(0.00134)	(0.00134)	(0.00132)	(0.00127)	(0.00136)	(0.00135)
Education	0.00511*	0.00511*	0.00517*	0.00551*	0.00523*	0.00553*
	(0.00258)	(0.00258)	(0.00258)	(0.00258)	(0.00256)	(0.00261)
HH agri. Labour	-0.00655	-0.00656	-0.00649	-0.00695	-0.00662	-0.00695
	(0.0115)	(0.0115)	(0.0116)	(0.0118)	(0.0116)	(0.0118)
Farm size	0.370	-	-0.0202	0.119*	-1.171	-
	(0.379)		(0.0154)	(0.0597)	(1.092)	
Fertility of land	0.0226**	0.0226**	0.0226**	0.0224**	0.0227**	0.0224**
	(0.00892)	(0.00891)	(0.00896)	(0.00896)	(0.00896)	(0.00887)
Tenure status	0.0110	0.0110	0.0107	0.0111	0.0104	0.0113
	(0.0252)	(0.0252)	(0.0252)	(0.0256)	(0.0256)	(0.0262)
Ext. advice	0.0429	0.0429	0.0433	0.0441	0.0444	0.0436
	(0.0237)	(0.0237)	(0.0238)	(0.0237)	(0.0229)	(0.0226)
Climate info.	0.00842	0.00841	0.00818	0.00871	0.00735	0.00934
	(0.0190)	(0.0190)	(0.0188)	(0.0190)	(0.0191)	(0.0204)
Credit facility	-0.0137	-0.0137	-0.0136	-0.0108	-0.0129	-0.0108
	(0.0204)	(0.0204)	(0.0202)	(0.0192)	(0.0206)	(0.0190)
Irrigation facility	-3.62e-06	-3.81e-06	-1.06e-06	4.37e-05	6.40e-06	4.73e-05
	(0.000368)	(0.000368)	(0.000373)	(0.000363)	(0.000366)	(0.000372)
Constant	3.779***	3.779***	3.778***	3.775***	3.778***	3.774***
	(0.0623)	(0.0623)	(0.0630)	(0.0626)	(0.0643)	(0.0635)
Model Summary						
Observations	432	432	432	432	432	432
R-squared	0.656	0.655	0.656	0.659	0.657	0.659
Adj. R-squared	0.6414	0.6414	0.6420	0.6440	0.6417	0.6433
AIC	-321.4605	-321.4273	-322.1526	-325.6847	-322.9063	-325.8687
BIC	-297.0499	-297.0168	-297.7420	-301.2742	-298.4957	-301.4582

Note: "-" denotes as omitted because of collinearity. Standard errors are in parentheses; *** p<0.01, ** p<0.05, * p<0.1; Regression results for log of yield of Aman rice are shown here. Climate variables are temperature and rainfall for the whole Aman rice growing period. Different columns show the different possible combinations of climate variables to cover the full possible range of functional relationships between net revenue and climate. In columns 1 & 2 the temperature variable only is considered but using linear and quadratic form respectively. Columns 3 & 4 are just like the previous two but here instead of temperature, only the rainfall variable is considered. In columns 5 & 6 the temperature and rainfall variables are both considered with linear and quadratic form respectively. Some of the variables (Temp, temp sq,, rain, and rain sq.) are not reported here as they are omitted because of collinearity. The full table is shown in Appendix 4.

Table 4.9 : Models considering the climate variables for three phases of Aman rice growth period (Dependant variable: log of Aman rice yield)

VARIABLES	1	2	3	4	5	6
Temp: sow * fsize	-0.0472	-4.174			0.718***	-11.27***
	(0.0388)	(2.180)			(0.0549)	(0.468)
Temp: sow sq. * fsize		0.0707				0.186***
		(0.0379)				(0.00780)
Temp: flower * fsize	0.0264	2.494			-0.948***	6.565***
	(0.0257)	(1.908)			(0.0805)	(0.399)
Temp: flower sq. * fsize		-0.0438				-0.118***
		(0.0343)				(0.00719)
Temp: ripe * fsize	-0.0287	2.459***			0.225***	7.465***
	(0.0303)	(0.645)			(0.0201)	(0.266)
Temp: ripe sq. * fsize		-0.0579***				-0.174***
		(0.0152)				(0.00619)
Rain: sow * fsize			0.000242**	0.00215***	0.00128***	-0.000513***
			(8.16e-05)	(0.000143)	(7.19e-05)	(2.80e-05)
Rain: sow sq. * fsize				-1.10e-06***		-
				(7.40e-08)		
Rain: flower * fsize			-0.000533**	-0.00806***	-0.00425***	-
			(0.000179)	(0.000414)	(0.000289)	
Rain: Flower sq. * fsize				7.40e-06***		-
				(4.15e-07)		
Rain: ripe * fsize			-0.00125*	-0.0116***	0.0137***	-
			(0.000639)	(0.00105)	(0.00119)	
Rain: ripe sq. * fsize				0.000194***		-
				(1.78e-05)		
Experience	0.00328*	0.00312*	0.00318*	0.00310*	0.00310*	0.00310*
	(0.00139)	(0.00132)	(0.00132)	(0.00131)	(0.00131)	(0.00131)
Education	0.00517	0.00571*	0.00498*	0.00531*	0.00531*	0.00531*
	(0.00272)	(0.00265)	(0.00249)	(0.00256)	(0.00256)	(0.00256)
HH agri. Labour	-0.00582	-0.00583	-0.00515	-0.00590	-0.00590	-0.00590
	(0.0112)	(0.0113)	(0.0110)	(0.0112)	(0.0112)	(0.0112)
Farm Size	1.247	-	0.0898**	1.286***	1.479**	-
	(1.224)		(0.0336)	(0.0717)	(0.467)	
Fertility of land	0.0224**	0.0211*	0.0201*	0.0198*	0.0198*	0.0198*
	(0.00901)	(0.00880)	(0.00899)	(0.00912)	(0.00912)	(0.00912)
Tenure status	0.00990	0.0105	0.0114	0.0107	0.0107	0.0107
	(0.0256)	(0.0267)	(0.0261)	(0.0267)	(0.0267)	(0.0267)
Ext. advice	0.0421	0.0431	0.0450	0.0449	0.0449	0.0449
	(0.0218)	(0.0233)	(0.0236)	(0.0237)	(0.0237)	(0.0237)
Climate info.	0.00885	0.0110	0.00831	0.0117	0.0117	0.0117
	(0.0205)	(0.0216)	(0.0213)	(0.0218)	(0.0218)	(0.0218)
Credit facility	-0.0148	-0.00967	-0.0102	-0.00943	-0.00943	-0.00943
	(0.0205)	(0.0177)	(0.0173)	(0.0176)	(0.0176)	(0.0176)

Irrigation facility	-3.18e-05	1.64e-05	-7.13e-05	2.76e-06	2.77e-06	2.80e-06
	(0.000364)	(0.000343)	(0.000379)	(0.000344)	(0.000344)	(0.000345)
Constant	3.779***	3.776***	3.786***	3.782***	3.782***	3.782***
	(0.0683)	(0.0687)	(0.0679)	(0.0696)	(0.0696)	(0.0696)
Model Summary						
Observations	432	432	432	432	432	432
F						
R-squared	0.658	0.666	0.664	0.670	0.670	0.670
Adj. R-squared	0.6419	0.6494	0.6482	0.6523	0.6524	0.6523
AIC	-324.2295	-335.3883	-331.8251	-340.1324	-340.1338	-340.1210
BIC	-299.8189	-310.9777	-307.4145	-315.7219	-315.7233	-315.7105

Note: "-" denotes as omitted because of collinearity. Standard errors are in parentheses; *** p<0.01, ** p<0.05, * p<0.1 ; This table is like the same as Table 4.8 but here the climate variable is for the three phases of Aman rice growing. See the explanation at the below of Table 4.8 in note section. Some of the variables (Temp sow, Temp sow sq, Temp flow, Temp flow sq, Temp ripe, Temp ripe sq, rain sow, rain sow sq, rain flow, rain flow sq, rain ripe, and rain ripe sq,) are not reported here as they are omitted because of collinearity. The full table is shown in Appendix 4.

4.5.2.1 Marginal Impact Analysis for Yield

The marginal impact of climate variables on yield of Aman rice is shown in Table 4.10. Here the linear specification for climate variable with all three stages of growth is considered (Model 5 of Table 4.9). The derivation of marginal impact equation is shown in Appendix 8. It is found that each 1^0C increase in average temperature in the sowing and ripening stages would increase the rice yield by 169% and 53% respectively for an average[14] farm in Bangladesh. In contrast, such a temperature change will reduce yield by 223% in the case of the flowering phase.

Table 4.10 : Marginal impact of climate change on yield per acre

Variables	Stages	% change in Yield
Temperature	Sowing	168.73
	Flowering	-222.78
	Ripening	52.88
Rainfall	Sowing	0.30
	Flowering	-1.38
	Ripening	3.22

It is also found that the effect of temperature is much more than that of rainfall on the yield of Aman rice. Moreover, although warmer conditions in the sowing and ripening period will have a positive effect on yield, the negative effect in the flowering stage will damage the yield more. The marginal impact found here appears to be large which might raise questions concerning their plausibility. However, it can be seen that a temperature increase in the sowing and ripening stage is associated with significant increases in yields, counteracting a significantly lower yield in the flowering season. The offsetting of the positive impact of sowing and ripening season temperature effects by the negative impact during the flowering season might be the explanation for no effect found when considering the whole growth period temperature (shown in Table 4.8). This again shows the importance of disaggregation of climate data for the different growth stages of the crop to identify more specific effects of climate change.

Previous studies on rice crops found that the temperature increase has a negative impact on rice production (Chen et al., 2014; Karn, 2014; Pattanayak & Kumar, 2014; Sarker et al., 2014). Although the present study reaches a similar conclusion, by looking at the all three stages of growing period it explains the reason more accurately. It is understood that it is the flowering stage in which the temperature and rainfall cause the negative influence, which in turn affects the overall reduction in quantity produced.

[14] Average farm size from the data is 2.35 acres.

4.5.3 Regression Results for Cost of Production

Like the previous two analyses, to examine the effect of climate variables on the cost of production of Aman rice, this study estimated multiple regressions using climate variables for two sets of rice growth periods (the whole growth period and the three stages of growth period). In addition, there are six different specifications of independent variables[15]. Again, it is expected that these different specifications of temperature and rainfall variables collectively cover all the possible forms of functional relationship between cost of Aman rice production and climate variables.

The results are reported in Table 4.11 and Table 4.12 which includes the AIC, BIC, R^2, adjusted R^2 and the significance of the independent variables. The results indicates: (a) As like the previous two analysis, the models considering the three stages of growth are preferable to models considering the whole growth period, although in terms of number of significant climate variables both models are quite similar. (b) Like the previous analyses here also the quadratic models are superior to the linear one as they improve the result qualitatively, and (c) like the previous two analysis here also the models with both temperature and rainfall variables are better than those that contains only either one.

Examining all the models shown in Table 4.11 and Table 4.12, the adjusted R^2 favours linear Models 11 and quadratic Models 6, 10 and 12. In quadratic Model 6 (in Table 4.11), the climate variables for the whole growth period are specified, whereas in the three other models all three phases of the growth period are specified. Models with all three phases of growth period can show impact of climate change on Aman rice cost of production in more disaggregated level. Therefore, this study prefers to choose models with climate variables for three phases of rice growth. In quadratic model 10 (in Table 4.12), the rainfall variable only considered, whereas in the two other model (model 11 and 12 in Table 4.12) both the climate variables are considered. Thus, in the rest of this section analysis is based on both linear and quadratic specifications where climate variables in different phases of the rice-growing period are specified (Models 11 and 12 in Table 4.12).

Model 11 in Table 4.12 indicates that the average temperature in the sowing and ripening phases has a positive and significant effect on the cost of Aman rice production. This finding is consistent with the quadratic model 12, which indicates that temperature in the sowing period will increase cost but at a decreasing rate. In contrast, Model 11 and 12

[15] In addition to these models, models with alternative definitions of temperature (representative month's average, maximum and minimum) were estimated, but the results showed little difference.

indicates that temperature in the flowering phase has a negative effect on cost of production. As model 12 is a quadratic one with positive coefficient for quadratic term therefore, it indicates that temperature increase in the flowering phase decreases the cost but at a decreasing rate. Although the temperature in the ripening phase is not statistically significant in linear model 12, the sign is consistent with the linear model 11.

Rainfall during the sowing and ripening stages has a significant and positive effect on Aman rice cost (shown in Models 11 in Table 4.12). Findings of a positive impact of rainfall during the sowing and ripening phases on cost of production is quite interesting. This is perhaps more surprising because, Aman rice grows in rainy season and the finding suggests that the cost of production increases with rain. A possible explanation could be that rainfall causes cloudiness, which hampers the photosynthesis process, causing nutrient deficiency as well as causing proliferation of fungi and root rot (Rosenzweig et al., 2001; Groth & Hollier, n.d.). To prevent these problems, farmers need to increase expenditure on supplementary nutrients, fertilizers and chemicals for pest control. However, the degree of the effect may vary from zone to zone because of zone differences in terms of rainfall as well as soil quality and input intensity. Zones with lower rainfall may be subject to lower (or higher) increases in cost because of these zone differences. Exploration of this could represent a future area of research.In the case of the flowering stage, the result here shows a negative effect of rainfall on the cost of production (shown in Model 11 in Table 4.12). Intuitively it is logical that in the flowering stage, the rice plant is quite mature and at this stage, a good amount of water is required for the development of the plant. Agronomic studies confirm that optimum time of flowering for rain fed rice crops often depends upon the availability of water (Fukai, 1999). Therefore, an increase in rain reduces the cost incurred for supplementary irrigation or chemical nutrient supplements. Again, the differences in the degree of effect might vary due to the zone differences like soil quality or input intensity.

Overall, this study finds that both temperature and rainfall variables of different phase of rice plant growth can explain significantly the variation of Aman rice costs across farm households. It also finds some evidence of non-linearity in the climate variable effect on the cost of production. Among the entire farm household level control variables, only the education of household head, household level agricultural labour and irrigation facility have statistically significant values and their sign is consistent with usual economic reasoning. Although other variables are not significant, their signs are also consistent with the usual economic reasoning.

Table 4.11 : Models considering the climate variables for whole Aman rice growth period (Dependant variable: log of Aman rice cost of production)

VARIABLES	1	2	3	4	5	6
Temp*fsize	-0.105*	0.107*			-0.0852	0.406***
	(0.0488)	(0.0501)			(0.0888)	(0.0879)
Temp sq. * fsize		-0.00372*				-0.0131***
		(0.00175)				(0.00285)
Rain * fsize			7.04e-05	-0.000355	1.39e-05	-0.00110***
			(3.75e-05)	(0.000374)	(8.49e-05)	(0.000260)
Rain sq. * fsize				1.36e-07		3.03e-07***
				(1.18e-07)		(6.93e-08)
Experience	0.000955	0.000955	0.000742	0.000467	0.000921	0.000858
	(0.00203)	(0.00203)	(0.00197)	(0.00192)	(0.00189)	(0.00187)
Education	0.0124**	0.0124**	0.0126**	0.0133**	0.0125**	0.0137**
	(0.00482)	(0.00481)	(0.00485)	(0.00540)	(0.00481)	(0.00546)
HH agri. Labour	-0.0823**	-0.0823**	-0.0826**	-0.0836**	-0.0824**	-0.0837**
	(0.0242)	(0.0242)	(0.0241)	(0.0251)	(0.0242)	(0.0258)
Farm size	3.014*	-	-0.0628	0.239	2.439	-
	(1.398)		(0.0414)	(0.265)	(2.627)	
Fertility of land	0.0113	0.0113	0.0115	0.0112	0.0113	0.0101
	(0.0123)	(0.0123)	(0.0123)	(0.0123)	(0.0122)	(0.0125)
Tenure status	0.0361	0.0361	0.0353	0.0362	0.0359	0.0395
	(0.0526)	(0.0526)	(0.0521)	(0.0525)	(0.0520)	(0.0524)
Ext. advice	0.0512	0.0512	0.0541	0.0558	0.0517	0.0486
	(0.0445)	(0.0445)	(0.0451)	(0.0452)	(0.0464)	(0.0456)
Climate info.	-0.0122	-0.0122	-0.0144	-0.0132	-0.0126	-0.00468
	(0.0401)	(0.0402)	(0.0405)	(0.0383)	(0.0399)	(0.0363)
Credit facility	-0.0289	-0.0290	-0.0270	-0.0210	-0.0286	-0.0202
	(0.0179)	(0.0179)	(0.0200)	(0.0195)	(0.0188)	(0.0183)
Irrigation facility	0.00221**	0.00221**	0.00223**	0.00233***	0.00221**	0.00237***
	(0.000613)	(0.000611)	(0.000613)	(0.000611)	(0.000626)	(0.000622)
Constant	8.977***	8.977***	8.976***	8.969***	8.976***	8.961***
	(0.124)	(0.124)	(0.128)	(0.120)	(0.126)	(0.105)
Model Summary						
Observations	432	432	432	432	432	432
R-squared	0.628	0.628	0.627	0.631	0.628	0.640
Adj. R-squared	0.6127	0.6125	0.6119	0.6152	0.6118	0.6230
AIC	213.8297	214.0609	214.7999	209.9975	213.7713	200.0985
BIC	238.2402	238.4714	239.2104	234.4081	238.1819	224.5091

Note: "-" denotes as omitted because of collinearity. Standard errors are in parentheses; *** p<0.01, ** p<0.05, * p<0.1 ; Regression results for log of cost of Aman rice are shown here. Climate variables are temperature and rainfall for the whole Aman rice growing period. Different columns show the different possible combinations of climate variables to cover all possible functional relationships between cost of production and climate. In columns 1 & 2 the temperature variable only is considered but using linear and quadratic form respectively. Columns 3 & 4 are like the previous two but here instead of temperature, the rainfall variable is considered. In columns 5 & 6 the temperature and rainfall variables are both considered with linear and quadratic form respectively. Some of the variables (Temp, temp sq,, rain, and rain sq.) are not reported here as they are omitted because of collinearity. The full table is shown in Appendix 4.

Table 4.12 : Models considering the climate variables for three phases of Aman rice growth period (Dependant variable: log of Aman rice cost of production)

VARIABLES	7	8	9	10	11	12
Temp: sow * fsize	0.0214	2.441			1.230***	8.036***
	(0.0655)	(2.077)			(0.0702)	(1.163)
Temp: sow sq. * fsize		-0.0450				-0.136***
		(0.0360)				(0.0194)
Temp: flower * fsize	-0.124	-5.569**			-1.430***	-8.779***
	(0.0705)	(1.842)			(0.0763)	(0.879)
Temp: flower sq. * fsize		0.0994**				0.158***
		(0.0330)				(0.0159)
Temp: ripe * fsize	0.0358	4.205***			0.364***	0.258
	(0.0474)	(0.720)			(0.0230)	(0.547)
Temp: ripe sq. * fsize		-0.0979***				-0.00607
		(0.0168)				(0.0127)
Rain: sow * fsize			-0.000179	0.00217***	0.00155***	0.000405***
			(0.000163)	(5.65e-05)	(9.31e-05)	(5.09e-05)
Rain: sow sq. * fsize				-1.31e-06***		-
				(2.56e-08)		
Rain: flower * fsize			0.000764*	-0.00863***	-0.00493***	-
			(0.000382)	(0.000357)	(0.000290)	
Rain: Flower sq. * fsize				9.01e-06***		-
				(4.40e-07)		
Rain: ripe * fsize			-0.000189	-0.00925***	0.0227***	-
			(0.00104)	(0.00200)	(0.00115)	
Rain: ripe sq. * fsize				0.000176***		-
				(3.46e-05)		
Experience	0.00112	0.000856	0.00116	0.000872	0.000872	0.000872
	(0.00194)	(0.00191)	(0.00194)	(0.00190)	(0.00190)	(0.00190)
Education	0.0124**	0.0135**	0.0129**	0.0138**	0.0138**	0.0138**
	(0.00503)	(0.00536)	(0.00518)	(0.00536)	(0.00536)	(0.00536)
HH agri. Labour	-0.0835**	-0.0859**	-0.0839**	-0.0859**	-0.0859**	-0.0859**
	(0.0254)	(0.0256)	(0.0255)	(0.0257)	(0.0257)	(0.0257)
Farm Size	2.118	-	-0.188**	1.289***	-2.956***	-
	(1.469)		(0.0738)	(0.116)	(0.579)	
Fertility of land	0.0112	0.0114	0.0130	0.0124	0.0124	0.0124
	(0.0123)	(0.0127)	(0.0130)	(0.0127)	(0.0127)	(0.0127)
Tenure status	0.0395	0.0380	0.0379	0.0379	0.0379	0.0379
	(0.0528)	(0.0528)	(0.0531)	(0.0530)	(0.0530)	(0.0530)
Ext. advice	0.0480	0.0494	0.0467	0.0480	0.0480	0.0480
	(0.0462)	(0.0469)	(0.0460)	(0.0472)	(0.0472)	(0.0472)
Climate info.	-0.00861	-0.00262	-0.00839	-0.00319	-0.00319	-0.00319
	(0.0377)	(0.0368)	(0.0371)	(0.0370)	(0.0370)	(0.0370)
Credit facility	-0.0275	-0.0246	-0.0296	-0.0248	-0.0248	-0.0248

	(0.0173)	(0.0192)	(0.0166)	(0.0193)	(0.0193)	(0.0193)
Irrigation facility	0.00226**	0.00248***	0.00232***	0.00249***	0.00249***	0.00249***
	(0.000644)	(0.000561)	(0.000620)	(0.000555)	(0.000555)	(0.000555)
Constant	8.972***	8.957***	8.963***	8.953***	8.953***	8.953***
	(0.114)	(0.0972)	(0.108)	(0.0948)	(0.0948)	(0.0948)
Model Summary						
Observations	432	432	432	432	432	432
F						
R-squared	0.632	0.643	0.636	0.644	0.644	0.644
Adj. R-squared	0.6151	0.6246	0.6190	0.6245	0.6245	0.6245
AIC	209.0839	200.1394	204.7087	195.2881	195.2871	195.2834
BIC	233.4945	232.6868	229.1192	219.6986	219.6977	219.6939

Note: "-"denotes as omitted because of collinearity. Standard errors are in parentheses; *** p<0.01, ** p<0.05, * p<0.1 : This table is like Table 4.11 but here the climate variable is for three growth phases of Aman rice. See the explanation in the footnote for Table 4.11. Some of the variables (Temp sow, Temp sow sq, Temp flow, Temp flow sq, Temp ripe, Temp ripe sq, rain sow, rain sow sq, rain flow, rain flow sq, rain ripe, and rain ripe sq,) are not reported here as they are omitted because of collinearity. The full table is shown in Appendix 4.

4.5.3.1 Marginal Impact Analysis for Cost of Production

The marginal impact of climate variables on cost of production of Aman rice is shown in Table 4.13. The linear specification for climate variables with all three stages of growth is considered here (Model 11 from Table4.12). The dependent variable is here in log form, so the estimated coefficient shows the elasticity. The derivation of marginal impact is shown in Appendix 9. It is found that each 1^0C increase in average temperature in the sowing and ripening stage would increase the cost of production by 289% and 86% respectively for an average[16] farm in Bangladesh. In contrast, a 1^0C increase in average temperature in the flowering stage is estimated to decrease the cost by 336%. Similarly, the increase in rainfall by 1 mm in sowing and ripening stages increases the cost by 0.36% and 5.33% respectively, whereas for flowering stage would decrease 1.16%.

Table 4.13 : Marginal impact of climate on cost per Acre

Variables	Stages	% change in cost
Temperature	Sowing	289.0
	Flowering	-336.05
	Ripening	85.54
Rainfall	Sowing	0.36
	Flowering	-1.16
	Ripening	5.33

Note: Model 11 from Table 4.10 is used here to see the marginal effect. "-" indicates that the coefficient is not statistically significant in the original regression results.

[16] Average farm size from the data is 2.35 acres.

From the results of marginal impact, it can be seen that the effect of temperature is much more than that of rainfall on the cost of production. Overall, both temperature and rainfall increase have a positive impact on the cost of production of Aman rice. Although including this study some other studies also found the positive impact of climate variables on the rice yield (Zhang et al., 2010; Chao et al., 2014; Wei et al., 2014), it can be concluded that the effect of climate variables on the yield is also accompanied with the increase in the cost of production.

4.5.4 Implications of this Study

Previous studies on the impact of climate change on agriculture in developing countries, which have used Ricardian approach, have mainly concluded that temperature increases reduce the agricultural net revenue (Kumar & Parikh, 2001; Deressa & Hassan, 2009; Kabubo-Mariara, 2009; Wang et al., 2009). Studies on the impact of climate change on yield of a crop (using the production function approach) report mixed results. Some studies have found a positive impact on yield associated with climate change (Zhang et al., 2010; Chao et al., 2014; Wei et al., 2014) whereas others have identified a negative impact (Chen et al., 2014; Karn, 2014; Pattanayak & Kumar, 2014). This research argues that farmers' action to reduce the adverse effect of climate change or even to take the best opportunity from changes in temperature and rainfall may have a relationship with cost. Cost of production is always one of the prime importance in economics, but studies of the impact of climate change on agriculture have always overlooked that.

In this study, the impacts of climate variables on net revenue, yield and cost of production are explored in turn. Therefore, this study not only shows that climate change has impacts on net revenue and quantity produced but also on the cost of production; a summary is shown in Table 4.14. It is found that temperature and rainfall changes have similar types of effect on all three, net revenue, yield and cost of production. However, in all cases, both climate variables have different impacts in different stages of the crop's development. Temperature and rainfall in both sowing and ripening stage have a positive impact whereas in flowering stage these have a negative impact on net revenue, yield and cost of production. It can be concluded that although it seems that an increase or decrease in yield is due to climate variables, those climate variables also affects costs of production in the similar fashion and consequently affect the net revenue. It is the effect of temperature and rainfall change that affect yield and cost that consequently resulted the effect on net revenue. Another important point is that the temperature effect is much higher than that of rainfall.

Table 4.14 : Climate change impact on net revenue, yield and cost of production

Variables	Marginal Impact (%Δ due to Δ in climate variables)		
	Net revenue	Yield	Cost
Temperature : sowing stage	10.36	168.73	289.0
Temperature : flowering stage	-28.85	-222.78	-336.05
Temperature : ripening stage	5.80	52.88	85.54
Rainfall : sowing stage	0.04	0.30	0.36
Rainfall : flowering	-0.16	-1.38	-1.16
Rainfall : ripening	0.3	3.22	5.33

Note: Δ refers to the change

The evidence presented in this chapter identified the impact for temperature increase as well as changes in the rainfall for Aman rice crop net revenues in Bangladesh. This chapter has also presented analysis of the reasons for this changes in net revenue, and in so doing makes a significant contribution to the existing literature. Several issues arise from the policy perspective. The positive association between climate variables and cost of production lead us to conclude that it is the cost of adaptation associated with the changes in climate increases the cost of production. Further investigation of those costs, availability of those inputs, and the prices of inputs at every stage in the growth of the crop should be undertaken to inform more accurately the policy prescriptions. However, in general it may be argued that policy should focus on those inputs, which are required in the face of temperature and rainfall increases. In other words, policy should focus on reducing the cost of production, helping farmers to reduce the adverse effect of climate change at less cost and consequently increase net benefit, or to take the opportunities that arise from climate change.

4.6 Conclusion and Policy Recommendation

In this study, the impact of climate change on agriculture is explored for a particular rice crop, Aman rice, in, Bangladesh. Cross-sectional survey data for 432 rice farms sampled from all the climatic zones in Bangladesh are used here for the analysis. Analysis is based on the link between climate variables and three different dependent variables: net revenue, yield, and cost of production. Each analysis is done separately and is able to measure the effect of temperature and rainfall. This research not only contributes to the existing knowledge on the impacts of climate change on agriculture (Ricardian and Production function approach), especially from developing countries' perspective, but also examined a new area of analysis considering the costs of production. The impact of climate change on the cost of production, which has been ignored in the literature, provides more insight on the impact.

Along with the whole growth period of Aman rice, climate variables are also considered in accordance with the three important phases of development of the rice crop: sowing, flowering and ripening. Linear and quadratic specifications of climate variables are explored here also. Some evidence is found of a non-linear relationship between climate variables and the dependent variables. Some farm-household level variables as well as unobserved regional differences are considered in the regression analysis. The regression results indicate a significant impact of temperature and rainfall on net revenue, yield and cost of production. However, regression results on net revenue, yield and cost of production provides the evidence of similar but significance impact in different stages of rice plant growth in Bangladesh. Among the farm-household level variables, experience, education, fertility of land, and farm size have also significant values.

The marginal impacts of climate variables on yield of Aman rice showed that an increase in temperature in different stages of rice production has different effect. The increase in temperature has positive effect on yield in sowing and ripening stages. On the contrary, increase in temperature in flowering stage has a deteriorative effect on yield. Although the effect is similar for the rainfall variable, the magnitude of the effect of temperate is greater than that of rainfall. In case of cost of production, the marginal effect analysis showed the similar types of effect like the yield from the changes in temperature and rainfall in all stages. Although the effect is same direction but the degree is more in case of cost than that of yield. Evidence presented here suggests that although production increases/decreases, there is also an increase/decrease in the cost of production and because of that similar type of effect on the net revenue. Therefore, in the analysis of climate change impact, using only net revenue or yield does not reveal the real scenario. When we consider the cost of production and compare the results with those for net revenue and yield, then a more accurate understanding of the effect can be obtained.

Some other interesting findings emerge from the results. Both temperature and rainfall increases in the sowing and ripening stages contribute to an increase in rice yield as well as costs of production. In contrast, both the climate variables in the flowering stage have a decreasing effect on both yield and cost of production. In general, agronomic studies predict that increase in temperature will be harmful for production but these studies do not include farmers' adaptation. However, the result here shows the opposite to be the case and the possible explanation could be that this is for the rice crop, as well as in a particular place. Moreover, using farm level data as well as including other farm-household level control variables can capture the adaptation decision. The increase in cost of production also supports the argument that to reduce the impact of climate change farmers take some adaptation actions, which in turn increase their cost of production.

Another plausible explanation is that farmers are spending inappropriately. During the sowing and ripening stages, farmers are spending more on some inputs like fertilizer, pesticides, or supplementary irrigation, which may not be required. Similarly, for the flowering stage, they are spending less whereas they could spend more and may be able to reduce the negative effect of climate variables. Therefore, a more comprehensive research on these matters is necessary.

Several important policy recommendations emerge from this study. Farmers are a vulnerable group in terms of climate change. As the cost of production for rice production increases, the policy direction should be there to reduce the cost of production. Providing inputs, which are required for adaptation, at a reasonable price has to be ensured from the government side. Since rising temperature has more effect than rainfall, therefore, future agricultural research should focus on the development of rice varieties that are more temperature tolerant. Inputs required for each stage of rice development are different in quantity as well as quality. Proper use of those has to be ensured and farmers' training as well as extension advice have to be available to them at their doorsteps.

Chapter 5: Extent and Determinants of Farmers' Perceptions of Climate Change in Bangladesh

5.1 Introduction

In Chapter 4, the impact of climate change on rice farms was analysed from the perspective of its impact on yield, cost and revenue. Apart from the issues of identifying the actual impacts in those areas, from that analysis several questions follow. One question is related to whether farmers know about climate change or not. For example, it may take time for farmers to realize that the unusual weather patterns represent a permanent shift in the climate (Maddison, 2007). If farmers recognise that change in climate is taking place, then the question of adaptation may become significant to them. In this respect, farmers' perceptions related to climate change play an important role (Maddison, 2007; Gbetibouo, 2009; Deressa et al., 2011; Di Falco et al., 2011). The issues of adaptation will be the subject of Chapter 6, but in this present chapter the extent and determinants of farmers' perceptions of climate change, which is an important factor for the adaptation decision, are analysed.

Although recognition of climate change is a necessary condition for adaptation, different social, economic and institutional factors affect the abilities of farmers to perceive and adapt to climate change (Bryan et al., 2009; Deressa et al., 2011). Therefore, investigation of these issues will both inform our understanding of climate change adaptation as well as inform the public policy on what can be done to increase farmers' recognition of climate change issues (Leiserowitz, 2006). Despite the importance of farmers' perception, research concerning the identification and analysis of factors affecting farmers' perception in developing countries is scarce (Habtemariam et al., 2016).

The analysis in this chapter addresses the following questions:

- Do farmers perceive changes in the climate system and if so, then what changes are noticed?
- What are the characteristics of farmers who have perceived climate change?
- What, if any, is the role of government to improve farmers' understanding about climate change?

The answers to these questions are very important for improving farmers' understanding of climate change, which will ultimately influence adaptation.

The chapter is structured in the following way: Section 5.2 develops the theoretical and empirical understanding of perception and decision making based on a literature review related to both theoretical and applied research. Section 5.3 details the analytical methodology employed to analyse the farmers' perceptions. Section 5.4 presents and discusses the findings, before the conclusion and recommendations are identified in the last section.

5.2 Literature Review: Perception and Decision-Making

5.2.1 Theoretical Insight

In the *rational agent model*, which dominates contemporary economic analysis, people are assumed to be economically motivated, fully rational and selfish, with computational capability and never making systematic mistakes (Cartwright, 2011). Given their preferences, they are assumed to behave in such a way as to maximize their utility/opportunities. This model is criticized in a number of ways. For instance, the formation and ordering of preferences (Levi et al., 1990) it is argued that similar individuals may have significantly different preferences or, at least, have different preference ordering. Moreover, despite having fixed and transitive preferences, individuals often make inconsistent and irrational decisions.

Elster (1990) criticized the rational choice theory by indicating its failure to explain people's behaviour due to indeterminacy (i.e. when and to what extent it fails to yield unique predictions) and inadequacy (i.e. when its predictions fail). He argued that when an individual is indifferent between two or more alternatives, each of which is deemed superior to all others, the rational agent model fails to yield a unique prediction. For example, when a consumer is indifferent between two cars with different strengths and weaknesses, then the consumer is unable to rank and compare the options. As a result, a prediction using rational choice theory would fail.

Cartwright (2011) argued that most people make wrong judgements on simple problems. For example, in response to the question:

> A bat and ball cost $1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost?

Most people would answer ten cents whereas the correct answer is five cents. In this way, critics argue that if people make mistakes like this, then the assumption about the complex calculation that the economic man routinely makes is wrong. Furthermore, the behavioural economics approach argues that the rational agent model cannot explain human decision making, especially under uncertainty (Wilkinson & Klaes, 2012). In this respect, using several experiments, Kahneman and Tversky (1979) demonstrated that people really are very different to "economic man", or at least not like the version assumed by the rational agent model, and systematically violate the requirements of consistency and coherence in their decision choices.

Reviewing empirical research from psychology, behavioural and experimental economics, Brekke and Johansson-Stenman (2008) argued that people make seemingly irrational decisions with respect to choices under risk and over time. Behavioural economics explains this as partly because of their cognitive limitations (Levi et al., 1990). Dawnay and Shah (2011) argued that climate change could be a perfect example of or issue under which rational-agent model analysis would not accurately describe human behaviour. For example, being rational, people should take an adaptation decision automatically in response to climate change to reduce the impact. However, the empirical research does not support this claim which is why Dawnay and Shah (2011) argued that policy design based on the rational agent model would not work. They also argued that insights from the fields of psychology and behavioural economics regarding human decision-making should be used in designing policy in this area.

Behavioural aspects of the human decision were based on the *Behavioural Decision Theory* originated by Von Neumann and Morgenstern (1944) though a huge body of literature which has tried to explain the behavioural aspects of human decisions has followed (McFadden, 1999). In this respect, Kahneman (2003) presents a model of judgement heuristics where he argues that most judgments and choices are made intuitively and the rules that govern intuition are mostly perception. The idea of his model presents a two-system structure as shown in Figure 5.1. The operations of System 1 are fast, automatic, effortless, and often emotionally charged, whereas the operations of System 2 are slower, effortful, and deliberately controlled. He argued that people often act intuitively and it is not because they reason poorly. Their behaviour is not guided by what they are able to compute; rather, it is guided by what they perceive at a given time.

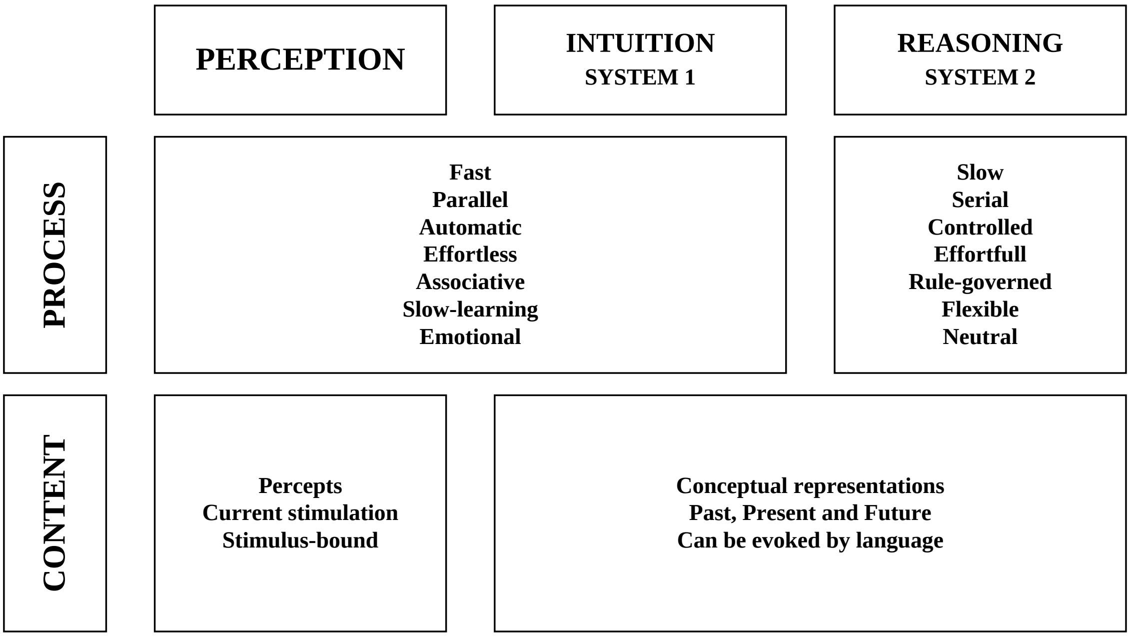


Figure 5.1 : Cognitive system (Kahneman, 2003)

The central idea of the Kahneman (2003) model lies in the role of perception in decision making. McFadden (1999) explained this more clearly in a decision process where he explained how choice behaviour is motivated by perceptions and beliefs (shown in Figure 5.2). According to him, the psychological views of the decision process are controlled by behaviours that are local, dependent on context, and influenced by complex interactions of perception, motives, attitudes, and affect[17]. More elaborately, the cognitive *process* is a mental mechanism for decision making, which is the central element here. It is where the cognitive task is defined and a choice is made, and where elements like perceptions, attitudes, affect, motivation and preferences enter.

In neoclassical economics it is assumed that humans behave according to information processed to form perceptions/beliefs using Bayesian principles which McFadden (1999) has termed *perception-rationality*. In this view, the cognitive process is nothing but preference maximization within the given market constraints (*process-rationality*) where preferences are assumed to be primitive, consistent, and immutable (*preference-rationality*). On the other hand, the psychological view of the decision-making process stresses the importance of behaviour, and the influence of complex interactions of perception, attitudes, affect, motivation and preferences. There may be feedbacks from *process*, *choice* and *preferences* as the decision maker reconciles trial choices; the mechanisms are shown in Figure 5.2 by the narrower arrows.

[17] *Perceptions* are the cognition of sensation, which are the mental models of the world through probability judgements and a*ffect* is the emotional state of the decision-maker (McFadden, 1999).

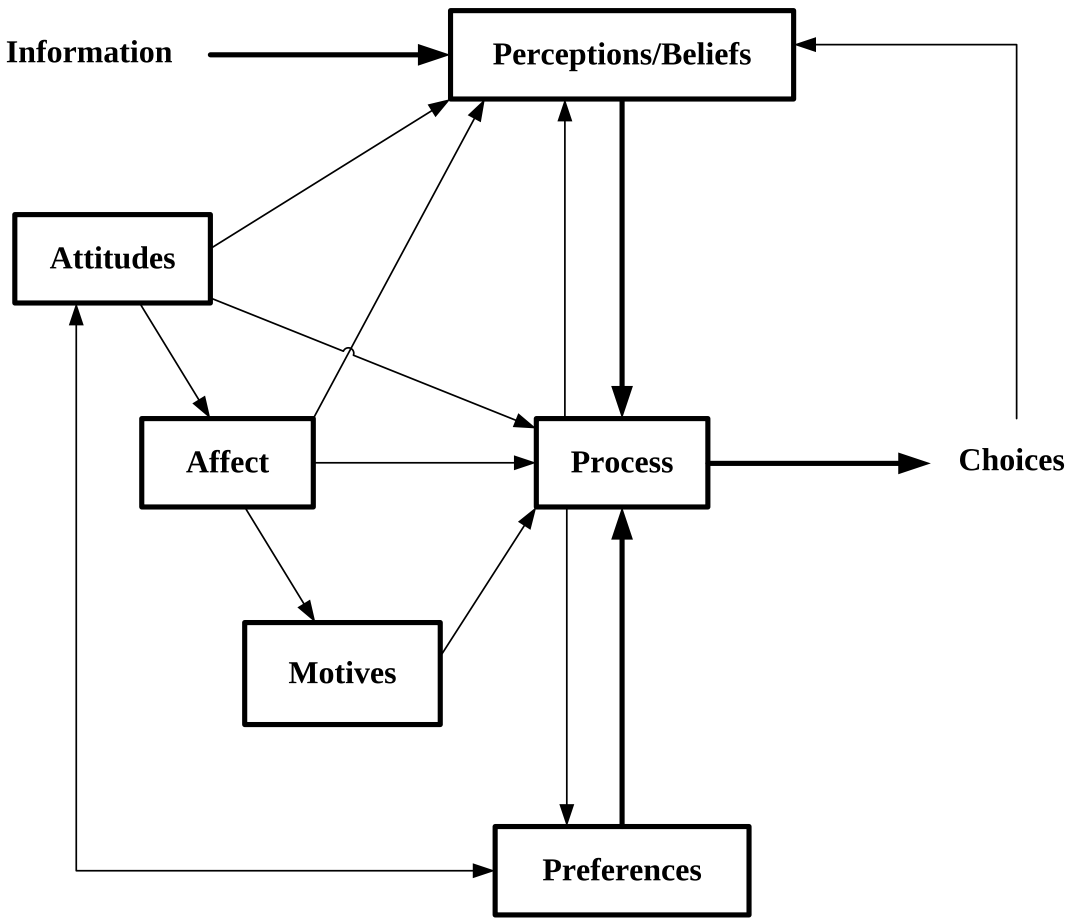


Figure 5.2 : Decision process (adopted from McFadden (1999))

From the above discussion, it may be concluded that although neoclassical economics and behavioural economics have different views of the decision making process, one of the central elements in both views is *perception*. So, related to climate change, it can be argued that although a combination of different factors is needed to induce a change in a person's behaviour, an understanding of climate change certainly provides an important cognitive basis for intervention. Whether there is empirical evidence in the literature to support these theoretical prepositions is the subject of the next section.

5.2.2 Empirical Evidence

Predictive choice models have gone beyond the random utility model in formulation and incorporation of behavioural aspects (McFadden, 2001). Such a behavioural framework emphasizes several elements of the cognitive process that are identified as important in the choice process. Perception is one of the important elements that govern the choice decision (McFadden, 1999; 2001; Ben-Akiva et al., 2002). In the case of literature on farmers' technology adoption decisions, the 'adopter perception' paradigm is well established (Adesina & Baidu-Forson, 1995; Kristjanson et al., 2005; Rahman, 2005). It suggests that the major factor determining adoption and use intensities is the farmer's perceptions of technology-specific attributes (Adesina & Zinnah, 1993). In this section, empirical evidence from the literature is reviewed on perception and decision issues, with particular focus on farmers' perceptions on climate change and the adaptation decision.

Some studies used farmers' classification based on farmers' perceptions of climate change. The classification varies across different studies based on farmers' perceptions. Some identify four types of farmers (Eggers et al., 2015; Hyland et al., 2016) and others identify six types (Barnes & Toma, 2012). All of these studies focus on livestock farmers, and they use principle component and cluster analysis to explain observed variation. While Hyland et al. (2016) analysed farmers in Wales, Eggers et al. (2015) focussed on farmers on the North German Plain, and Barnes and Toma (2012) focussed on Scotland, and they all found significant differences among farmers in their perceptions of climate change, and this impacted their willingness to take adaptation or mitigation measures.

Barnes and Toma (2012) found that among their six constructed groups of farmers, half believed that climate change would have a negative impact on them in the future in the form of productivity losses and increasing input costs due to increases in disease and pests. Eggers et al. (2015) also found that both economic factors and emotional reasoning are factors that influence farmers to take adaptation measures. Laboratory studies also provide evidence of a possible causal impact of cognition and preferences (Benjamin et al., 2013). Therefore, it can be hypothesized that those who have higher awareness and perceptions of risk are more likely to adopt mitigation and adaptation measures (Hyland et al., 2016).

Using a large-scale survey of farmers in 11 different countries in Africa, Maddison (2007) found that a significant number of farmers believed that temperature had increased and precipitation had decreased. In this respect, Maddison (2007) analysed the perceptions of farmers with regard to climate change under three conditions. First, whether the perceptions are dependent on the years of experience of the farmers; it would be expected that more experienced farmers would be better at differentiating inter-annual variation from climate change. Second, whether individual respondents' perceptions are spatially autocorrelated. Third, whether farmers' perceptions of climate change are aligned with the evidence provided by nearby climate stations. Positive relationships were found in all three cases in Maddison's study.

Mertz et al. (2009b) analyse the perception of climate change in the savannah zone of central Senegal. They found that households were aware of climate variability that farmers linked to poor livestock health, reduced crop yields and a range of other problems. Gbetibouo (2009) found that farmers' perceptions about climate change were in line with the climatic data recorded in the Limpopo River Basin of South Africa. Moreover, farmers' perceptions are not fixed, they continually update their problem perceptions, ideas of options, and expectations when new information is obtained (Öhlmér et al., 1998). Several other studies also analyse farmers' perception related to climate change: for example, Acquah and Onumah (2011) in Ghana, Ajao and Ogunniyi (2011) in Nigeria, and Wheeler et al. (2013) in Australia and Glenk et al. (2014) on Scottish dairy farmers. The evidence from these studies shows that farmers had perceived the changes in temperature and rainfall pattern.

Dang et al. (2014) report research on psychological factors that influence farmers' adaptation behaviour in response to climate change. Undertaking a structured interview involving 598 rice farmers from Mekong Delta in Vietnam he found that farmers are more likely to have an adaptation intention when they perceive higher risks of climate change and greater effectiveness of adaptation measures. In contrast, they are less likely to intend to adapt when they do not perceive climate change risk.

Reviewing insights from history, sociology and psychology, Adger et al. (2009) argued that an adaptation decision will be taken if the individual anticipates or experiences the change in the climate or perceives it as a risk. However, the findings from different studies suggest that not all people perceive the change (Arbuckle Jr et al., 2013) and also not all perceive it as risky (Prokopy et al., 2015). This suggests the existence of some possible factors that cause the perceptions to vary. Understanding these sources of variation is one essential component to develop appropriate government policies and communication strategies. By understanding these factors, policy makers can effectively use resources to minimize the gap in climate change perceptions to speed up adaptation (Habtemariam et al., 2016).

Despite their importance, farmers' climate change perceptions have not been adequately studied (Habtemariam et al., 2016). Reviewing the literature it is found that more work has been undertaken in developed countries (Bryant et al., 2000; Harrington & Lu, 2002; Akter & Bennett, 2011; Saleh Safi et al., 2012; Arbuckle Jr et al., 2013; Rejesus et al., 2013; Wheeler et al., 2013; Liu et al., 2014; Prokopy et al., 2015). Although climate change impact is expected to be high in developing countries where adaptation capabilities is limited, less work has been undertaken in such countries. Maddison (2007) in Africa, Deressa et al. (2011), Habtemariam et al. (2016) and Legesse et al. (2013) in

Ethiopia, and Silvestri et al. (2012) in Kenya are among the limited studies that tried to identify factors that influence farmers' perceptions of climate change.

The findings of empirical studies of farmers' perception issues have varied from study to study, and from country to country. Based on survey data in four states in the U.S.A., Rejesus et al. (2013) found that the majority of farmers do not perceive changes in climate and do not believe there will be negative effects on average crop yield. In contrast, using survey data from six locations (Scotland, Midwestern United States, California, Australia, and two locations in New Zealand), Prokopy et al. (2015) found that the majority of farmers in each location believed that the climate is changing. Similarly, studies in developing countries also found that some farmers were able to identify changes in climate which is consistent with meteorological evidence whereas some cannot (Maddison, 2007; Roco et al., 2015).

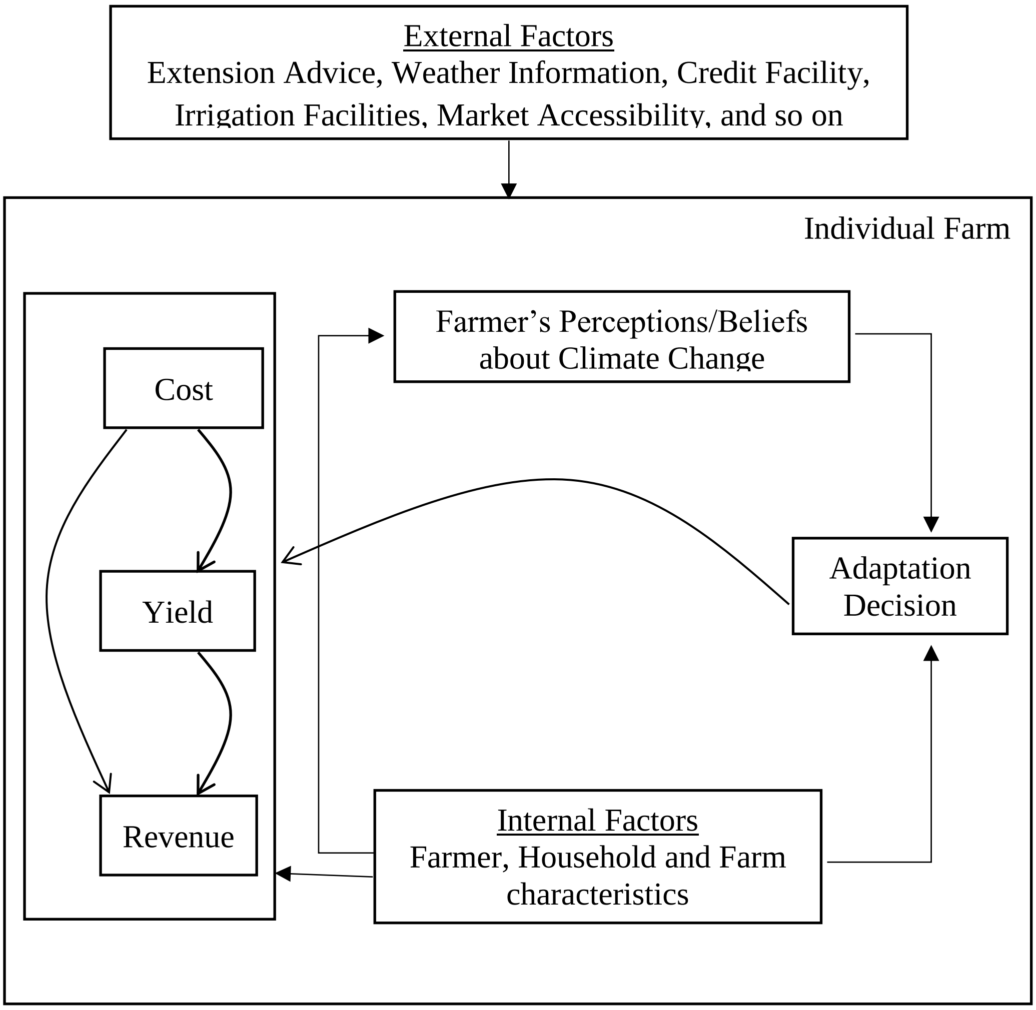
In the context of developing countries, studies that focused on identifying the factors influencing farmers' perceptions about climate change also found differences. For instance, the study by Deressa et al. (2011) in Ethiopia found older farmers, and Silvestri et al. (2012) in Kenya found that more experienced farmers, are significantly more likely to perceive changes in climate. The argument is that age or experience matter because living and working in a place for a long time can facilitate recognizing changes in climate variables (Habtemariam et al., 2016). Again, a study by Roco et al. (2015) in Chile found an opposite and significant relationship between age and perception. Apart from those, a broad array of variables is found to be related to perception.

Bangladesh is one of the most vulnerable countries in the world in the face of climate change. Sarker et al. (2013) and Kamruzzaman (2015) just studied farmers' perception on climate change in Bangladesh on a very limited scale. Sarker et al. (2013) interviewed 550 farm households in only one district, Rajshahi in Bangladesh. With this data, they showed what farmers perceived regarding the changes in yearly temperature, rainfall and drought over the past 20 years. They showed what percentage of farmers perceived an increase, decrease, and no change in those climate variables. In this study, they did not check whether or not farmers' perceptions are consistent with the meteorological evidence. Moreover, an analysis of the determinants of those perceptions using regression analysis was not undertaken.

In Kamruzzaman's (2015) study, he interviewed only 150 farmers in one district, Moulovibajat in Bangladesh. He considered farmers perception regarding causes of climate change, changes in timing of the onset and offset of seasons, changes in duration of the seasons, coldness, hotness, drought, flood, rainfall and changes in mean duration of seasons in months. This study also only assessed perceptions, without checking their validity using actual climate data. Moreover, no attempt was made to identify the factors that brought about those perceptions. No regression analysis was undertaken to see the determinant of farmer's different perceptions. In this study, Kamruzzaman (2015) only tried to identify whether farmers' perceptions on the causes of climate change are associated with the level of education and extension advice received using simple chi-square tests of association. However, the association of other climate change perceptions considered in their research was not tested. Further study is required considering all regions of Bangladesh to understand farmers' perceptions, especially those of rice farmers', and concerns about climate change using regression analysis.

From the above discussion, considering both theoretical and empirical evidence, a simple conceptual model of climate change adaptation is developed here from an individual farmer's perspective (Figure 5.3). An individual farmer decides what to produce and how to produce it, in light of external and internal factors. External factors are those external facilities that influence the farmer in his strategic decisions on farming activities such as extension advice, credit facility, advance weather information, irrigation facilities available in the area, and market facility. Internal factors are the characteristics of the farm, farm operator (i.e. farmer) and farm-household. For the simplicity of the model, government policy and all prices are taken as constant. Therefore, the farmer's decision on production using certain inputs is reflected in production cost, in yields and in revenue.

Figure 5.3 : Conceptual model of farmers' adaptation to climate change



The farmer's decision to adapt in response to climate change will have effects on the cost of production and yield, and will have consequences for revenue. However, this decision whether to adapt is influenced by whether a problem or opportunity has been identified – the climate change perception or belief. If a farmer perceives the climate change properly, then he/she might decide to take action, that is, to adapt. Both internal and external factors affect the way farmers perceive climate change as well as whether they take an adaptation decision. However, farmers' perceptions may vary, because of the influence of both external factors and because of particular characteristics of the individual farmer, farm, and farm-household.

In summary, the literature suggests that farmers' climate change perceptions and factors affecting that perceptions vary across locations. However, investigation of factors that influence the perception of climate change in developing countries is still limited. Moreover, there has been limited focus on rice farmers' perceptions of climate change in developing countries (Sarker et al., 2013). Considering these gaps in research this study first investigates Bangladesh rice farmers' perception to climate change, and then identifies factors that influence farmers' climate change perception. In case of identifying farmers' perceptions, it also analyses the relationship between perceptions and the actual trends in key climatic variables. To the best of our knowledge, this is the first attempt to investigate the factors that drive farmers' perceptions in Bangladesh. The findings of this study contribute not only to the literature concerning Bangladesh but also more generally to understanding of farmers' perceptions of climate change in developing countries.

5.3 Methodology and Data

5.3.1 Data and Survey Description

Data for this research was collected from a cross-sectional household survey in seven different districts of Bangladesh. Employing a multi-stage random sampling, data for 432 rice farmers was collected during the 2015 production year. At the first stage of the survey, the sample districts were purposely selected to represent the major rice producing districts of seven different climatic zone. In each selected district, two *upozila* (sub-districts), then one block from each *upozilla*, and then two villages in that block were randomly selected. The Sub-Assistant Agricultural Officer (SAAO) of the Department of Agriculture, responsible for the villages, maintain a village-wide list that includes each farmer's name, address and the farm size. In the survey, 15% of all rice farmers in each selected village were randomly selected from that list and interviewed in a structured questionnaire based face-to-face meeting. The details of the survey procedure are explained in Chapter 3 and Appendix 2.

A structured questionnaire was used in face-to-face interview by the researcher to collect the data. The questionnaire includes several sections to elicit information on socio-economic background, perception of climate change, adaptation measures and cost-production data. In line with the objective of this chapter, discussion is limited here to those questions related to perceptions of climate change.

Concerning climate change, farmers were asked about their perceptions of different variables related to climate. Farmers were asked that if they had noticed any changes in average annual temperature and rainfall since they became farmers. Temperature and rainfall are very different in different seasons in Bangladesh. For this reason, questions were also asked regarding average changes of those variables over three seasons (summer, rainy and winter). Farmers' responses were recorded by category: (1) increase, (2) decrease, (3) no change, and (4) do not know. Farmers were also asked if they had noticed any changes in the occurrence of drought and floods, severity of heat waves and cold waves, and availability of groundwater and surface water.

In addition to the household-level data, recorded local meteorological data for 50 years (1966-2015) were used to validate farmers' perceptions about the changes in the local climate. For this, monthly maximum and minimum temperature as well as total rainfall data from a weather station located within or close to each study district was used. Average of maximum and minimum temperature are used as monthly average. Climate data for zone A (Noakhali district), B (Sylhet district), D (Bogra district), E (Rajshahi district), and F (Jessor district) were obtained from the weather stations located in each district. However, zone C (Kurigram district) and G (Gazipur district) do not have any weather station within the district. Therefore, for those two districts, climate data from Rangpur and Dhaka stations were used, since these were located within 30 km of the respective districts.

5.3.2 Farmers' Characteristics and Climate Change Perceptions: Estimation Method

Farmers' perceptions about the changes in the climate are analysed first using simple descriptive and statistical tools. In this case, the respondent's beliefs are shown through graphs and percentages. All the respondents' perceptions are analysed from the whole country perspective as well as by zone. Then the analysis is undertaken to identify farmer characteristics of those that have a statistically significant relationship with climate change perception. To do so, the perception variable is defined as correct perceptions that align with meteorological data evidence.

The general form of the functional relationship to identify factors that influence farmer perception can be specified as:

$$Y_i = F(X_i'\beta) \tag{5.14}$$

where Y_i is farmer i's perception of climate change, X_i' is a $1 \times k$ vector of observed farmer characteristics that might be associated with the climate change perception of i, and β is $k \times 1$ vector of unknown parameters.

The construction of a model that links the farmer's perception to a set of factors involves the general framework of a probability model (Greene, 2012). In such a model, the dependent variable is a binary variable taking a value of 1 for yes and 0 otherwise. The model estimates the probability that $Y = 1$ as a function of the explanatory variables that influence the formation of a particular perception:

$$p_i = \Pr[Y_i = 1|X] = F(X_i'\beta) \tag{5.15}$$

To construct the regression model, a simple binary logit model is used (Greene, 2012). The estimates can be done using either a logit or probit model. However, logistic regression is used in many application because of its mathematical convenience (Greene, 2012). Moreover, previous study on perceptions of climate change also used the logit model (Silvestri et al., 2012). Following the logit model, the probability of a farmer perceiving no change is:

$$P_i = \Pr[Y_i = 1|X] = \frac{\exp(X_i'\beta)}{1 + \exp(X_i'\beta)} \tag{5.16}$$

The analysis limits the perception variable to whether or not the farmer perceived the occurrence of changes correctly. In this case, the analysis considers all perceptions that align consistently with meteorological data evidence. Therefore, the dependant variable (farmer perception) takes the value of 1 if a farmer perceived the changes (increase or decrease) that is consistent with meteorological evidence and 0 if the perception is not consistent with meteorological evidence.

For the empirical analysis, perception on summer temperature and rainfall in rainy season is considered. Farmers perceptions on these variables consist of four alternatives: increase; decrease; no change; and do not know. In this respect, to analyse the determinants of farmers' perceptions, a multinomial logit model (MNL) could be used. However, the interest of this research is to see the factors that have a relationship with farmers' correct perception. The correct perception is that which is consistent with the meteorological evidence. Therefore, creating that correct perception variable automatically implies that the variable is binary. Previous studies on determinants of perception also create binary variables and do not employ the MNL model (Maddison, 2007; Deressa et al., 2011; Silvestri et al., 2012). Moreover, results from MNL model would not give additional information, whereas interpretation of results towards policy importance would be better and more focused in case of simple logit model. That is why, MNL model is not used here and simple binary logit model is used.

The explanatory variables in the regression model includes a range of variables that include farmer, farm and institutional accessibility characteristics chosen based on the previous literature, intuition and data availability. Farmers' characteristics include education, experience, and belonging to a group (i.e. whether he or she are engaged in a group or not). To avoid a collinearity problem, age is not included in the regression as it was found to be significantly correlated with experience.

Other farm-household variables included here are the number of household's own worker, electricity (whether or not farm-household have electricity), the number of literate household members, the value of household's assets, agricultural income, non-agricultural income, farm size (total cultivable land), fertility of farm-land, tenure status, livestock ownership (whether or not owned livestock) and the value of farm assets.

Variables related to institutional accessibility, like whether or not the farmer received any formal extension advice, get weather information, access to credit, percentage of land with irrigation facility and distance to input market are included in the analysis. A dummy variable for district (zone) is also used to capture the regional effect. The definitions of all the variables considered in the model and their expected effects on climate change perception are shown in Table 5.1. The expected effects are based on findings from previous literature on climate change perceptions.

Table 5.1 : Variable used in the models and hypothesized effects

Variable	Description	Expected Effect
Dependant variable		
Perception on change in summer temperature	Dummy variable = 1 if the respondent perceived correctly (means the direction of changes they perceived consistent with meteorological evidence) the changes in summer temperature and 0 otherwise	
Perception on change in rainy season rainfall	Dummy variable = 1 if the respondent perceived correctly (means the direction of changes they perceived is consistent with meteorological evidence) the changes in rainy season rainfall and 0 otherwise	
Perception on climate change	Dummy variable = 1 if the respondent perceived both the changes in summer temperature and rainy season rainfall correctly (means the direction of changes they perceived is consistent with meteorological evidence), and 0 otherwise	
Explanatory variable		
Education	Years of schooling	+
Experience	Number of years doing farming	+/-
Group	Dummy variable =1 if farmer is a member of any co-operative or any farmers-club	+
Own labour	Number of labour provided by own household	?
Electricity	Dummy variable = 1 if farm household has electricity facility	+
Literacy	Number of literate members in the household	+
Household Asset	Total values of important assets of the household in Taka	+
Agricultural Income	Total income from agricultural sources in Taka in 2015	+/-
Non-agricultural Income	Total income from the non-agricultural sources in Taka in 2015	+
Farm size	Total cultivable land area of the farm in acres	-
Fertility of land	Dummy for farmer's own perception of the fertility level of his land, 1=low fertile, 2=medium fertile, 3=fertile, 4=very fertile	-
Tenure Status	Dummy variable = 1 if farmer declared himself as tenant farmer and 0 otherwise	?
Livestock	Dummy variable = 1 if the household owned any livestock and 0 otherwise	?
Farm Asset	Total values of agricultural machinery owned by farm in Taka	?
Extension advice	Dummy variable = 1 if the farmer has access to formal extension advice	+
Weather information	Dummy variable = 1 if the farmer has access to weather information from any source	+
Credit	Dummy variable = 1 if the farmer has access to credit facility	-
Irrigation	Percentage of land with irrigation facility	?
Market	Distance from farm to nearest input market in km	?
Zone	Dummy variables for each zone = 1 if farm is located in that zone and 0 otherwise	?

5.4 Results and Discussion

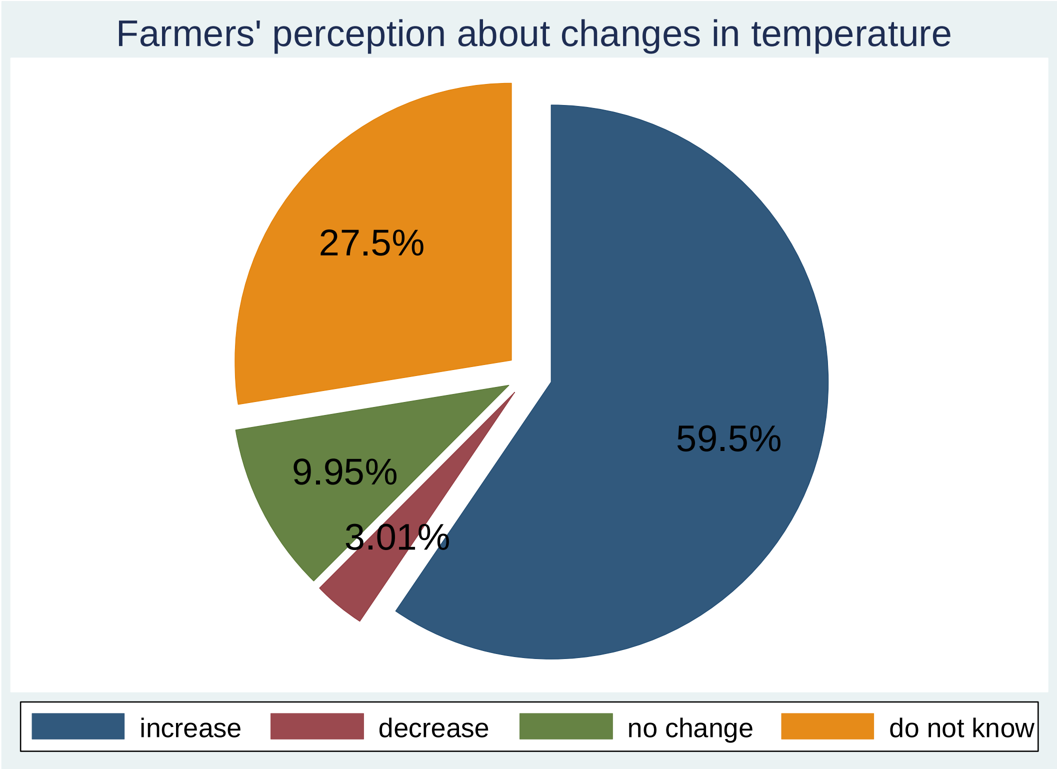
5.4.1 Farmers' Perception about Climate Change

From the survey data, it is found that a large majority of farmers, around 93%, reported that they had noticed changes in the climate since they started farming. The average length of farming experience of sample farmers are 31 years. Therefore, it can be derived that farmers had noticed the long term changes in temperature. In order to understand the nature of the farmers' perceptions, firstly, their views on overall annual changes in temperature and precipitation are presented and analysed. It is found that the majority of farmers believed that the annual temperature has increased (around 60%, Figure 5.4) whereas the annual rainfall has decreased (around 63%, Figure 5.5) since they started farming.

While a very few respondents believed that there had been a decrease or no change in temperature and increase or no change in precipitation, a considerable portion of farmers (around 28%) were uncertain for temperature and rainfall. A possible explanation could be that they were unable to identify climate change from an annual aggregate perspective. They may identify climate change more confidently from the seasonal perspective. Findings from the seasonal perspective, which are discussed in the next paragraph, support this explanation.

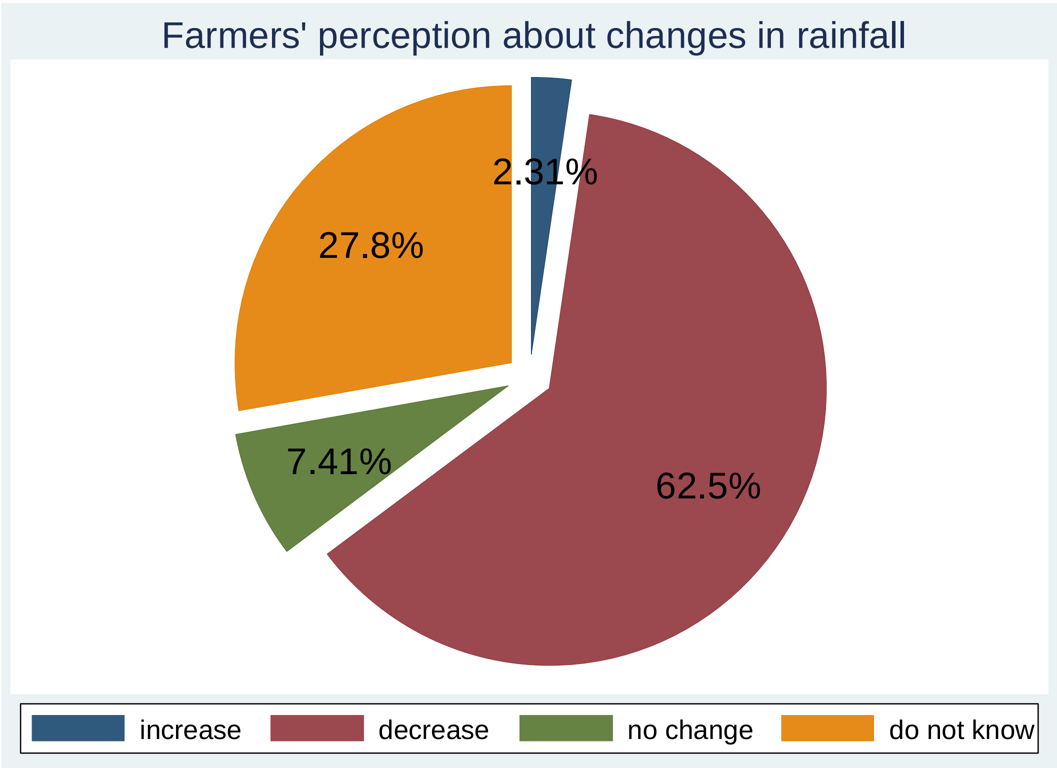
Farmers' perceptions on changes in climate from the seasonal perspective are shown in Table 5.2. The majority of farmers believed that the temperature in both winter and summer has increased. Moreover, most farmers, around 79%, reported that the temperature, especially in the summer time, has risen over time. In contrast, the majority of the farmers claimed that rainfall has declined in all seasons. However, the largest proportion of farmers, 89%, believed there had been a decline in rainfall in the rainy season. Previous studies on Bangladesh have reported similar findings on farmers' perceptions, that is of increasing temperature and declining rainfall trends (Sarker et al., 2013; Kamruzzaman, 2015), although those studies were focussed only on one particular region in Bangladesh. Other studies based on African countries also found similar findings (Deressa et al., 2011; Habtemariam et al., 2016).

Figure 5.4 : Farmers' perception about changes in annual temperature



Source: Author's Field Survey, 2015/16

Figure 5.5 : Farmers' perception about changes in annual rainfall



Source: Author's Field Survey, 2015/16

Some farmers were also described the variability as well as the uncertainty about climate variables. They described that previously, they knew the general pattern of weather. Now, these patterns are changed. Before, they could predict when there would be hot or warm weather or rain. They acknowledged that suddenly in the summer, the day becomes very hot and again suddenly, less warm. Similarly, in the winter season the weather can turn suddenly very cold or foggy, and then again less cold. According to them, the uncertainty as well as suddenness of rainfall occurrence is happening more often than previously. When rain is needed it does not happen and when, after waiting, they irrigate their land, then suddenly the rain occurs.

Table 5.2 : Farmers' perception about climate change (% of respondents)

Climate components	Period	Increase	Decrease	No change	Do not know
Temperature	Winter	61.81	12.73	24.54	0.93
	Summer	78.7	12.27	9.03	0.00
Rainfall	Winter	2.08	51.16	36.11	10.65
	Summer	1.39	85.65	10.42	2.55
	Rainy Season	3.24	88.66	8.1	0.00
Occurrence of drought	Annual	73.84	8.8	12.96	4.4
Occurrence of flood	Annual	4.86	62.04	27.78	5.32
Severity of heat wave	Annual	78.24	9.95	10.65	1.16
Severity of cold wave	Annual	10.88	71.30	16.44	1.39
Groundwater availability	Annual	0.69	68.11	14.12	17.13
Surface water availability	Annual	2.08	86.11	11.11	0.69

Source: Author's Field Survey, 2015/16

Farmers' perceptions on some other climate related extreme events were also analysed. It was found that, as with temperature increase and rainfall decline, the majority of the farmers claimed that occurrence of drought has increased, whereas the occurrence of flooding has decreased. Moreover, the majority of the respondents claimed that both surface water (around 86% of farmers) and ground water (around 68% of farmers) availability has decreased over the period. A probable explanation for such outcomes could be less rain and excessive use of water for irrigation reduced availability. Research findings of others have also confirmed the depletion of the groundwater table in Bangladesh (Shahid & Hazarika, 2010; Rahman & Mahbub, 2012).

5.4.1.1 Perception of Climate Change by Zone

Farmers' perceptions about the climate change are presented by zone in Table 5.3. Here only the temperature in the summer season and rainfall in the rainy season are considered. The climate variables are such characteristic features of those two periods that it was expected that farmers would be able to identify any change more accurately and with greater confidence; these were the reasons for focusing only on these two seasons. The result also validates this argument as no farmers chose the 'do not know' response option. As a result, the analysis can be undertaken based on all respondents. Moreover, during the interviews, the researcher also found that farmers answered this question elaborately and without hesitation.

Table 5.3 : Perception of climate change by zone (% of respondents)

Perception	Zone						
	A	B	C	D	E	F	G
Summer							
Trend coefficient	0.046	0.034	0.006	0.011	0.007	0.023	0.016
Increases temperature	73.3	76.6	74.1	82.5	84.8	89.1	62.5
Decreases temperature	13.3	10.9	13.8	8.8	13.6	4.7	27.5
No change in temperature	13.3	12.5	12.1	8.8	1.5	6.3	10
Rainy season							
Trend coefficient	-3.23	-6.51	1.63	-1.96	-5.98	3.11	0.29
Increased rainfall	1.7	3.1	00.0	00.0	12.1	3.1	2.5
Decrease rainfall	88.3	85.9	89.7	91.3	86.4	90.6	87.5
No change in rainfall	10.0	10.9	10.3	8.8	1.5	6.3	10.0
Total respondent	60	64	58	80	66	64	40

Source: Author's calculation from field survey, 2015/16; Trend coefficient is the coefficient of linear trend line shown in Figure 5.6 and Figure 5.7 where actual meteorological data for 1966-2015 is used.

It is found that across the seven climatic zones considered in this study, the majority of farmers believed that the temperature in summer had increased. In contrast, very few farmers believed that there had been a decline or no change in temperature in summer. . In an earlier study undertaken in zone E alone, Sarker et al. (2013) found that the majority of farmers (97%) had noticed a rising annual temperature and a very few believed that there was no change (1%) or a decrease (0.55%) in annual temperatures. In this region, this present study also found that a majority of farmers perceived temperature increase (around 85%) and a few perceived no change (1.5%). Similarly, a study in only zone B, Kamruzzaman (2015), found that 88.7%, 5.3% and 6% of farmers' perceived that 'hotness' in temperature has increased, decreased or no change respectively. This is quite similar to the findings of this present research in that zone.

In the case of rainfall in the rainy season, opposite opinions were found. In all seven zones significant numbers of farmers believed that rainfall had decreased, while very few farmers believed that there had been an increase in rainfall. Indeed, in two zones (C and D), none of the respondents believed that there had been an increase in rainfall. Previous studies on zone E (Sarker et al., 2013) and zone B (Kamruzzaman, 2015) found similar evidence with respectively 99% and 83.3% of farmers believing that annual rainfall had reduced. Corresponding figures from this present study are 86.4% and 85.9% for zones E and B respectively. Although the results are similar, this study later extends the analysis by considering the validity as well as the determinants of farmers' perceptions in Bangladesh using regression analysis.

These results may suggest that farmers in Bangladesh are recognizing changes in the climate system. However, there may be doubt as to whether their perceptions of climate change are correct or not. Maddison (2007) in this respect suggested that neighbouring farmers might influence farmers views. Such influence might make them report witnessing particular forms of change when in reality they did not. It is therefore necessary to validate their claims before drawing a firm conclusion that Bangladesh farmers are as perceptive as it might appear. Maddison (2007) also suggested three ways in which this corroboration could be undertaken: by checking the spatial auto-correlation of their perceptions, by checking the responses with the meteorological evidence and, finally, by looking more closely at the characteristics of those who reported perceiving changes.

5.4.1.2 Is Farmers' Perception of Climate Change Spatially Co-related?

To check the spatial patterns of a variable Moran's I test is employed, where an auto-correlation statistic is calculated (Anselin, 1988). Maddison (2007) also used this in his study to see whether farmers' perceptions of climate change are spatially auto-correlated. That is, is the same type of climate change perception validated by the neighbouring farmers? Following Maddison (2007), this study also uses the Moran's I statistics where a distance weights matrix on the farmers with particular type of perception within a particular sub-district is used. While it could have been a better test if village level clustering were done, lack of spatial coordinates (longitude and latitude) meant this test was only possible at the sub-district level.

The Moran's I test results for farmers with a particular type of perception are shown in Table 5.4. The result suggests that there is no evidence of spatial auto-correlation for perceptions of climate change. Although in Maddison's (2007) study he found evidence of spatial auto-correlation regarding perceptions of a few variables, in this respect this result differs from that of Maddison. Maddison raised the possibility that there could be a case of prominence bias in the questionnaire dealing with climate change. However, while collecting data researcher took care of it asking the respondent to answer freely whatever they felt and believed without concerning other peoples' belief. Therefore, it is argued that farmers were free from neighbouring farmers' influence and perceived the changes by themselves.

Table 5.4 : Spatial auto-correlation in perception of changes in climate

Perception	Moran's I value	Z score	P-value
Summer			
Increases temperature	0.003	0.927	0.177
Decreases temperature	0.003	0.824	0.205
No change in temperature	-0.002	0.071	0.472
Rainy season			
Increased rainfall	0.004	1.118	0.132
Decrease rainfall	-0.006	-0.688	0.246
No change in rainfall	0.002	0.648	0.258

Source: Author's calculation from field survey, 2015/16

The above analysis shows that the majority of the respondents believed that the climate has become hotter in summer and drier in the rainy season, and their perception is not spatially correlated. This evidence leads to the inference that farmers were independent of the neighbourhood effect regarding these perceptions and it was really they themselves who perceived the changes. However, the question still remains whether their perceptions are consistent with meteorological data. To determine whether this is the case, comparison of farmers' perceptions with the meteorological station data is the subject of the next section.

5.4.1.3 Validity of Farmers' Perception Comparing with Actual Climate Data

If the meteorological evidence for each zone shows consistency with farmers' perceptions, then it can be inferred that farmers of Bangladesh are capable of perceiving the changes in the climate system. In order to compare farmers' perceptions with actual climate evidence, Figure 5.6 and Figure 5.7 show the trends in summer temperatures and total rainfall for the rainy season respectively as recorded by weather stations for each zone. For the convenience of comparison, actual climate trends and farmers' perceptions for each zone are placed adjacently in the graph. By showing the data through graphs and by placing the actual trends and farmers' perception in this way for each zone (shown in

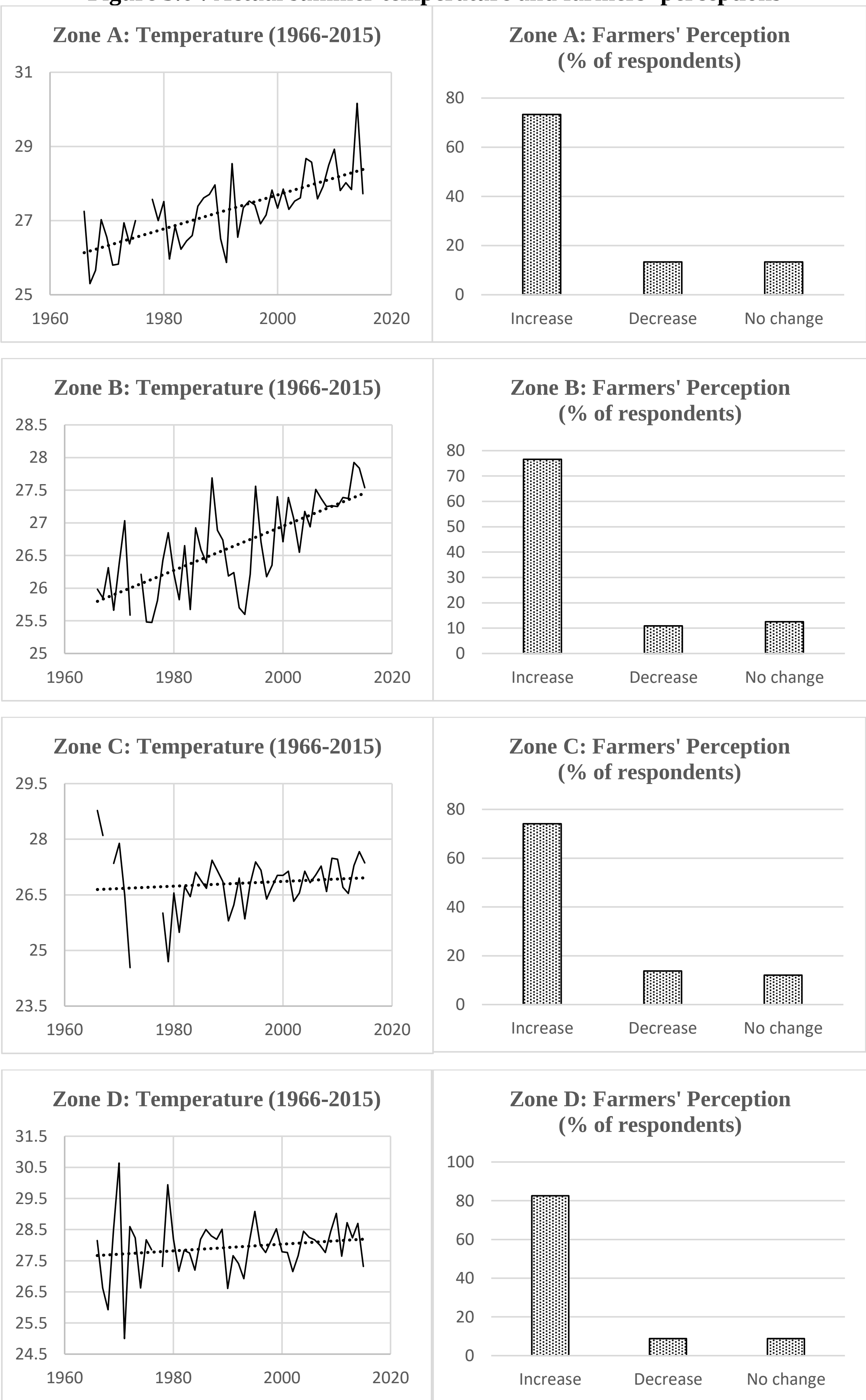
Figure 5.6 and Figure 5.7) farmers' perceptions are compared and validated in a clear way.

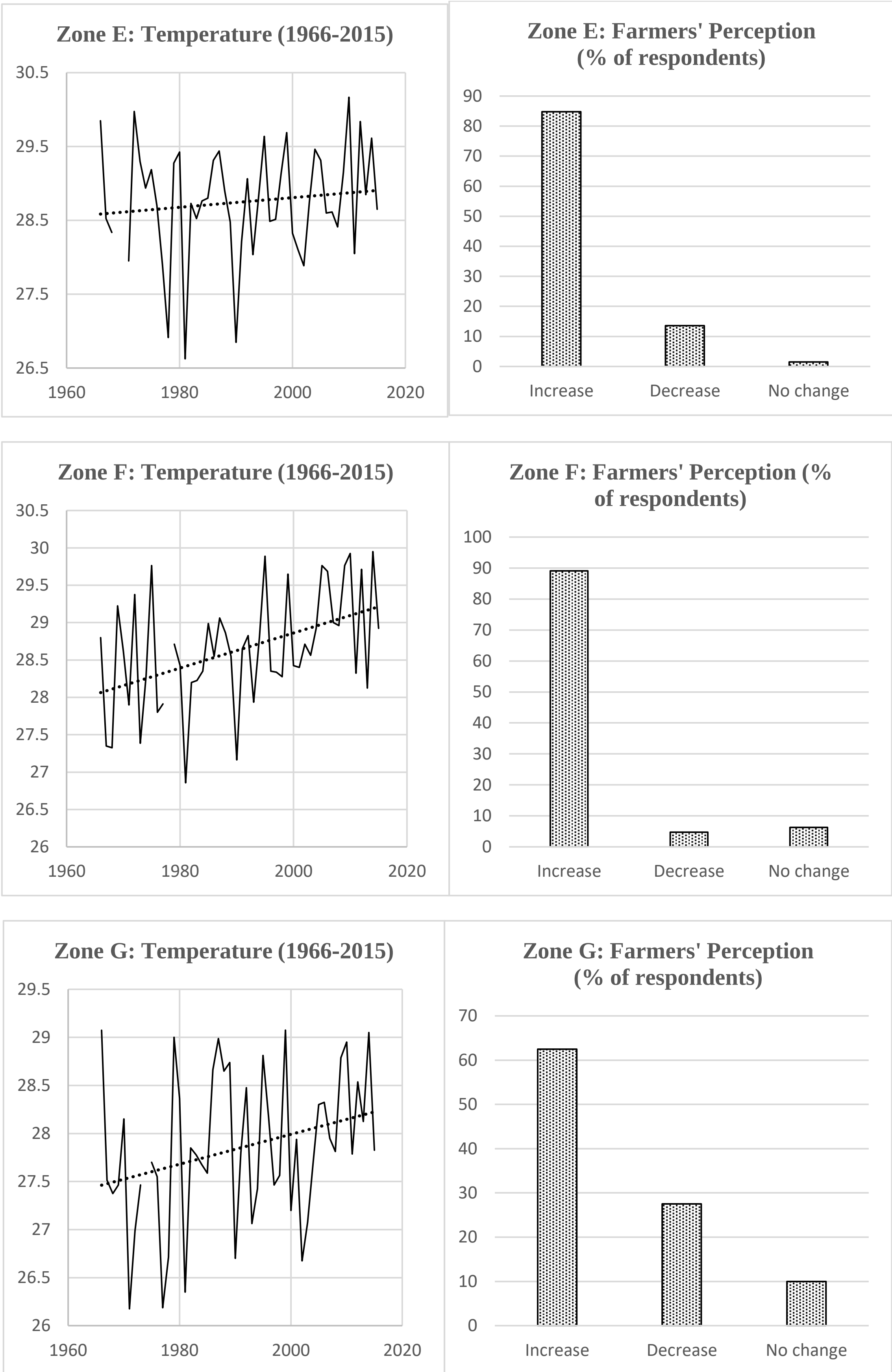
The temperature trends shown in Figure 5.6 are based on the average over the months that constitute the summer period for each zone. It is seen from Figure 5.6 that all the zones experienced an increase in summer temperature. A large number of farmers from all those zones also believed that temperature had increased over time. Therefore, the trend in summer temperature and the beliefs of a large percentage of farmers are consistent.

The rainfall trends shown in Figure 5.7 are based on the total rainfall over the months that constitute the rainy season. The graph indicates decreasing trends of rainfall in most of the zones. Similarly, a large number of farmers in those zones also believe the same. In contrast, in three zones (C, F and G) although the majority of the farmers stated that rainfall in the rainy season had decreased, the meteorological data does not show such evidence.

To conclude, it can be argued that the meteorological data has validated the majority of farmers' understanding of rising temperatures in summer. In the case of rainfall, although in some places meteorological evidence contradicted farmers' perceptions, in the majority of the locations there are consistent outcomes. In four out of the seven zones, the majority of farmers stated that the rainfall in the rainy season had decreased, which was evidenced in the meteorological data. Overall, these findings are evidence that farmers in Bangladesh are capable of accurately perceiving whether there is climate change.

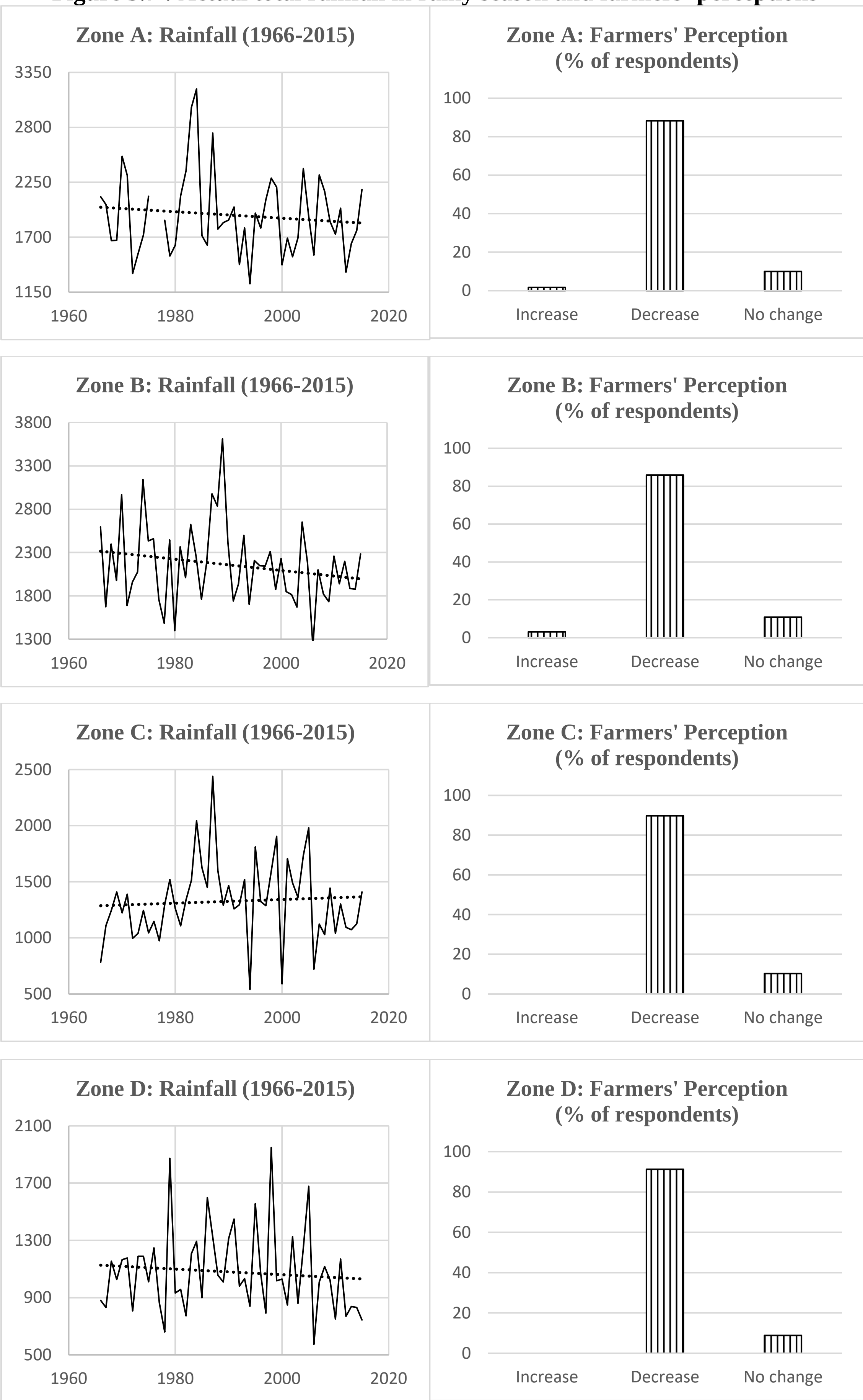
Figure 5.6 : Actual summer temperature and farmers' perceptions

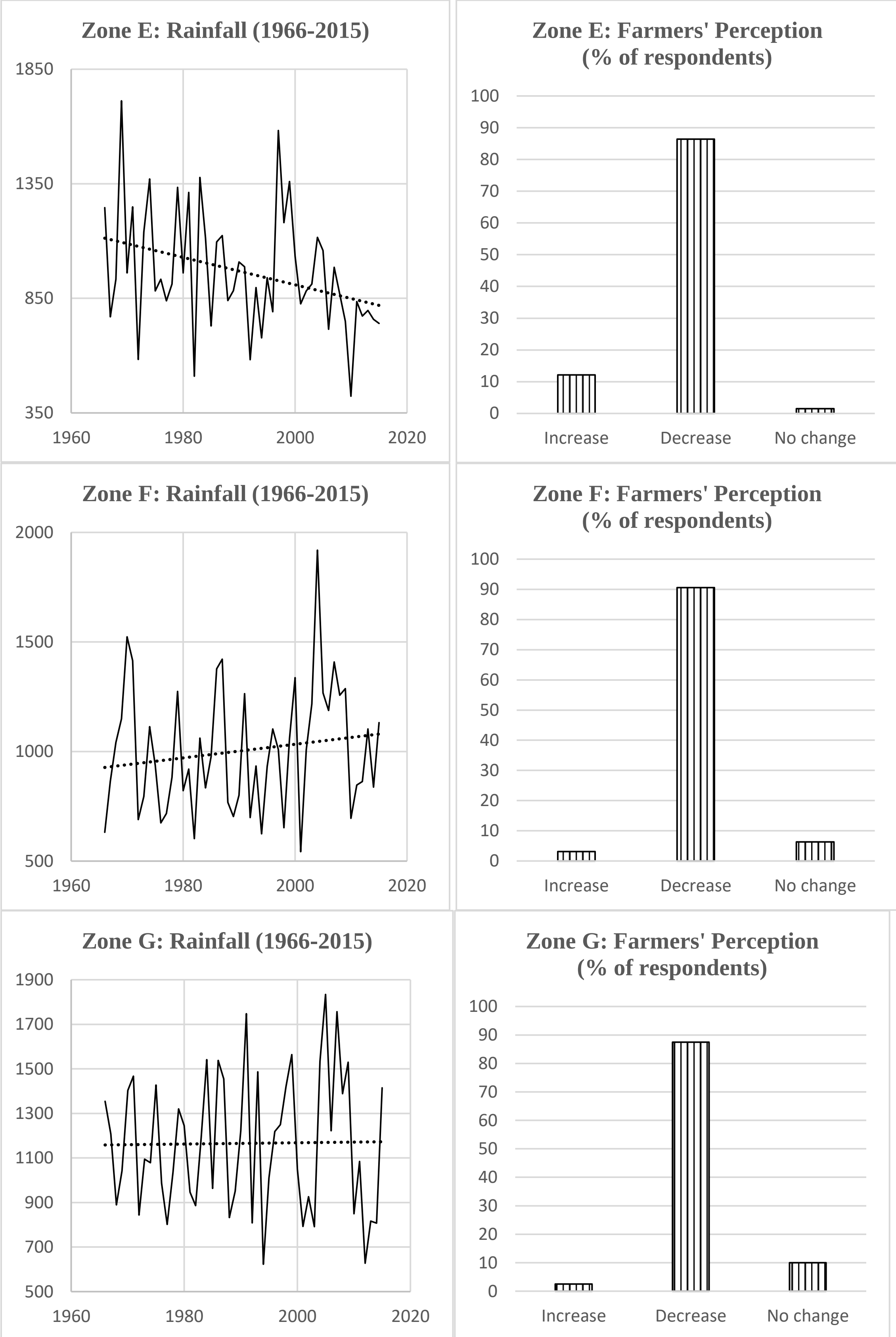




Note: The temperature trends showed in Figure 5.6 are based on the average over the months that constitute the summer period for each zone. It is seen that in all zones, the majority of farmers' view regarding increase in temperature during the summer season over the period is consistent with the meteorological data.

Figure 5.7 : Actual total rainfall in rainy season and farmers' perceptions





Note: The rainfall trends shown in Figure 5.7 are based on the total rainfall over the months that constitute the rainy season. Although in some places the meteorological evidence contradicts farmers' belief, in majority of places (four zones out of seven zones; zones A, B, D, and E) the majority of farmers stated that the rainfall in the rainy season has decreased, which is evidenced in the meteorological data.

5.4.1.4 Farmers' Characteristics and Climate Change Perceptions

As we see, the majority of farmers perceived the direction of climate change correctly. The question may come, what kind of farmers perceived the changes (Maddison, 2007). We may presume first that experience of farming may shed some light on the accuracy of their perceptions. Therefore, the classification of the perceptions of climate change according to the farmers' years of farming experience would be relevant in this respect. In Table 5.5, the respondent farmers are classified into those having less than 15 years, between 16 and 25 years and more than 25 years of experience. There is no real justification for this cut off years. In the literature also there is no consistency in groping, for instance, Maddison (2007) considered as less than 20 years, between 20 and 39 years and 40 or more years whereas Silvestri et al. (2012) did it considering less than 16 years, between 16 and 22 years and over 22 years.

From Table 5.5, it appears that those farmers having more years of experience are more likely to perceive that the annual temperature has increased and annual rainfall has decreased. Moreover, more experienced farmers are less likely to claim that there has been no change in those climatic variables. In terms of the seasonal perspective (summer temperature and precipitation in the rainy season) for temperature and rainfall, the results are very similar to the annual perspective. These results are also consistent with Maddison's (2007) study in Africa.

Table 5.5 : Perception of climate change by farming experience (% of respondent)

Perception	Years of Experience		
	0-15	16-25	25+
Increased Annual Temperature	47.06	47.31	63.66
Decreased Annual Temperature	0.00	4.30	2.8
No Change in Annual Temperature	41.18	21.51	4.97
Increased Annual Rainfall	0.00	3.23	2.17
Decreased Annual Rainfall	52.94	51.61	66.15
No Change in Annual Rainfall	41.18	18.28	2.48
Increased Summer Temperature	47.06	72.04	82.30
Decreased Summer Temperature	11.76	8.6	13.35
No Change in Summer Temperature	41.18	19.35	4.35
Increased Rainfall in Rainy Season	0.00	4.30	3.11
Decrease Rainfall in Rainy Season	58.82	75.27	94.10
No Change in Rainy Season Rainfall	41.18	20.43	2.80

Source: Author's calculation from field survey, 2015/16

Note: Respondent farmers' perceptions about different changes in climate variables are classified in accordance with three different experience group. It appears that experienced farmers are likely to claim that temperature has increased and rainfall has decreased. Moreover, they are less likely to have the view that there has been no change.

The pattern showing in the Table 5.5 does not indicate that whether the differences in views for different experienced group are statistically significant. It does not either show whether the farmers' perception are also sensitive to other factors. Other factor such as farmers' educational attainment can also have effect on perceptions. Therefore, factors that influence farmers' perception are analysed in the next section with regression.

5.4.2 Factors Influencing Farmers' Perceptions of Climate Change

5.4.2.1 Which Farmers Perceived the Climate Change Correctly?

The previous section concerned farmers who stated that there is a change in the climate variables. The change could be in either direction, and there is the question of the validity of their perceptions. To identify the explanatory factors influencing farmers' perception it is important to consider the correct perception of climate change. To do that the definition of the dependent variable has to be such that it will separate farmers who have a correct perception of climate change from those who do not (Roco et al., 2015). In this present study, the perception variables on climate change are converted to binary variables that relate to perceptions that align with historical meteorological evidence. Farmers' perceptions on summer temperature and rainfall in rainy season are used to create binary correct perception variables for this analysis.

To create the correct perception variables, the meteorological data evidence for each zone is used. Whatever the directional change the meteorological evidence shows (shown in Figure 5.6 and Figure 5.7) farmers' perception in that direction is taken as the *correct perception* for each zone for each variable (summer temperature and rainfall in the rainy season). Thus, the binary perception variables that align with the district evidence are created as:

1. Whether a farmer correctly perceived a change in past summer temperature. So the perception for summer temperature variable scores 1 if the farmers have the *correct perception* and 0 otherwise.
2. Whether a farmer correctly perceived a change in past rainfall in rainy season. So the perception for rainfall in the rainy season variable scores 1 if the farmers have *correct perception* and 0 otherwise.
3. Whether a farmer perceived correctly both the changes in past summer temperature and rainfall in the rainy season. So the *correct perceptions*

considering both temperature and rainfall variable scores 1 if the farmer has the *correct perception* on both and 0 otherwise.

The econometric estimates of the logit regression are shown in Table 5.6 for those three categories of perception. Overall, the results indicate that some explanatory factors are related to all three categories of climate change perceptions and some are relevant only to a certain category. The explanatory variables that are statistically significant at least at the 10% level are education, experience, electricity, household asset, farm size, extension advice, credit and irrigation.

Education shows a positive and significant relationship in all three cases, indicating that educated farmers are more likely to perceive both features of climate change. It is assumed that farmers with a higher education level have better cognitive skills which enable them to observe the changes in the climate variables correctly (Habtemariam et al., 2016). The likelihood of a farmer perceiving changes in both temperature and rainfall correctly increases by 1.6% for completion of each year of schooling (shown in the column in Table 5.6). This result is quite close to the result of Roco et al. (2015), who found an equivalent result of 1.8 % in Chile. This finding reinforces the findings of Kamruzzaman’s (2015) study in Bangladesh, which was based on only one location. It should be noted here that the education variable may have a relationship with other explanatory variables like household asset, and agricultural and non-agricultural income. However, the correlation coefficients (shown in Appendix 11) do not indicate the severity of the problem.

The *Experience* variable shows again a positive and statistically significant association in all three cases. This is in agreement with the prior expectation of this study, and consistent with other studies undertaken in Ethiopia (Deressa et al., 2011; Habtemariam et al., 2016) and Kenya (Silvestri et al., 2012). However, these other studies used age instead of experience in the analysis and argued that older farmers are likely to be more experienced in farming and so have gained an understanding of their environment that enables them to identify the changes in climate. In this present study, just to see the differences, age variable is also used instead of experience. The result did not vary in this case as well.

Among the different household variables, an *electricity* facility and *household assets* show a positive and significant relation with some perceptions. However, these two variables may have a relationship between themselves, and be related to other variables like agricultural and non-agricultural income. However, electricity and household assets variables are statically significant and the correlation coefficient (shown in Appendix 11) between them and with other variables is small. The marginal impact result indicates that having an electricity facility increases the likelihood of perceiving both the changes correctly by 13%, which is a stronger influence than that of education and experience. Similarly, an increase in household assets by one unit from its sample mean increases the probability of perceiving temperature change by 7.6%. Households having electricity facility and more assets may reflect their access to higher levels of technology or the market or both (Hassan & Nhemachena, 2008). It can be argued here that farmers with technology and market access are expected to have more information that may help them to recognize change and shape their perception.

Both *agricultural* and *non-agricultural income* are not found to be an important factor to determining any of the perception categories in Bangladesh. There may be some relationship between them as well as with other variables like education, the size of household agricultural labour, farm size and farm assets. However, correlation coefficients (shown in Appendix 11) do not suggest the problem is serious. Moreover, the findings here is consistent with the findings by Habtemariam et al. (2016). However, previous studies have reported mixed results for agricultural income and farmers' perception. For example, Silvestri et al. (2012) for Kenya found no relation but Roco et al. (2015) for Chile found a positive relation. Even for the same country, Ethiopia, Deressa et al. (2011) found a positive relation between agricultural income and farmers' perceptions whereas Habtemariam et al. (2016) found no relation.

Farm size and *irrigation* facilities are found to be important explanatory variables but negatively related and only for perception of the rainy season rainfall. The estimation results for these variables does not show statistically significance with other perception variables. The relationship between farm size and other variables like farm asset, household asset and household agricultural income could affect these findings. Although it was not significant also in Habtemariam et al.'s (2016) study, farm size shows a directional consistency with this study. As expected, farmers with less land and lower percentage of land with irrigation facilities are more likely to perceive correctly the change in rainfall. As rainwater is an important requirement for the rice crop, farmers with less irrigation facilities are more likely to face difficulties as well as perceive correctly the rainfall change.

Credit facilities are also found as an important explanatory variable for perceiving climate change. In contrast with the initial assumption, access to credit has a positive relation with perception of changes in both temperature and rainfall together. The initial assumption was that farmers having access to credit have better financial capital to cope with any difficulties; therefore they are less likely to perceive the change (Habtemariam et al., 2016). It can be argued here that the findings might support an argument that the farmers with access to credit are more able to invest in their farm or have already invested in their farm. Therefore, they may be more concerned about capital loss due to unforeseen changes in the climate (Mendelsohn, 2012) and more likely to perceive changes correctly. In support of this finding, Rejesus et al. (2013) also found that the farmers with more assets invested in farming were more likely to have correct beliefs about climate change.

The result also indicates that farmers with *livestock* are more likely to perceive temperature changes only. An explanation for this finding is found in a number of studies (Mertz et al., 2009b; Silvestri et al., 2012). Mertz et al. (2009b) found that households in Senegal linked the poor livestock health with climate variability. Similarly, Silvestri et al. (2012) for Kenya found that households identified problems with availability of feed as an impact of climate change. Households also reported that they have experienced shortages of feed, in particular during the long dry season. Thus climate change is expected to have direct influences on feed or fodder and hence affect livestock health (Wheeler & Von Braun, 2013).

It is believed that extension advice can create awareness among farmers regarding climate change because extension advice may provide information about climate change (Maddison, 2007). Although this study did not have any information on whether or not climate change information is provided by extension advice to farmers, the results of this study show that farmers with *extension advice* are more likely to perceive the changes in temperature and rainfall. This is consistent with the findings of Gbetibouo (2009) that the probability of perceiving change in temperature increases with the access to extension. However, Silvestri et al. (2012) found a negative effect of extension advice on perceptions and argued that this may be because of the limited number of visits and information delivery difficulties.

Previous studies related to farmers' perceptions on climate change also found some evidence of a relationship between perceptions and other variables not discussed above, for example, soil fertility (Gbetibouo, 2009), weather information (Deressa et al., 2011;

Habtemariam et al., 2016), market distance (Maddison, 2007), and tenure status (Roco et al., 2015). In this study, no statistical evidence is found that those variables influence perception of climate change among rice farmers in Bangladesh. Some of these variables might have some relationship with other variables that might affect their statistical significance. Soil fertility with education, experience and farm agricultural income may be examples of such variables. However, while acknowledging this possibility, the findings from this study suggests that soil fertility, weather information, market distance and tenure status do not have any effect on farmers' perception in Bangladesh.

Table 5.6 : Determinants of correctly perceived changes in summer temperature and rainy season rainfall

Independent variables						
	Temperature		Rainfall		Both	
	Coefficient	Marginal effect	Coefficient	Marginal effect	Coefficient	Marginal effect
Farmer's Characteristics						
Education	0.118**	0.0161**	0.140*	0.00987*	0.140**	0.0161**
Experience	0.0294**	0.00401**	0.0645***	0.00455***	0.0328*	0.00376*
Group	-0.217	-0.0297	-0.0867	-0.00611	-0.194	-0.0222
Household's Characteristics						
Own labour	-0.0495	-0.00676	-0.191	-0.0134	-0.0867	-0.00995
Electricity	0.813**	0.111**	0.841	0.0593	1.134***	0.130***
Literacy	0.0335	0.00458	0.000413	0.0000292	-0.105	-0.0120
Household Asset	0.555**	0.0759**	0.480	0.0338	0.409	0.0469
Agri. Income	0.115	0.0157	0.584	0.0412	0.219	0.0251
Non-agri. Income	-0.0440	-0.00601	-0.112	-0.00787	0.0133	0.00152
Farm Characteristics						
Farm size	-0.177	-0.0242	-0.340**	-0.0239**	-0.216	-0.0247
Fertility of land	0.133	0.0183	-0.343	-0.0242	-0.0843	-0.00967
Tenure Status	0.163	0.0222	0.198	0.0139	-0.116	-0.0133
Livestock	0.669*	0.0915*	0.579	0.0408	0.581	0.0667
Farm Asset	-0.0240	-0.00328	-0.378	-0.0266	-0.305	-0.0350
Institutional Accessibility						
Extension advice	0.732**	0.100**	0.932*	0.0657*	0.107	0.0123
Weather info	-0.109	-0.0149	0.280	0.0198	0.166	0.0190
Credit	0.555**	0.0759**	0.276	0.0195	0.739**	0.0848**
Irrigation	-0.00265	-0.000362	-0.0138*	-0.000977*	-0.00769	-0.000882
Market	-0.0833	-0.0114	-0.146	-0.0103	-0.224	-0.0257
Constant	-1.736		0.880		-0.390	
Zone fixed effect	Yes					
Observations	432		374		374	

Percent correctly predicted	80.79	91.18	83.16
Wald Chi-square (25)	66.64***	122.49***	105.45***
Log pseudolikelihood	-184.93	-90.24	-136.1488
Pseudo R^2	0.1734	0.6293	0.4695

Note: *** p<0.01, ** p<0.05, * p<0.1 ; The econometric estimates of the logit regression model for perception are shown here considering three correct perception variables. To create the correct perception variables, the meteorological data evidence for each zone is used. Whatever directional change the meteorological evidence shows (shown in Figure 5.6 and Figure 5.7) farmers' perception in that direction is taken as a *correct perception* for each zone for each variable (summer temperature as *temperature* and rainfall in the rainy season as *rainfall*). The *both* variable is where both *temperature* and *rainfall* are perceived correctly. Overall, the results indicate that some explanatory factors are related to all three categories of climate change perceptions and some are relevant only to a certain category. The explanatory variables that are statistically significant at least at the 10% level are education, experience, electricity, household assets, farm size, extension advice, credit and irrigation. *Farm size* and proportion of land that has *irrigation* facilities are only negatively related to climate change perception apart from all those significant variables. The zone/district fixed effect is considered using the dummy variable. The full table is given in the Appendix 5. The estimated models have pseudo R^2 value of 0.17, 0.63 and 0.47 with quite high Wald Chi-square value significant at the 1% level. The models are also able to predict around 81, 91 and 83 per cent of the dependent variable correctly. All these statistics imply that the model used here is quite reliable and appropriate.

5.5 Conclusion and Policy Implications:

To minimize the negative effect of climate change, farmers have to adapt their farming system. However, to make adaptation decisions farmers need to have a prior knowledge of climate change. Therefore, in adaptation decisions, farmers need to perceive the nature of climate change and then respond to the changes through adaptation. The role of perception in decision-making is supported by the theory of behavioural economics. In the field of adaptation to climate change research, the role of perception is also supported by empirical evidence. However, empirical evidence suggests farmers' perception to climate change varies from country to country. Different socio-economic and environmental factors affect farmers' ability to perceive climate change differently in different places.

From the policy perspective, it is important to understand farmers' perceptions about climate change. An important element of any policy is to understand how farmers would respond to climate change and the basis for this understanding would be farmers' prevailing perception of climate change. Moreover, understanding the determining factors that influence perceptions would give indications to policy makers on where and how to intervene. Overall, understanding farmers' perceptions and determining factors that influence perceptions would enable policy makers to ensure that actions are correctly directed to improve adaptation and reduce the impact of climate change on agriculture.

Therefore, in this study an attempt has been made to identify farmers' perceptions of climate change and the determinants that influence perceptions of climate change. The study was conducted in Bangladesh, which is one of the vulnerable countries in the world in the face of climate change. Household level data collected from a field survey on rice farmers are used here. It is found that the majority of the farmers were able to perceive correctly the direction of changes in the temperature and rainfall situation when compared to local meteorological records. It is found that the variables that influence farmers to perceive correctly the changes in climate are education, experience, electricity, household asset, farm size, extension advice, credit and irrigation facilities.

In general, this study found that the majority of the farmers correctly perceive the changes in climate in the sense that their perceptions were consistent with the local meteorological evidence. However, there are some farmers (37-40 %), who did not have any opinion or whose perceptions were different to actual historical data. Policy makers need to ensure that these groups understand climate change and the associated potential risk it poses.

Targeted and farmer-specific extension advice can be provided to specific farmer groups to inform their understanding of climate change. There is a need to provide scientific information about climate change from different sources to influence farmers' perceptions about climate change risks (Weber, 2010). In this respect, extension workers may need to be trained to convey climate change information to farmers. Therefore, future policy focus should be given to creating awareness of climate change among both extension workers and farmers.

It is also found here that agricultural extension advice plays a role in enhancing farmers' perception about climate change. Therefore, provision of extension advice should be targeted towards less educated and less experienced farmers. The result also suggests the need for extension advice provision to large farmers, farmers with a higher proportion of land having irrigation facilities and farmers who have less access to credit facilities. Moreover, factors identified in this research as affecting the perception of climate change are related to infrastructure and institutions in general. This implies that more needs to be done to develop prevailing infrastructure and institutions, especially in education, electricity facilities, extension advice and credit facilities.

Finally, there are number of ways in which this research contributes to the literature. This research contributes to the literature on climate change as it is one of the first of its kind to examine Bangladesh rice farmers' perceptions of climate change and their determinants. The identified factors enable policy makers to target specific issues to enhance farmers' climate change understanding. In this respect, the contribution to knowledge is location specific, related to Bangladesh specifically. Although the findings are location specific, they may have more general relevance to countries with similar agricultural and socio-economic conditions. Hence, this study will add to the knowledge related to developing countries in general. Apart from those, this research is particularly relevant in the context of farmers who are cultivating rice, as this is the first research that analyses rice farmers' perceptions.

Chapter 6: Rice Farmers' Adaptation to Climate Change: Patterns and Determinants

6.1 Introduction

Adaptation is one of the solutions to reducing the impact of climate change (IPCC, 2014a). In the case of developing countries, this is the best or only option on which to concentrate because of high levels of damage from climate change (Mendelsohn et al., 2006). Even from a cost effectiveness point of view, these economies, whose emissions contribution are very low, should concentrate more on efforts at adaptation (Chisari et al., 2016). More specifically, adaptation should be promoted in agriculture in those countries, given the importance of agriculture to the livelihoods of the rural poor (Malik & Smith, 2012).

Different aspects of adjustment made by economic agents in a changed environment is one of the main areas of interest in economics. Theoretical interest in this area in general has been evident since Samuelson (1947), but it has gained greater interest with the study of economics of climate change (Di Falco et al., 2011; Mendelsohn, 2012; Zilberman et al., 2012; Di Falco, 2014; Eisenack & Kähler, 2016). Many climatic changes are occurring on a slow time-scale, indeed, it is taking place over decades. Therefore, one of the important challenges in climate change adaptation is to anticipate the adjustment behaviour of economic agents in response to these slow changes. Burke and Emerick (2016) argued that rapid adjustment could minimize the damages associated with climate change whereas slowness in response or inability to adjust could result in damage being much greater and of greater concern to policy.

However, despite the recognition of the importance of adaptation, research on farmers' adaptation for South Asia, and especially Bangladesh, is scarce (discussed in Section 6.2). Local adaptation strategies that farmers are taking, the barriers that farmers are facing while undertaking adaptation and the factors that affect their decision to adapt are relatively unexplored in the literature. The research reported in this chapter is an attempt to contribute knowledge on these issues.

More specifically the research reported in this chapter addresses the following questions:

- What do rice farmers perceive about the damage caused to rice farming by climate change?

- What are the main strategies rice farmers have adopted in response to climate change?
- What are the obstacles rice farmers face while undertaking adaptation?
- What are the factors that allow or encourage rice farmers to take the adaptation decision?
- What are the factors that influence the resource-poor rice farmers to overcome obstacles relating to climate change adaptation?

This chapter is organized into four sections. Section 6.2 is a literature review where both theoretical and empirical evidence related to climate change adaptation is presented. Section 6.3 discusses the data, the collection procedure adopted to collect that data and the analytical methods used to investigate the research questions. In Section 6.4, the findings from this study are presented and discussed. Finally, Section 6.5 concludes the chapter and provides policy recommendations.

6.2 Literature Review

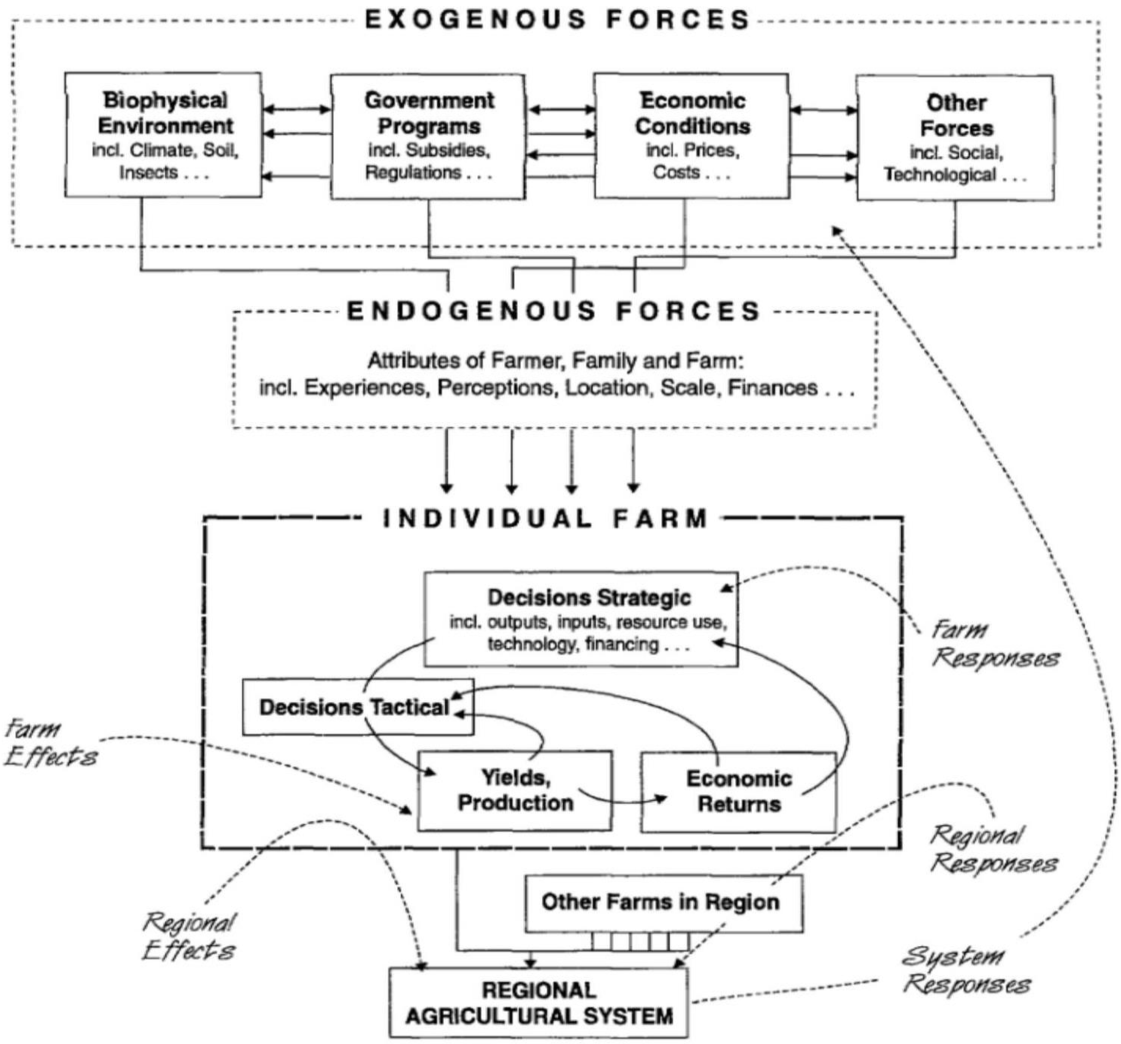
6.2.1 The Concept, Process and Economics of Adaptation

Adaptation to climate change refers to any adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (Smit et al., 2000; IPCC, 2014a). Adaptation actors such as households, firms and the government will take adaptive action to reduce the harm or increase the gains from climate change (Zilberman et al., 2012). In this respect, it is expected that with the changes in climate, all actors will take some form of adaptation. However, adaptation can be autonomous or planned. Adaptation is autonomous when actors undertake it independently, and it is planned when influenced by policies or direct actions associated with public initiatives (Stern, 2007). Adaptation can also be either private or public. According to Mendelsohn (2012), private adaptation is that when only the decision maker is affected by taking the adaptation. Many adaptation decisions are of this kind, taken by households and firms. In contrast, actions or decisions taken by government that affect many beneficiaries are categorised as being public adaptations (Mendelsohn, 2012).

In the case of agriculture, at the field level, individual producers are the main actors in adaptation (Konrad & Thum, 2014). Therefore, from the farmers' perspective any actions or strategies taken by them at the farm level, in response to the changes in climate, can be consider to constitute their adaptation. Although the strategic decision on adaptation is place and context specific (IPCC, 2014a), it can be reactive or anticipatory (Fankhauser et al., 1999). When the adaptation measures are taken in response to climate change then it is reactive, whereas anticipatory measures are taken in advance, before the event. However, as climate change is a continuous process, in practice it may be difficult to delineate between 'before and after' the event. Moreover, the two strategies can be complementary or substitutive (Fankhauser et al., 1999). Reactive and anticipatory strategies could be complementary if one adaptation increases the marginal benefit of another adaptation and vice versa. For example, removing a crop subsidy may enable farmers to react more quickly to climate change. However, these can be substitutes if anticipatory adaptation may reduce the need for subsequent reactive adaptation.

From the policy perspective, understanding the process of adaptation is very important. According to Fankhauser et al. (1999) a successful adaptation depends on three things: the timely recognition of the need to adapt: an incentive to adapt: and an ability to adapt. According to Smit et al. (1996), individual farmers take the strategic decision on what to produce and how to produce it in the light of exogenous forces such as the biophysical environment, government programmes, and economic conditions (Figure 6.1). The effect of these exogenous forces may vary among farmers because of their perception of and sensitivity to exogenous forces.

Figure 6.1 : Agricultural adaptation to climate change



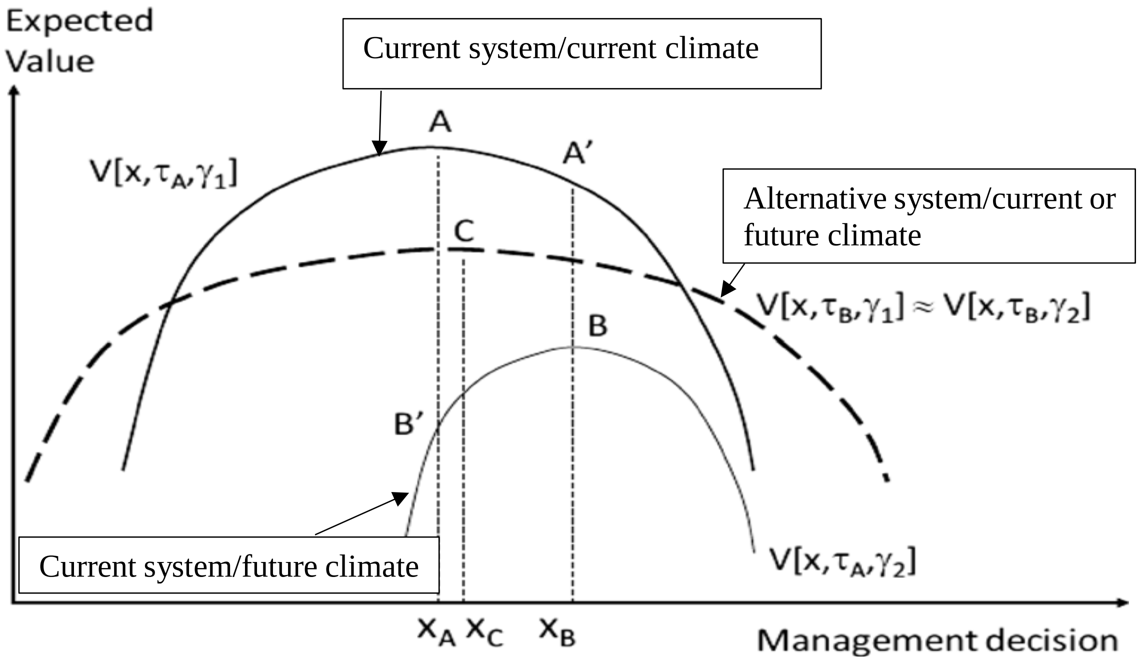
Source: Smit et al. (1996)

The perception of and sensitivity to exogenous forces are influenced by particular characteristics of the individual farm, farm operator and farm family. The farmers will judge the short term tactical decisions by translating it into economic terms by incorporating input costs and commodity prices. Mandryk et al. (2014) found evidence that in practical decision-making farmers are focused more on economic result maximization. This economic effect is most likely to stimulate longer-term changes in the farming system in the form of strategic decisions such as changes in the type of crop or livestock or management system (Di Falco & Veronesi, 2013). When many farms in the region undertake strategic responses or adaptation, a change in the regional agricultural system becomes apparent.

Antle and Capalbo (2010) illustrated this from the management decision perspective. In their analysis the expected value curve represents the relationship between the net expected economic value of agricultural activities and short-term management decisions

(Figure 6.2). The expected value of a given production system at a given location is a function of management decision X with a given production system τ_A and current climate γ_1. Here the management decision X serves as a proxy for crop choices, planting time, application of seeds, nutrients, water, labour and other inputs uses. Farmers having the present value function $V[x, \tau_A, \gamma_1]$ of that particular location with present technology and climate will choose management decision X_A to maximize the value of production at point A. Now if the climate changes to γ_2 , the expected value function will shift to $V[x, \tau_A, \gamma_2]$ and the economically efficient management decision X_A is not optimal and will result in the lower value B'. By adapting the short term management decision from X_A to X_B, the farmer can reduce the negative impact given by the vertical distance between A and B. Here, the adverse impact is AB' and the gain from adaptation is the amount of BB'. Moreover, a higher maximum value can be attained with changing climate by adapting short term management and changing to system τ_B, at point C. This may be in the short run or in the long run depending on several things. According to Antle and Capalbo (2010), long term adaptation depends on whether short term adaptations are made and on changes in policies, institutions and technology.

Figure 6.2 : Climate change impact and adaptation



Source: Antle and Capalbo (2010)

Mendelsohn (2012) explains the economics of adaptation from the firm's capital adjustment perspective. According to him, a firm's adaptation decision can be explained on the basis of a profit maximization decision. A firm will try to maximize their profits (π):

$$\text{Max } \pi = P_Q Q(Z,C) - \sum P_Z Z \tag{6.1}$$

where P_Q is the price of output Q, P_Z is the prices of purchased inputs Z, and $Q(Z,C)$ represent a production function that involves a vector of inputs Z and climate C. As climate enters into the production function, it will alter the input output relation. The first order condition for maximizing profit is to equate the price of each input to its marginal productivity as:

$$P_z = \frac{dQ(Z,C)}{dZ} \tag{6.2}$$

The marginal productivity in industries such as agriculture and forestry will be affected more by the climate. Accordingly, there will be a change in inputs as the marginal productivity of these inputs changes. In some cases, the firm may have to shift its output mix as well. For example, one output may be less profitable to produce than another in case of climate warming. In case of agriculture, farmers may change their crop or livestock variety with climate change.

Firms may decide to invest in capital (K) and will try to maximize the present value of future profits. The profit maximizing decision of the firm will be:

$$\text{Max} \int \left[P_Q\, Q_t(Z,K,C) - \sum P_Z\, Z_t\right] e^{-rt} dt - P_K\, K \tag{6.3}$$

where P_K represents the capital price. The first order condition of optimization shows the equality of the price of capital with the present value of the marginal productivity gains over time:

$$P_K = \int P_Q\, \frac{\partial Q_t(Z,K,C)}{\partial k} e^{-rt}\, dt \tag{6.4}$$

The firm's decision to invest more (less) in capital will be affected by how climate increases (decreases) the marginal productivity of capital. In this respect, difficulties may occur if there is considerable uncertainty about the magnitude of climate change. Actors would be reluctant to abandon the existing capital prematurely and prefer to wait for it to depreciate before acting. They will be concerned about how the climate would change and how their decision to invest in capital involves benefits accruing far into the future. Under uncertainty, they would probably undertake less anticipatory adaptation than they would under perfect information.

6.2.2 Adaptation Options

Different potential agricultural adaptation measures are suggested in the literature to reduce the expected adverse impact of climate change. Smit and Skinner (2002) gave a typology of adaptation, which focus particularly on Canadian agriculture but they do have more general relevance. The typology groups the agricultural adaptation options into four main categories based on the scale of adaptation and the stakeholders involved (shown in Table 6.1): (1) technological developments, (2) government programmes, (3) farm production practices, and (4) farm financial management. These categories are not mutually exclusive and are often interdependent. For example: technology developed by government and private agents (type 1) will be taken up by farm operators (type 3), technology provided by the government at a subsidized rate (type 2) will be taken up by farm operators (type 3), and crop insurance provided by government (type 2) will be taken up by farm operators (type 4).

In Smit and Skinner's (2002) typology, there are two types of adaptation involved from the farmers' perspective, one related to production practices and the other to financial management. Adaptation related to farm production practices involves changes in farm operations with respect to production, land use, land topography, irrigation and the timing of operations (Smit & Skinner, 2002). Parry et al. (1998) broadly classified those options into three categories as: (1) adaptation by altered crop choice, (2) adaptation by altered tillage and crop management, and (3) adaptation by altered inputs.

Changing farm production activities is one of the major adaptation strategies that could reduce climate related risks and increase the flexibility of farm production to take the opportunity of changing climate. Kaiser et al. (1993) argued that farmers' adaptive strategies include adopting later maturing cultivars to take advantage of a longer growing season due to climate warming.

Table 6.1 : Adaptation options

Types	Adaptation options
1. Technical development	Develop - new climate tolerant crop variety - weather and climate information system - resource management (including water, irrigation and other farm-level resource management)
2. Government programs	Develop - policies to influence farm level adaptation - agricultural subsidy to crop insurance, investment to production practices and financial management - private insurance
3. Farm production practices	- change or diversify crop types, livestock types - change the intensification of production - change the land use and land topography - change in irrigation practices - change in farm operations timing
4. Farm financial management	- purchase crop insurance - invest to support change in production practices - diversify household income

Source: Smit and Skinner (2002)

Several studies also found a tendency in farmer's adaptations towards changes in crops or livestock variety in the face of climate change. Kim et al. (2012) found that the majority (70.7%) of farmers in Korea preferred to change variety as an adaptation strategy to climate change. Acquah and Onumah (2011) found that choosing different crop varieties is one of the major adaptation measures taken by farmers in Ghana. Using a sample of 5000 farmers across 11 countries in Africa, Kurukulasuriya and Mendelsohn (2008a)) found that switching to different new crops to match the climate they face is the major adaptation decision taken by the farmers. They also claimed that farmers would continue to do so if there is no barrier to the adoption of appropriate crops. Similarly, based on a survey of 949 farmers across seven countries in South America, Seo and Mendelsohn (2008a) found that farmers tend to change the crop varieties in accordance with climate change; farmers will switch away from maize, wheat, and potatoes towards squash, fruits and vegetables.

Studies also found that climate variables are influencing farmers to choose their primary species. A study on 5000 African farmers by Seo and Mendelsohn (2008c) found that farmers are likely to switch from beef cattle to more heat-tolerant goats and sheep in warmer locations, and switch from cattle and sheep to goats and chickens in wetter locations. A similar study by Seo et al. (2010) on 1300 livestock farmers in seven countries of South America also found that the farmers' choice of primary species to grow and probability of adopting any livestock species increases with warming and decreases with more rain. However, one important finding in their research is that this influence varies from country to country. For example, under the hot dry scenario, the tendency to adopt dairy cattle increases in Argentina and Uruguay, but decreases in other countries. In addition, in a milder and wetter scenario, the choice of beef cattle increases in Argentina and Chile whereas it declines in Colombia, Ecuador, and Venezuela. Similarly, the tendency to choose sheep decreases in Chile but increases in Venezuela and Colombia. Similarly, Chatzopoulos and Lippert (2015) found that in Germany, permanent-crop farms are more likely to dominate in higher temperature locations whereas forage or mixed farms would be found at higher precipitation levels.

Apart from the crop choice, farmers in a location characterised by changing climate adopt other forms of adaptation such as changing input use, tillage techniques and soil conservation techniques. In a case study of a grain farm in southern Minnesota in US, Kaiser et al. (1993) found while the crop mix was an adaptation decision given a changing climate, farmers also altered the timing of operations to take advantage of a longer growing season. Similarly, Kim et al. (2012) found farmers' preferences in South Korea were to change the seed/harvest timing as their adaptation strategy. In a study by Di Falco et al. (2012) of 1000 farms producing cereal crops in the Nile basin of Ethiopia, it was found that along with changing crops, soil conservation techniques and planting trees are other important adaptation options taken by farmers. Similarly, Gbetibouo et al. (2010) in South Africa and Acquah and Onumah (2011) in Ghana found that soil conservation and water harvesting techniques, and changing planting dates are other important climate change adaptation decisions, along with selection of different crop varieties.

Overall from the empirical research it is seen that adaptation strategies taken by farmers are place and context specific (IPCC, 2014a). Strategies taken by farmers differ from place to place in accordance with need as well as the availability of different options. However, the most common methods of adaptation are changes in crop varieties, changes in soil conservation technique, changes in planting schedule such as early or late planting, and improved water management and irrigation systems (Maddison, 2007; Bryan et al., 2009; Deressa et al., 2009).

Using focus group discussion and key informant interviews, Ahmed (2000) and Thomas et al. (2013) analysed the potential and suitable adaptation of crop agriculture in Bangladesh. Harun-ur-Rashid and Islam (2007) have also suggested some adaptation strategies for Bangladesh agriculture. All these studies focused on agriculture as a whole and were descriptive in nature. Although a few empirical studies are available, all of them particularly focused on a specific region in Bangladesh (Habiba et al., 2012; Sarker et al., 2013; Alauddin & Sarker, 2014; Alam, 2015). Sarker et al. (2013) and Alam (2015) considered only one district whereas Habiba et al. (2012) considered two districts, but all of them are in the North-western region. Although Alauddin and Sarker (2014) considered more districts in their study, it also covered only three of the seven climatic zones in Bangladesh. The regions examined by these studies are considered drier than others in Bangladesh.

Habiba et al. (2012) particularly interested on drought issue and found that it is the main problem affecting agriculture as well as farmers' social life and health in the study area because of rainfall and temperature variation. They also found that to cope with drought, farmers have been adapting various practices mainly through agronomic management, crop intensification, and water resource exploitation. The agronomic practices like manuring and composting, ail lifting, tillage and shedding are common which help to improve holding rainwater and distributing rainwater uniformly into field. Crop intensification is through crop diversification (diversified crops like sugarcane, different type pulse and oil crops, vegetables and different fruit crops like mango, and jujube) and changing cropping pattern in their cropping field. Water resource exploitation include water harvesting through re-excavation of pond and use of deep tube well, shallow tube well and low lift pump. Although they did not use any regression analysis, through simple classification of farmers they concluded that owner farmers have more capacity to adopt new technology than tenant farmers.

Sarker et al. (2013) studied in the same region that Habiba et al. (2012) examined, looking farmers' adaptation from climate change perspective. They have found that farmers have adopted a variety of adaptation strategies. More irrigation is the main adaptation there, 75% of the sample farmers. Other adaptation strategies taken by farmers they found are Aman rice with supplementary irrigation (8%), short-duration rice varieties (4%), changing planting and harvesting dates (8%), the conversion of paddy land into mango orchards (0.18%), agro-forestry (0.55), using different crop varieties (1.09), the cultivation of various pulses (2%) and the cultivation of jute and wheat (0.73). In the same region, Alam's (2015) study also found similar range of adaptation strategies taken by farmers as increased use of groundwater irrigation (56.04% of the total surveyed farmers), crop diversification and farming calendar adjustments (23.81%), land use change (9.71%), increased use of surface water irrigation (4.21%) and others (6.23%, which included water conservation and conservation tillage).

Alauddin and Sarker (2014) studied in a bigger scale considering more farmers in their sample as well as considering three climatic zones in Bangladesh. However, their study also includes the same region studied by other studies discussed above. They found that four most preferred adaptation strategies are cultivation of short duration rice varieties (20.1%), use of more irrigation (17.4%), supplementary irrigation for aman rice (14.9%) and cultivation of non-rice crops, such as wheat, maize, potato, pulses and oilseeds (11.2%). The two least preferred options they found were use of water saving technology (0.7%) and direct seeded rice (2.6%). A small percentage of households (5.6%) did not adopt any adaptation measures in their study. Their findings on preferred strategy is different than that of Sarker et al. (2013) and Alam (2015). Sarker et al. (2013) and Alam (2015) found that majority of the farmers took more irrigation as their main strategy, around 75% and 56% of farmers respectively. On the contrary, only 17.4% of respondent took this strategy in Alauddin and Sarker's (2014) study. However, it is among the other four important strategies they found as farmers important adaptation strategy, not the preferred one. The reason of differences could be the differences in the study area considered, Alauddin and Sarker's (2014) one considered a wider region than the other two.

Overall, these studies identified several farm level adaptation strategies in Bangladesh such as changing planting date, short-duration rice, direct seeded rice, cultivation of drought tolerant rice varieties, supplementary irrigation, increased use of groundwater irrigation, increased use of surface water irrigation, agro-forestry, land use change, water conservation technique, diversify crop production and other crop varieties.

6.2.3 Determinants of Farmers' Adaptation Decisions

It is the farm household or the farmer that will take the adaptation decision (Mendelsohn, 2012). Farmer's adaptation to climate change requires making choices among a set of adaptation options. There is a growing interest in the climate change literature in understanding the reasons underlying farmers' responses. For successful adaptation, especially in the developing countries to reduce the adverse impact of climate change, information on the process of adaptation decision, barriers and drivers to influence farmers is required.

Öhlmér et al. (1998) identified a decision making process through studying 18 individual farms in Sweden over three years, through repeated interview. They found that there are four stages in the decision-making process: problem detection, problem definition, analysis and choice, and lastly implementation. In the process of making any change in the farm operation, farmers first have to detect the problem. In the case of climate change adaptation, this is also true. Before identifying potentially useful adaptation options and implementing them, farmers first have to notice that the climate has changed (Maddison, 2007). Studies related to farmers' adaptation to climate change considered this as farmers' perception about climate change (Maddison, 2007; Bryan et al., 2009; Gbetibouo, 2009; Mertz et al., 2009b; Acquah & Onumah, 2011; Deressa et al., 2011). In this research, farmers' perception has already explored in the last chapter.

Maddison (2007) argued that climate change adaptation is a two-step process. In the first step, farmers perceive that a change in climate system has occurred, and then in the second step, they act accordingly by taking adaptation measures. In considering this proposition, farmers' adaptation decisions were studied for 11 countries in Africa by Maddison (2007), for South Africa by Gbetibouo (2009) and for Ethiopia by Deressa et al. (2011) using Heckman's sample selection model. Deressa et al. (2011) argued that as farmers' adaptation decision is conditional upon perceiving climate change, so the standard probit technique applied in estimation would yield biased results because of the presence of the sample selection problem. However, Maddison (2007) and Gbetibouo (2009) did not find evidence of sample selection bias in their study.

Now the question arises, whether understanding the occurrence of climate change is sufficient to take the adaptation decision. Several studies found that despite perceiving changes in the climate system, a considerable number of farmers did not take any adaptation strategy (Maddison, 2007; Bryan et al., 2009; Gbetibouo, 2009; Bryan et al., 2013). Behavioural economics would argue that these farmers simply interpret the low output as idiosyncratic bad luck rather than the result of a structural change in climate conditions (Kahn, 2015). Thus, it can be argued that farmers need to not only perceive the changes in climate but also to perceive the risks associated with those changes. Dang et al. (2014) found evidence among rice farmers from the Mekong Delta in Vietnam, that farmers are more likely to have an intention to adapt when they perceive higher risks of climate change whereas they are less likely to hold such intensions when they do not recognise the risks associated with climate change.

Apart from the perception of climate and its impact, it is also argued that the climate may not play the main role in influencing farmers to make adaptation decisions; rather it is economic, social and political reasons that could play a greater role (Mertz et al., 2009). In this respect, barriers that farmers may face and determinants that influence farmers undertaking any adaptation come into the adaptation decision process.

Empirical studies have acknowledged several barriers to adaptation. Gbetibouo et al. (2010) in their study of the Limpopo basin in South Africa found that 60% of the respondents who did not undertake any adaptation acknowledged financial constraints to be the main reason for that. Maddison (2007) also found that inability to borrow was the main barrier. Similarly, Ringler (2010) and Nhemachena and Hassan (2007) in South Africa, and Bryan et al (2009) and Deressa et al. (2009) in Ethiopia found that lack of financial resources was the main barrier to adaptation. Apart from credit availability, the lack of information about adaptation strategies and lack of climate information are also found to be important barriers in the literature (Nhemachena & Hassan, 2007; Bryan et al., 2009; Deressa et al., 2009; Sarker et al., 2013; Alauddin & Sarker, 2014). All these studies underscore the importance of adaptation policy and government support to provide information on adaptation options, information on climate and access to credit for successful adaptation in agriculture.

Empirical research has also identified several determinants and their effects on the adaptation decision. Those determinants can be categorised into four types. They are:

Household Characteristics:

These include age, gender, farming experience, education of the household head, household size and family wealth (Bryan et al., 2009). Empirical findings about the effect of these determinants are not the same for all studies. Some studies found that age of the household head is a significant determinant and affects the adaptation decision positively

(Nhemachena & Hassan, 2007; Bryan et al., 2009; Deressa et al., 2009; Gbetibouo et al., 2010; Acquah & Onumah, 2011), whereas other studies found the opposite (Nyangena, 2008). The argument is that older farmers are more experienced and so able to judge the situation and consequently are more likely to adopt new practices; in contrast, because of risk aversion and the likelihood of being less flexible, older farmers may not adopt new technology. Similarly, studies found that male headed households have a greater tendency to adopt (Bryan et al., 2009; Deressa et al., 2009) whereas others found the opposite to be the case (Nhemachena & Hassan, 2007). Apart from the factors discussed above, other factors that may affect adaptation decisions are wealth and education.

Farm Characteristics:

These include farm size, farm income and fertility of the farmland (Gbetibouo et al., 2010; Sarker et al., 2013). Farm size and farm income have a positive influence on adaptation (Nhemachena & Hassan, 2007; Deressa et al., 2009). Soil fertility of the land is argues to be an important determinant of the adaptation decision by Di Falco and Veronesi (2014). Gbetibouo et al. (2010) found that farm size and farmers' perception that their land as highly fertile have a significant and positive relation to choose adaptation measures.

Institutional Factors:

These include access to extension service, credit, climate information, off farm employment opportunity and tenure status. Access to extension, credit, adaptation information as well as climate information are the most important determinants found in the literature (Bryan et al., 2009; Deressa & Hassan, 2009; Gbetibouo, 2009; Deressa et al., 2011; Di Falco et al., 2011; Di Falco et al., 2012; Kim et al., 2012). Along with those factors, farmers' off farm employment opportunities serve as a risk diversification measure (Ito & Kurosaki, 2009) and helps them to invest in farming activity, and so increases the likelihood of adaptation (Gbetibouo, 2009). Although Maddison (2007) did not find any significant effect of farmers' tenure status on the propensity to adapt, other studies found that land ownership has a positive influence (Gbetibouo, 2009; Acquah & Onumah, 2011; Yegbemey et al., 2013; Di Falco, 2014).

Other factors:

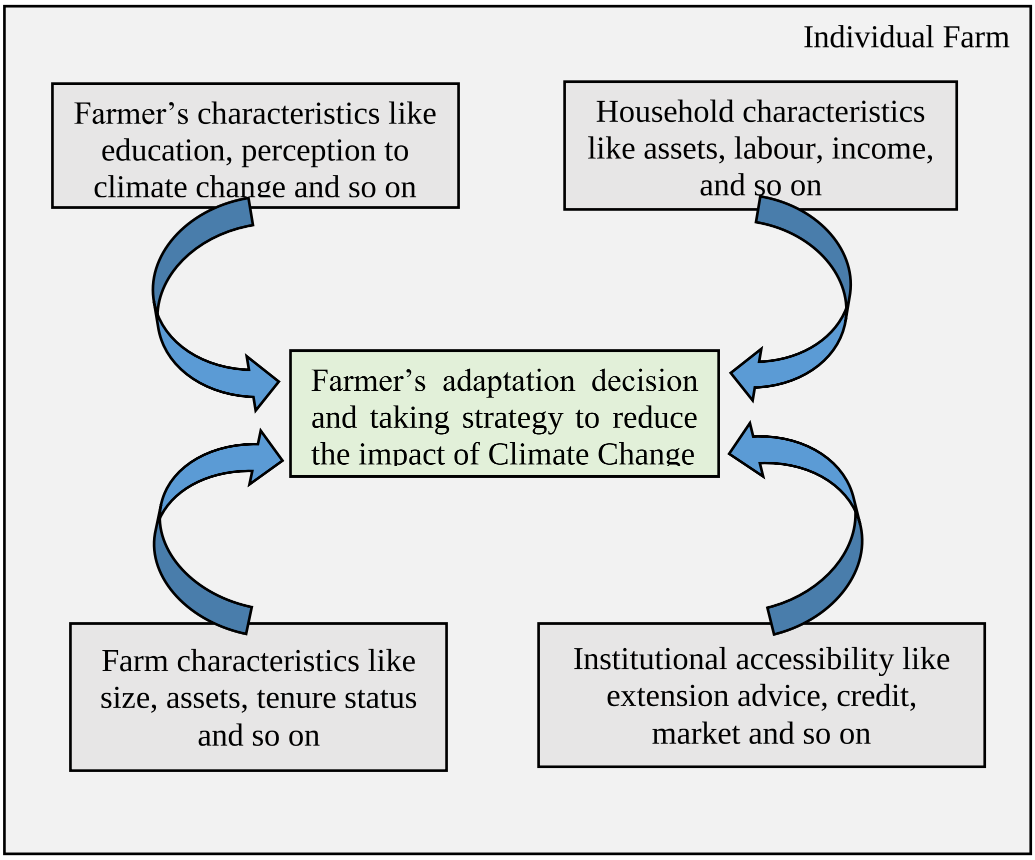
These include factors related to social learning like farmer-to-farmer extension and number of relatives in the neighbourhood (Deressa et al., 2009). Existing social networks affect farmers' ability to learn about and influence decisions to adopt a new practice (White & Selfa, 2013). Bandiera and Rasul (2006)) also found that social learning might lead to a farmers' decision to adopt a new technology. In this respect, relatives and friends influence adoption decisions. In this respect, Kim et al. (2012) also found that the number of farmer organizations and involvement in them have a significant impact on adaptation to climate change.

Overall, from the above discussion it can be concluded here that although the literature identifies a reasonably large number of determinants, there is no agreement in the literature of what constitutes the key determinants. The effects of the determinants differ from study to study and place to place. Moreover, from the developing countries' perspective, most of these studies are undertaken for African countries. As a result, the findings cannot be generalized to all developing countries and a country-specific study is required to understand the determinants of climate change adaptation in particular locations.

6.2.4 Conceptual Model for Farm Level Adaptation to Climate Change

From the above discussion, considering both theoretical and empirical evidence, a simple model for farm level adaptation to climate change is developed here from the perspective of an individual farmer (Figure 6.3). An individual farmer decides whether he will undertake adaptation or not. His decision is influenced by his own characteristics, farm characteristics, household characteristics, and access to institutional support and markets. For the simplicity of the model, government policy and all prices are taken as constant here. It can be argued that government policy would be reflected to some degree in those characteristics.

Figure 6.3 : Farm level adaptation to climate change



Upon deciding to undertake adaptation, a farmer will choose among the different adaptation strategies available. The decision to adopt a particular strategy may also be influenced by different factors like farm-household characteristics as well as institutional accessibility. However, there would be different barriers like information about options, what they involve and associated outcome, advice on how to implement, credit and so on, while taking adaptation.

6.3 Data and Method

6.3.1 Data Sources

The survey used to provide the primary evidence for the research on adaptation was carried out in Bangladesh among farm households during the period between October 2015 and February 2016. There are seven climatic zones in Bangladesh. To cover all climate zones, one representative district from each climate zone was selected for this study. The district is purposely selected mainly on the basis of climate data availability as well as being a major rice producing area. Following the procedures of multi-stage sampling, in each selected district, first two *upozila* (sub-district), then one block[18] from each *upozilla*, then two villages in that block, and finally the sample households from those villages are randomly selected. Capturing 15% of total farm households in each selected village, the final dataset comprises 432 farm households. The survey procedure is described more fully in Chapter 3.

The survey questionnaire was very comprehensive, eliciting information on farmers' socio-demographic characteristics, farm and household characteristics, institutional accessibility, farmers' perception about crop damage caused by climate change, adaptation strategies taken in response to climate change, and barriers faced while undertaking adaptation. The questionnaire that was used is provided in Appendix 10. Descriptive statistics of variables used in this research are presented in Table 6.2.

6.3.2 Binary Model for Adaptation Decision

A growing interest in the literature on adaptation to climate change is to explain the farmers' decision to take the adaptation (Bryan et al., 2009; Deressa et al., 2011; Alauddin & Sarker, 2014). Farmers' adaptation decision can be considered as a binary variable A coded 1 if a farmer takes adaptation and 0 otherwise. Then it can be defined as,

$$A = \begin{cases} 1 & \text{with probability } p, \\ 0 & \text{with probability } 1 - p. \end{cases} \quad (6.5)$$

To see the determinant factors that influence the adaptation decision, we need to model the p, which determines the probability of the positive outcome (i.e. taking adaptation decision). We need to have a regression model that will parameterize the p which will depend on a regression vector x and $K \times 1$ parameter vector β. The commonly used model for this type of variable is a single-index form with conditional probability (Cameron & Trivedi, 2005), represented as

$$p_i \equiv \Pr[A_i = 1|x] = F(x_i'\beta) \quad (6.6)$$

where $F(.)$ is a cumulative distribution function (cdf).

[18] The agricultural extension office divides the sub-district into several blocks for their working convenience. Each Sub-Assistant Agricultural Officer are responsible to look after 4 blocks. There are several villages in each block.

The estimates can be obtained using either a logit or probit model. In the case of the logit model, $F(.)$ is the cdf of a standard logistic distribution, whereas in the case of the probit model the cdf is of a standard normal distribution. In other words, the main source of difference between logit and probit model lies in the assumption of the distribution of the error term, ε (Bryan et al., 2009). In the case of the logit model it is assumed that the error term has a standard logistic distribution whereas in the case of the probit model it is a standard normal distribution. Economists tend to prefer the probit model because of its normality assumption, given that the properties of normal distribution make it more easy to analyse the specification problems (Wooldridge, 2006). Therefore, in this study to analyse the factors that influence farmers' adaptation decision, a probit model is used.

6.3.3 The Heckman Sample Selection Model

Maddison (2007) argued that the farmers' adaptation decision is a two-stage process that involves perceiving the changes in climate first, then taking the adaptation in response. Therefore, it can be argued that the second stage of adaptation (those who responded to changes) is a sub-sample of the first (where those who did not perceive the changes are also included). Therefore, the second stage sub-sample is likely to be non-random and necessarily different from the first. This may create a problem of sample selection bias. Following Deressa et al. (2011) a two-step maximum likelihood procedure proposed by Heckman (1976), popularly known as Heckman's sample selection model, is used here to correct this bias. Following Heckman's sample selection model it is assumed here that there exists a latent variable A^* (the propensity to take the adaptation decision) defined as

$$A_i^* = x_i'\beta + \varepsilon_{1j} \qquad (6.7)$$

where x is a vector of explanatory variables that may affect farmers' adaptation decision, β is the parameter estimate and ε_{1j} is an error term. The binary outcome of farmers' adaptation decision can be observed using the probit model as

$$A_i^{\text{probit}} = (A_i^* > 0) \qquad (6.8)$$

The dependant variable is not always observed, however, for the observation *i* it is only observed if

$$A_i^{\text{select}} = (z_i\delta + \varepsilon_{2j} > 0) \qquad (6.9)$$

where $\varepsilon_1 \sim N(0, 1)$

$$\varepsilon_2 \sim N(0,1)$$
$$\text{corr}\ (\varepsilon_1,\ \varepsilon_2) = \rho$$

Here A_i^{select} is whether a farmer has perceived the changes in the climate system or not, z is a vector of explanatory variables (i.e. farmers' socio-economic variables) that affect the farmers' perception, δ is the parameter estimate and ε_{2j} is the error term.

Following Heckman's procedure, the first step is the selection model, which represents farmers' perception about climate change (equation 6.9). Then the second step is the outcome model, which represents the farmers' adaptation decision (equation 6.7) which is conditional upon whether the farmer has perceived the climate change. The two error terms, ε_1 and ε_2, are normally distributed with mean zero and variance one. When these two error are correlated or $\rho \neq o$ then a standard regression technique (i.e. the probit model here) applied to the first equation (equation 6.7) yields biased results. In this type of research, Van de Ven and Van Praag (1981) found that Heckman's selection estimate yields consistent and asymptotically efficient estimates for all parameters. Therefore, in this research, Heckman's probit selection model is also used to analyse the farmers' climate change adaptation in Bangladesh.

6.3.4 Multinomial Logit Model for Adaptation Strategies

In this research, the determinant of farmers' decisions to take a particular strategy as climate change adaptation is also analysed. The adaptation decision can be explained under the general framework of utility or profit maximization (Gbetibouo, 2009; Gbetibouo et al., 2010). A rational farm household would choose a set of climate change adaptation strategies to maximize the expected utility from the net revenue with given resources, technology and their perception about the climate change (Gbetibouo et al., 2010; Di Falco et al., 2012). Although the utility function is unobserved, the utility derived from an adaptation strategy is postulated to be a function of the vector of observed farm and farmer specific characteristics (Adesina & Zinnah, 1993). Under this assumption, the adaptation options taken by the farm household can be expressed as:

$$A_{ij} = f(x_i) \qquad (6.10)$$

where A_{ij} is the adaptation decision taken by the farm household i to take adaptation strategy j; x is a vector of farmer and farm-household characteristics as well as farmer climate change perceptions. Under the revealed preference assumption, the farmer will practice an adaptation option if it generates net benefits, otherwise he will not (Gbetibouo et al., 2010). So, this observable discrete choice of practice can be related to the unobservable (latent) continuous utility variable.

Let A^* be the latent variable that captures the utility gained by a farmer from taking an adaptation decision, against no adaptation. Therefore using the latent regression model (Greene, 2012) farmers' adaptation decision model would be,

$$A_{ij}^* = x_i'\beta + \varepsilon \quad \text{with } A_{ij} = \begin{cases} 1 & \text{if } A_{ij}^* > 0 \\ 0 & \text{otherwise} \end{cases} \tag{6.11}$$

That means farmer *i* will take the adaptation decision ($A_{ij} = 1$) through implementing *j* strategy to reduce the impact of climate change if the utility gain is positive ($A_{ij}^* > 0$), and will be 0 otherwise. Moreover, farmer *i* will choose an adaptation strategy *j* over adaptation strategy *k* if and only if the expected utility derived from *j* is greater than the expected utility derived from *k*:

$$E\left[A_{ij}^*\right] > E[A_{ik}^*] \qquad \text{for all } k \neq j \tag{6.12}$$

If the farmer *i* choses to take the particular strategy *j* then it can be assumed that A_{ij}^* is the maximum among all the utilities. Following Greene (2012) the statistical model for this kind of choice situation is driven by the probability that choice *j* is made over all the choices as

$$P\left(A_{ij}^* > A_{ik}^*\right) \qquad \text{for all } k \neq j \tag{6.13}$$

Following Adesina and Zinnah (1993) and Gbetibouo (2009) the probability that A_{ij} equals one (i.e. farmer *i* will choose adaptation option *j* among the set of adaptation options) can be defined as :

$$\begin{aligned} P(A_{ij} = 1 \mid x) &= P(A_{ij}^* > A_{ik}^* \mid x) \\ &= P(\beta_j x_i + \varepsilon_j - \beta_k x_i - \varepsilon_k > 0 \mid x) \\ &= P(\beta_j x_i - \beta_k x_i + \varepsilon_j - \varepsilon_k > 0 \mid x) \\ &= P(\beta^* x_i + \varepsilon^* > 0 \mid x) \\ &= F(\beta^* x_i) \end{aligned} \tag{6.14}$$

where $\varepsilon*$ is the random disturbance term, $\beta*$ is a vector of unknown parameters that can be interpreted as the net influence of the vector of explanatory variables influencing adaptation, and $F(\beta^* x_i)$ is the cumulative distribution of $\varepsilon*$ evaluated at $\beta^* x_i$.

The model is designed to analyse the determinants of farmers' adaptation decisions involving multiple choices, which can be operationalized using either multinomial logit (MNL) or multinomial probit (MNP) models. The main advantage of the MNL model specification is that it is easier to calculate the choice probabilities than the alternative MNP model (Tse, 1987). This model provides a convenient closed form for underlying choice probabilities, which makes it simple to compute the choice situation among many alternatives. On the other hand, because of the need to evaluate multiple integrals of the normal distribution, the probit model has found rather limited use in this setting (Greene, 2012). Because of these advantages MNL has been widely used in many fields, including economics, market research, politics, finance, and transportation engineering (Greene, 2012).The main limitation of the model is the independence of irrelevant alternatives (IIA) property, which means that the ratio of the probability of choosing two alternatives, $\left(\frac{P_{ij}}{P_{ik}}\right)$, is independent of the remaining probabilities of the choices (Greene, 2012).

Thus, this study uses a MNL logit model to analyse the determinants of farmers' adaptation decisions in Bangladesh. Following Greene (2012) the probability that the adaptation option *j* will be chosen by the household *i* with characteristics *x* can be expressed as:

$$P_{ij} = \text{Prob}\left(A_{ij} = j \mid x_i\right)$$
$$= \frac{\exp(\beta_j x_i')}{1 + \sum_{k=1}^{J} \exp(\beta_k x_i')}, \quad j = 0, 1, 2, \dots \dots \dots J \tag{6.15}$$

where β is a vector of parameters that satisfies $\left(\frac{P_{ij}}{P_{ik}}\right) = x_i'\left(\beta_j - \beta_k\right)$

The parameters of the model are estimated by the maximum likelihood method. To have unbiased and consistent estimates of the parameters, the validity of the IIA assumption is tested using Hausman's (1978) specification test, which is based on the fact that if a subset of the choice set is irrelevant then omitting it from the model altogether will not change parameter estimates systematically (Greene, 2012).

The above MNL specification will provide the direction of the effects of the explanatory variables (e.g. farmer characteristics) on the dependant variable (i.e. the probability of choosing a particular strategy), but it will not provide the actual magnitude of the change or the probability (Deressa et al., 2009; Gbetibouo et al., 2010). The marginal effect of the explanatory variables can be obtained by differentiating equation 6.15 with respect to each explanatory variable as

$$\frac{\partial P_{ij}}{\partial x_i} = P_{ij}(\beta_j - \sum_{j=1}^{J} P_{ij}\beta_j) = P_{ij}[\beta_j - \overline{\beta}\,] \qquad (6.16)$$

This marginal effect will show the expected change in the probability of a particular choice being made with respect to a unit change in an explanatory variable (Hassan & Nhemachena, 2008).

Here the vector x represents explanatory variables that affect the likelihood of adopting, such as farmer and farm-household characteristics, institutional accessibility, and the farmer's perception of climate change. The choice of explanatory variables used in this study is based on the behavioural hypothesis as well as previous empirical literature. Table 6.2 shows the definition as well as some descriptive statistics about the variables used in the empirical estimation in this research.

Table 6.2 : Descriptive statistics for variables used in this study

Variables	Description	%/mean (sd)
Dependent variables		
Adaptation decision	1=yes; 0=No (Table 6.5, 6.6 and 6.7)	72; 28
Adaptation Strategies taken	0= No adaptation, 1= More inputs for all crops, 2= Changing planting date, 3= Different rice varieties, and 4= Planting fruit & wood trees (Table 6.9, 6.10)	
Adaptation strategies in accordance with obstacles	0= No adaptation, 1= Less costly, 2= Medium costly and , 3= High costly (Table 6.11)	
Independent variables		
Farmer's Characteristics		
Education	Education of household heads (years)	5.46 (4.1)
Experience	Farming experience of household head (years)	31.5 (8.9)
Group	Member of any co-operative/society/institutional group (1=yes; 0=No)	11; 89
Household Characteristics		
Own labour	Household Agricultural labour (numbers)	2.8 (1.19)
Electricity	Household has electricity facility (1=yes; 0=No)	71; 29
Literacy	Literate members in the household (numbers)	3.19 (1.56)
Household Asset*	Value of household's asset (in Taka)	-3.02^{-08} (0.999)
Agri. Income*	Household's agricultural income (in Taka)	-1.70^{-07} (1)
Non-agri. Income*	Household's non-agricultural income (in Taka)	-7.31^{-08} (1)
Farm Characteristics		
Farm size	Total land the farm has (in Acre)	2.35 (2.16)
Fertility of land	Farmer's perception about the fertility of their farmland (1=Low fertile; 2=Medium fertile; 3= Fertile; 4=Highly fertile)	2.34 (0.9)
Tenure Status	1=tenant farmer, 0=owner farmer	43.75; 56.25
Livestock	Ownership of livestock (1=yes; 0=No)	85.65; 14.35
Farm Asset*	Value of farm's asset (in Taka)	5.33^{-08} (1)
Institutional Accessibility		
Extension advice	Access to formal extension advice (1=yes; 0=No)	70; 30
Weather info	Advance weather information (1=yes; 0=No)	34; 66
Credit	Access to credit facility (1=yes; 0=No)	44; 56
Irrigation	Percentage of land has irrigation facilities	86.42 (26.68)
Market	Distance to input market (km)	1.96 (1.31)
Climate Change Perception		
Perceived climate change	Believed that both summer temperature has increased and rainfall in rainy season has decreased (1=yes; 0=Otherwise)	75.93; 24.07
Perceived Temperature change	Perceived correctly about summer temperature (1=yes; 0=No)	79; 21
Perceived Rainfall change	Perceived correctly about rainfall in rainy season (1=yes; 0=No)	89; 11
Perceived Climate Change correctly	Perceived correctly about both summer temperature and rainfall in rainy season (1=yes; 0=Otherwise)	55.79; 44.21

* These variables are standardized.

6.4 Results

6.4.1 Perceived Effects of Climate Change on Rice Crops

It is expected that climate change will have a negative effect on the yield of the rice crop. Farmers should have perceived that effect in order to take the adaptation strategies (Habtemariam et al., 2016). To identify farmers' perception of the effect of climate change on rice, farmers were asked to identify the long-term changes in the climate variables (details are described in chapter 5). Farmers were then asked about what they thought about damage done by these changes to their rice yield. It is expected that different rice verities would be affected differently. Therefore, respondents were asked to identify the damage for each rice variety as well as overall damage. Responses regarding yield damage for different rice crops were recorded on a five-category scale as: very adversely affected, adversely affected, moderately affected, slightly affected, and not affected at all.

Farmers' perception about the damage incurred only because of the climate change is shown in table 6.3. It is found that 84% of the farmers who identified the occurrence of climate change considered that their crop production is reduced because of changing climate. It is found that farmers' perception regarding the damage due to climate change varied for different rice (Aman, Boro and Aus) varieties. The majority of the farmers believed that climate change reduces the yield moderately: around 54% for Aman, 58% for Boro and 52% for Aus. In contrast, very few farmers (in some cases none) perceived that the damage is extremely high or there is no damage at all. This is a logical finding because the climate of Bangladesh (rainfall and temperature) is well suited to rice crops and because of changes in climate farmers have not suffered yield loss substantially yet.

Table 6.3 : Farmers' perception about the crop damage due to climate change

Farmers' opinion on crop damage	Major crops			
	Aman rice	Boro rice	Aus rice	Overall crop
Very high	0	0	00.91	0
High	37.46	9.21	35.45	24.78
Moderate	54.28	58.73	51.82	64.90
Slightly	08.26	27.62	10.91	10.03
Not at all	0	04.44	0.91	0.29

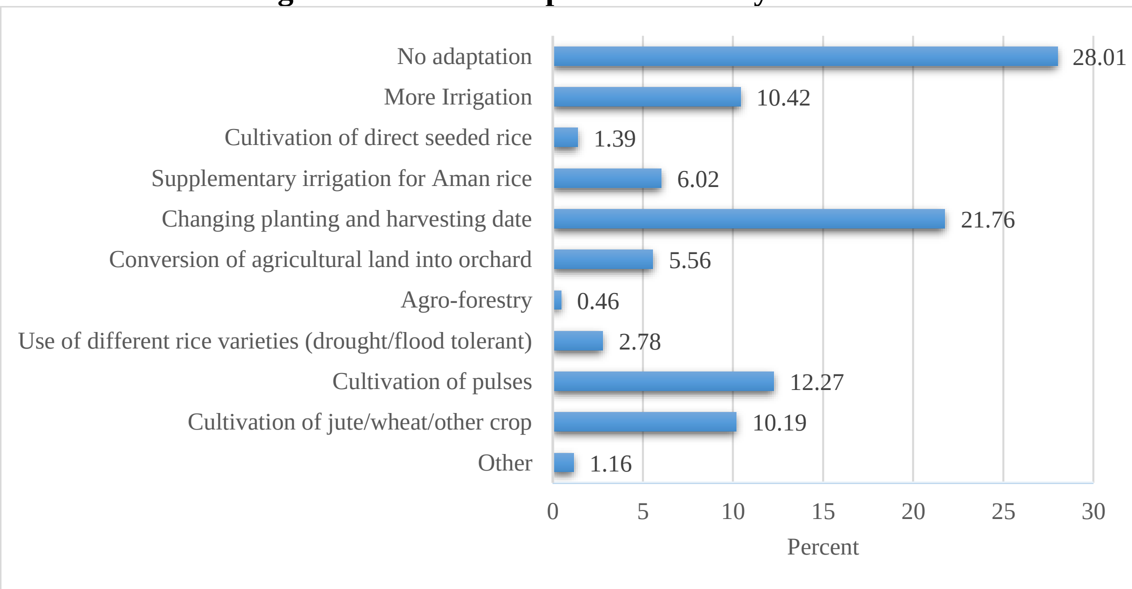
Figures shown in the table indicate percentage; Source: Field Survey, 2015/16

Farmers perceiving the yield reduction caused by climatic changes believed that high damage is more evident in the case of Aman rice (around 37% of farmers) and Aus rice (around 35% of farmers) compared to Boro rice (around 9% of farmers). This is also logical as Aman and Aus rice are rain-fed crops, more climate dependent, and changes in that climate (temperature and rainfall) would potentially have a greater effect on their yield. On the other hand, Boro is a dry season crop completely dependent on irrigation, so being less climate dependent, and less vulnerable to the climate change. Overall, most of the farmers (around 65%) perceived that crop yield reduction due to changes in climate is moderate, while a smaller proportion (around 25%) perceived it as high.

6.4.2 Adaptation Strategies Taken by Farmers

A number of studies have found that although farmers perceived a change in climate, they did not take any adaptation (Bryan et al., 2009; Deressa et al., 2009; Kim et al., 2012; Tessema et al., 2013). Similarly, this study also found that despite having perceived the changes in climate, as well as its negative effect on rice crop yields, a large number of farmers did not take any adaptation strategies. Overall, around 28% of farmers did not take any adaptation in Bangladesh (shown in Figure 6.4). Previous studies in Bangladesh conducted by Sarker et al. (2013) and Alauddin and Sarker (2014) also found that 0.55% (total of 550 farmers) and 5.6% (total of 1800 farmers) of farmers respectively did not adopt any adaptation strategies. The previous studies considered the drought-prone areas covering limited climatic zone (one zone E, and three zone E, D, G respectively) in Bangladesh. The differences in the magnitude found in this present study may be explained by the wider study area considered, covering all seven climatic zones in Bangladesh.

Figure 6.4 : Main adaptation taken by farmers



Source: Field Survey, 2015/16; Numbers shown in the figure indicate percentage

Figure 6.4 shows the different adaptation strategies taken by farmers in Bangladesh. These different strategies are more irrigation, cultivation of direct seeded rice, supplementary irrigation for Aman rice, changing planting and harvesting date, conversion of agricultural land into orchard, agro-forestry, use of different rice varieties (drought/flood tolerant), cultivation of pulses, cultivation of jute/wheat/other crop and other. Adaptation strategies such as growing short duration rice variety, application of more fertilizer and pesticides, and growing vegetables are included in the 'other' category. Changing planting and harvesting dates is the most commonly selected strategy, whereas agro-forestry is the least likely response among the adaptation strategies identified in Bangladesh. Other important adaptation strategies taken by farmers are more irrigation, cultivation of pulses, and cultivation of jute/wheat/other crops.

Rice is the staple food and farmers' main cultivated crop in Bangladesh. Therefore, changing planting and harvesting date found here, as the preferred adaptation strategy to the farmers is quite reasonable. However, quite a reasonable number of farmers acknowledged having adaptation strategies like cultivation of pulses (around 12%) and cultivation of other crops (around 10%). It means that more than one fifth of the respondent farmers is adapting by switching another crop completely. The argument for this is that this might be the case when other less water required crops like wheat and pulses are grown instead of irrigated rice (i.e Boro) in dry season not the Aman rice. Increase in crop diversification in Bangladesh is also supporting this argument (Rahman, 2009). Cropping pattern of Aman rice-potato/wheat-Aman rice is gaining popularity among farmers in Bangladesh (Timsina & Connor, 2001). Moreover, these crops are high valued compare to rice. High net return from these crops may be another reason that contribute to production diversification away from rice towards other crops (Mahmoud & Shively, 2004).

It is also found that conversion of agricultural land into orchard is another strategy farmers are taking, around 6% of respondent farmers in this study. Agro-forestry is another adaptation strategy, though it is the least preferred option among all (only 0.46% of respondent). These adaptation options would change the land use pattern completely from rice crop to fruits/wood. This is a major change and costly change for rice farmers in Bangladesh. However, in another research on this cropland transformation issue, Sarker et al. (2015) found that farmers are transforming cropland into mango, litchi and jujube orchard. Moreover, they also identified that water scarcity, high profitability and easy cultivation process are the main reasons for this transformation. Like the same, Rahman and Farhana (2005) found that agroforestry system gives positive and much higher net present value (NPV) than that of agriculture. Even farmers also perceive that fruit cultivation is economically more profitable than other crops (Kowasari et al., 2014). Overall, from the above discussion, it can be said that farmers might considering economic reason apart from climate in choosing adaptation strategies. Exploration on these issues would be interesting area of further research in future.The adaptation strategies taken by farmers in Bangladesh are similar to other findings in the climate change adaptation literature in other countries (Bradshaw et al., 2004; Bryan et al., 2009; Gbetibouo et al., 2010; Deressa et al., 2011; Di Falco & Veronesi, 2014; Tesfaye & Seifu, 2016), with the only difference being found in terms of importance of the strategies taken. For example, soil conservation and planting trees are found to be the strategies most commonly adapted by farmers in Ethiopia (Bryan et al., 2009). In an earlier study on eleven countries in Africa, Maddison (2007) found that planting different crop varieties is the most common strategy, whereas, in this study of Bangladesh, it is found that changing the planting and harvesting date is the most common strategy. Therefore, it can be argued that the adaptation strategies taken by farmers are place specific. Moreover, the present study is focused on rice farmers. Therefore, it can also be argued that adaptation strategies are not only place specific but also crop specific.

The adaptation strategies taken by farmers found in this study are similar to those found by other studies in Bangladesh (Sarker et al., 2013; Alauddin & Sarker, 2014), although the most commonly taken adaptation strategies are different in those studies. This may be because of the study area considered in those studies. Sarker et al. (2013) focused on only two sub-districts in one climatic zone and the study found that more irrigation was the most common adaptation strategy. The zone they studied is characterize as (Rajshahi district in zone E) less rainfall and high temperature than the other zones, comparatively dry zone among all in Bangladesh (shown in Table 2.8). Therefore, more irrigation is likely to be the preferred adaptation for that region only. Farmers of other zones may not prefer this; therefore, the results from their study cannot be generalized. That is why in the other study by Alauddin and Sarker (2014) where they considered a slightly bigger study area (nine sub-districts in three climatic zone) in the same region found that different rice varieties was the preferred adaptation choice.

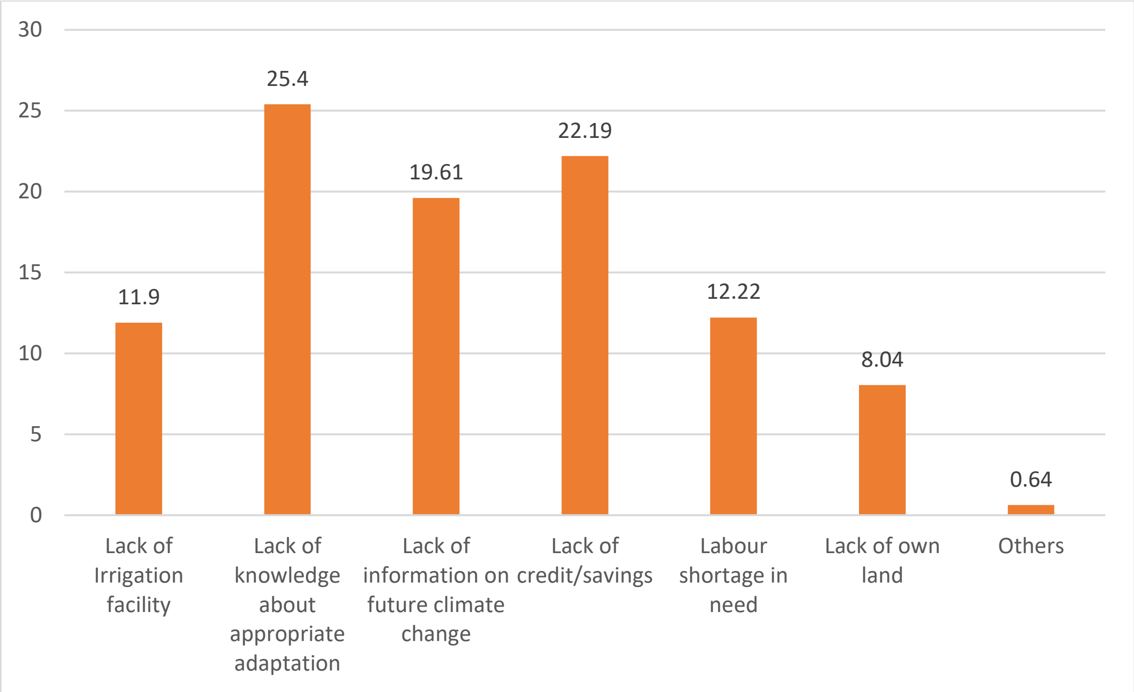
In the present study, these adaptation choices (more irrigation and different rice varieties) are also found to be important strategies but not the most preferred one. In this study, the most preferred adaptation strategy is the changing planting and harvesting date. Given the importance of rice as staple food, it is quite likely that farmers will grow the rice by adjusting farming timing according to climate, which is the easiest options rather than go for other options. Then it is likely that other preferable adaptation would be to give more irrigation to grow crops or cultivation of other non-rice crop. The result from this study also found that more irrigation is among other most preferable adaptation options in Bangladesh. This is consistent with the findings of Alauddin and Sarker's (2014) study. Moreover, they also found that around 11% of farmers prefer cultivation of other crops like wheat, maize and potato, which is quite similar to our results (around 10% of respondent farmer).

However, there are several differences found in the findings of this study from the previous studies. For example, it is found that cultivation of pulses is another important preferred choice (around 12% of respondent) which was found less popular in Sarker et al.'s (2013) study (2% of respondent). A small percentage of farmers were found that did not adopt any adaptation measures in previous studies, 0.55% in Sarker et al.'s (2013) study and 5.6% in Alauddin and Sarker's (2014) study. In contrast, the present study found a considerable potion, around 28% of the respondent, did not take any adaptation. This is a serious concern in the face of climate change from the policy perspective. The differences in these results is because of less zone considered by the previous studies. Therefore, as this study considered widely dispersed geographical locations considering all climatic zones in Bangladesh, it is likely that the overall results are more general.

6.4.3 Perceived Barriers to Adaptation

The literature on climate change adaptation suggests that many factors may affect farmers' ability to adapt. Although the effect of different factors on farmers' adaptation decisions is examined later in this chapter using some econometric techniques, here farmers' view on barriers they face while doing adaptation is explored. It will provide information regarding the problems they face as well as the relative importance of the factors. In this study, farmers mentioned many constraints they face while taking adaptation (shown in Figure 6.5). Although the relative importance of these factors differs from other studies, these barriers are similar to those reported in other studies in other developing countries (Maddison, 2007; Nhemachena & Hassan, 2007; Bryan et al., 2009; Deressa & Hassan, 2009; Gbetibouo et al., 2010; Ringler, 2010). Insights gained from the survey for each of these barriers are discussed below, along with their importance.

Figure 6.5 : Main constraints faced by farmers while taking adaptations (%)



Note: N=311; Numbers shown in the figure indicate percentage; Source: Field Survey, 2015/16

The most important barrier perceived by farmers is the *lack of knowledge about appropriate adaptation*. Clear information regarding what to do, what adaptation strategies farmers can take, what would be the outcome if any strategy taken, what would be the outcome if adaptation is not taken in the face of climate change is very limited to farmers in Bangladesh. Agricultural extension advice provided by the government can be a source of such information. However, it is found that around 30% of farmers did not receive such agricultural extension advice (Shown in Table 6.2). Even those who had access to this advice complained about its timely availability as well as the quality of the advice. In this respect, farmers have acknowledged that in cultivating new crops they faced more difficulties. In taking such decisions, they discussed this with other farmers, input sellers and finally used their own intuition formed through experience.

Agricultural investment and production choices of smallholder farmers in developing countries are constrained by their financial environment (Karlan et al., 2014). In the case of climate change adaptation in Bangladesh, *lack of savings/credit facility* is found to be another important constraint faced by farmers. For example, farmers acknowledged that when they required to use more inputs (irrigation, fertilizer, pesticides) they faced difficulties. The survey data on which this study is based shows that around 41% of farmers claimed not to have any access to formal credit facilities.

Table 6.4 : Main Adjustment made by farmers while taking adaptations

Adjustment Made	Frequency	%
Credit Taken from Commercial Bank	4	1.29
Credit Taken from Micro-credit institution	14	4.5
Credit Taken from Shopkeeper (input seller)	52	16.72
Credit Taken from Friends/Relatives	45	14.47
Sales/mortgage of land	8	2.57
Sales of livestock	61	19.61
Sales of other assets	7	2.25
Family member migrated to cities	27	8.68
Others	22	7.07
Nothing	71	22.83
Total	311	100

Source: Field Survey, 2015/16; N=311

Farmers who had undertaken adaptation were asked about what main adjustment they had to make while taking adaptation. Their responses are presented in Table 6.4. This shows that most of those adjustments are related to the financial constraints faced. Two informal sources, input sellers and friends/relatives are found to be the most significant sources for providing credit to farmers. Farmers acknowledged that although it is very easy to get funds from these sources, the rate of interest is very high, which affected their economic condition later on. Moreover, it is found that a considerable proportion of farmers (around 31%) had to sell/mortgage their agricultural land, livestock and/or other assets to make adaptation possible.

The farmers in Bangladesh consider *lack of information concerning future climate change* as another important barrier to adaptation. In the survey data, it was found that only 34% of the farm households had regular access to advance weather information. However, the only sources of that was the media, i.e. weather reports from radio, television and newspaper. This information is very general and typically national, so sometimes misleading to farmers. Farmers claimed that based on the weather forecast, they sometimes waited for rain but latter on had to employ irrigation. Without having the proper information regarding climate change they cannot permanently undertake some adaptation, like switching to other crops.

Labour shortage, *lack of irrigation facilities* and *lack of own land* are other important barriers to adaptation mentioned by the farmers in this study. Labour shortage became more acute when farmers chose to switch crops (to maize, wheat and so on) or change planting and harvesting dates. During the crop season, some labour migrates from other areas in Bangladesh. Therefore, because of the unusual timing for their crops, farmers face a problem meeting their labour needs. Lack of their own land also hinders farmers' decisions to switch to other crops from rice. Along with the rent given to the landowner, farmers consider their own food security. As rice is the staple food in Bangladesh, they think of growing rice as their preferred crop, so at least they are in more control of their own household food security.

Overall, the factors that farmers perceived to be the constraints to changing their farming practices as climate change adaptation in Bangladesh are lack of information on both appropriate adaptation and future climate change, lack of credit, lack of irrigation facilities and the availability of labour. These barriers stated by farmers are also similar to the findings of other studies in Bangladesh (Sarker et al., 2013; Alauddin & Sarker, 2014). It can be argued that lack of information about adaptation and climate change limits their options to adapt. Lack of credit limits their ability to get the necessary resources and technologies to adapt. Finally, lack of their own land, irrigation facility and labour shortage limits their ability to implement their adaptation decision.

6.4.4 The Determinants of Adaptation

6.4.4.1 Determinants of Adaptation Decision: The Binary Probit Model

The results of the binary probit model for farmers' adaptation decisions are presented in **Error! Reference source not found.**. The table also presents the marginal effects of the adaptation decision from a unit change in an independent variable from the mean value keeping other variables constant. It indicates that farmers' decisions to adapt in Bangladesh is influenced by a number of factors.

Firstly, it is seen from the results that farmers' *education* and *experience* are important characteristics that significantly influence their adaptation decision. It is apparent from the sign of the coefficient that the level of education (measured in years) increases the probability of farmers' adaptation decision. Although Nyangena (2008) found the opposite outcome in the case of a Kenyan study, the finding here is consistent with other studies in other African countries (Maddison, 2007; Bryan et al., 2009). The finding is consistent with the argument that education increases understanding of the benefits of adaptation and so increases the probability of adoption. In a similar notion, it is apparent that more experienced farmers are more likely to take the adaptation decision. This finding is also consistent with other studies for African countries (Maddison, 2007) as well as for Bangladesh (Alauddin & Sarker, 2014).

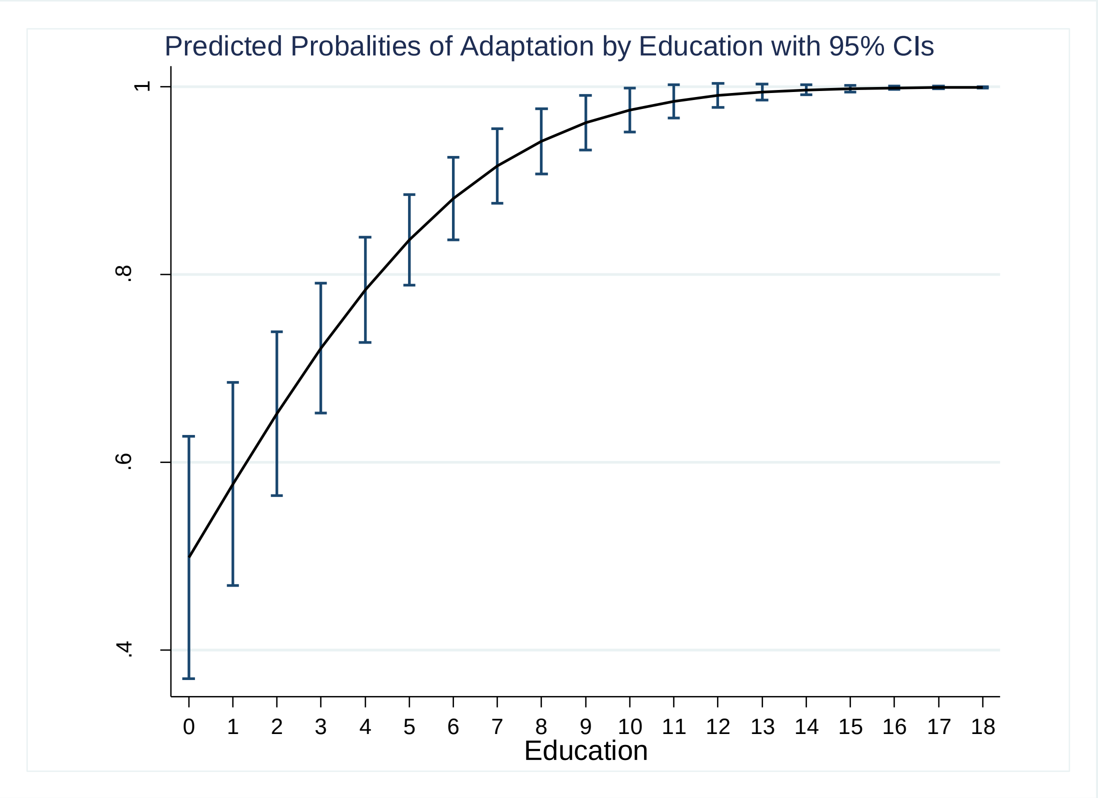
The results also suggest that between these two variables, education impact is stronger than that of experience (shown in the marginal effect column in Table 6.5). An increase of one year of education (from the mean of 5.46 years of education) would increase the probability of adaptation by around 3%, whereas in the case of experience, it increases the probability by only around 1%. This result is clearer from the predicted probability curves on adaptation decisions by education and experience shown in Figure 6.6 The probability curve for education is steeper than that for experience, indicating much more effect on the probability of farmers' decision to adapt by just increasing one more year of education compared to experience. However, it is also seen here that the effect of education is greater at relatively low level of education and probability increases at a decreasing rate up to about 10 years of education. This may lead to a policy prescription for some sort of training programme to educate least educated farmers as a way to promote climate change adaptation in future.

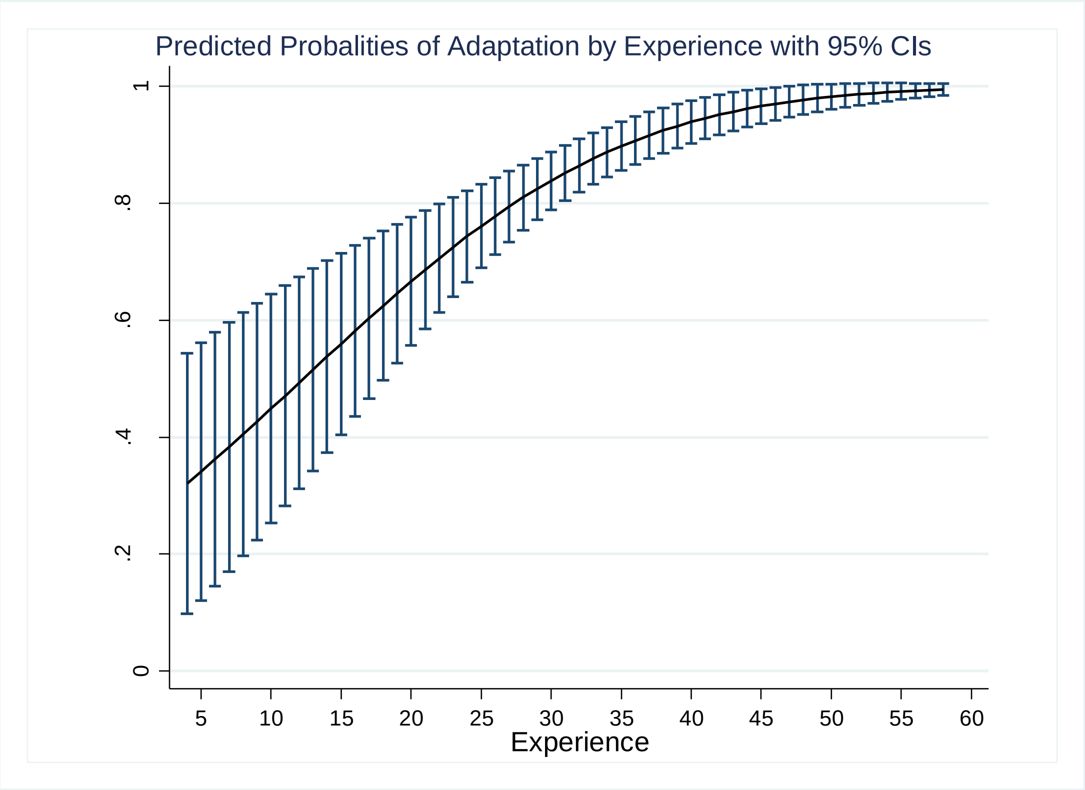
Table 6.5 : Determinants of adaptation decision: Probit model

Explanatory variables	Independent variable: Adaptation decision			
	Coefficient	S.E	Marg. Effect	SE
Farmer's Characteristics				
Education	0.197***	(0.0315)	0.0291***	(0.00403)
Experience	0.0559***	(0.0116)	0.00824***	(0.00162)
Group	0.441	(0.298)	0.0651	(0.0433)
Household Characteristics				
Household's own labour	-0.0297	(0.0956)	-0.00438	(0.0141)
Household has electricity	0.476**	(0.220)	0.0703**	(0.0321)
Number of literate members	0.0332	(0.0695)	0.00489	(0.0103)
Household's asset	-0.0521	(0.156)	-0.00769	(0.0230)
Household's Agri. income	-0.0521	(0.209)	-0.00768	(0.0308)
Household's Non-agri. income	-0.0962	(0.100)	-0.0142	(0.0147)
Farm Characteristics				
Farm size	-0.0338	(0.0913)	-0.00499	(0.0135)
Fertility of land	-0.670***	(0.117)	-0.0989***	(0.0156)
Tenure status	0.252	(0.211)	0.0372	(0.0308)
Livestock owned	0.173	(0.283)	0.0254	(0.0416)
Farm asset	-0.115	(0.118)	-0.0170	(0.0174)
Institutional Accessibility				
Extension advice	1.193***	(0.212)	0.176***	(0.0277)
Weather info	-0.0392	(0.228)	-0.00578	(0.0336)
Credit	-0.132	(0.214)	-0.0194	(0.0313)
Irrigation	-0.0113***	(0.00404)	-0.00166***	(0.000588)
Market	-0.0389	(0.0780)	-0.00574	(0.0115)
Perceive climate change	1.025***	(0.226)	0.151***	(0.0305)
constant	-1.251	(0.765)		
Zone fixed effect	Yes			
Observations	432			
Percent correctly predicted	87.04			
Wald Chi-square (26)	163.26***			
Log likelihood	-115.86			
Pseudo R^2	0.5478			

Note: *** p<0.01, ** p<0.05, * p<0.1; This table shows the result of Probit model coefficient and marginal effect for farmers' adaptation decision. The coefficient shows the direction of probability and the marginal effect indicates the marginal change on the probability, while dy/dx is for discrete change of dummy variable from 0 to 1. It is seen that education, experience, electricity facility, fertility of land, extension advice, irrigation facility and perception of climate change have influence on farmers adaptation decision (statistically significant at least 5%). Among these factors, fertility of the land and irrigation facilities (proportion of land have irrigation facility) are only negatively related to adaptation decision. Perception about climate change is positively related to adaptation decision and statistically significant at the 1% level. Full table with the zone dummies are shown in Appendix 6.

Figure 6.6 : Predicted Probability of Adaptation Decision by Education and Experience





Among different rural services (such as electricity, extension, weather, and credit), it is found that only electricity and extension advice strongly increase the probability of farmers' decision to adapt. Farmers with access to electricity for their households are 7%

more likely to take the adaptation decision and farmers with access to extension advice are around 18% more likely to adapt. The survey data also revealed that 29% and 30% of farmers are without access to electricity and extension services respectively. Therefore, from the policy perspective, an increase in the availability of electricity to all farm households and extension advice to all farmers are needed to promote adaptation in Bangladesh.

It also appears that fertility of the land and irrigation facility to the land negatively influence the adaptation decision. Farms with highly fertile land and having a greater proportion of land with irrigation facilities are less likely to take adaptation to climate change. Gbetibouo (2009) also found that farmers' perception of having highly fertile land decreases the probability of taking up adaptation. A possible explanation for this finding could be that high fertility of the land and a greater proportion of land having irrigation facilities give farmers a sense of security in production, so they have less concern for climate risk or adaptation. However, there is no evidence that farm size, wealth of the household/farm, credit, tenure status and weather information influence the probability of adaptation.

The coefficient on *perceived climate change* indicates that the farmer's decision to adapt is also influenced greatly by climate change perceptions. Those farmers who perceived that there is a change in the climate system are 15% more likely to take adaptation strategies. It is sometimes argued that adaptation is a two-step process where the farmer first perceives the climate change, then in the second stage goes for adaptation (Deressa et al., 2011). In that case, a standard probit model would be inappropriate to explain the factors that affect the adaptation to climate change (shown in Table 6.5). That is why in this study, the two-step process of adaptation to climate change is also tested using Heckman's sample selection model.

6.4.4.2 The Determinants of Adaptation Decision: The Heckman Probit Selection Model

The results from the probit sample selection model are presented in Table 6.6. The results from this selection model identify the factors that influence the perceptions of climate change. The results from the outcome model show the factors that affect farmers' adaptation decision. The results show that although the likelihood function of the overall model is significant (Wald Chi-square = 76.03, with $P < 0.001$) there is no correlation between the error terms of the outcome and selection models (indication of sample selection problem). The rho is not significantly different from zero (Wald Chi-square=0.00, with P = 0.9459). This result suggests that the adaptation equation and perception (selection) equation are statistically independent of one another.

To the best of our knowledge, only three studies try to analyse farmers' adaptation decision considered as a two-step process using the Heckman probit selection model. These studies are: Maddison (2007) on 11 countries in Africa; Gbetibouo (2009) on South Africa; and Deressa et al. (2011) on Ethiopia. Although Deressa et al. (2011) found the evidence of a sample selection problem (i.e. dependence of the adaptation on perception model), Maddison (2007) and (Gbetibouo, 2009) did not find such evidence and therefore their findings are consistent with that of this study. Therefore, a standard probit model is appropriate to explain climate change adaptation (shown in Table 6.5) in Bangladesh where perception is one explanatory variable with other socio-economic and environmental factors, but not the pre-requisite condition.

Although the results from the Heckman probit model (shown in Table 6.6) are not superior to the standard probit model, they show the robustness of the findings. The results from the selection model show that education, experience, household's access to electricity, household assets, livestock ownership, access to extension and credit positively affect the perception of climate change. The results from the adaptation (outcome) model indicate the influence of some new factors affecting adaptation decision apart from those found in previous analysis (using the standard probit model in Table 6.5), specifically belonging to a group, farm assets and market.

Belonging to a group (such as co-operatives and farmers' clubs) may help farmers to get information and so affect positively the adaptation decision. Yohe and Tol (2002) and Below et al. (2012) interpreted this in terms of social capital, which positively influences farmers' decision making process. Moreover, literature on social networks strongly supports the notion that socially engaged communities are most disaster resilient (Carpenter, 2013).

The coefficient of *farm assets* indicates that having more assets in the farm negatively influences probability to adapt. However, coefficients on the farm household's assets and farm household's non-agricultural income are also negative, although they are not statistically significant. These results suggest that wealthier farmers are less likely to take adaptation decisions, the opposite finding of Bryan et al. (2009). A possible explanation could be that, as poor farmers are less able to cope with the shocks of crop damage from climatic change, they are more likely to take an adaptation decision in order to reduce climate related risk.

The input *market* could be a means of sharing and exchanging information and so increasing distance from the market would have a negative impact on adaptation decision (Maddison, 2007). It can be an indicator of the quality of public services available and transaction costs related to the market. Therefore, an increase in market access costs reduces farm profitability, which acts as an economic disincentive to invest in adaptation (Nyangena, 2008). The result here validates the claims as the probability of adaptation decreases with distance to input markets. In terms of physical capital (Below et al., 2012) and infrastructure (Deressa et al., 2011) it indicates that improving market access would increase farmers' ability to adapt (Bryan et al., 2009) as well as increase the adoption of different land management practices in rural areas (Pender et al., 2004).

The Heckman probit selection model here does not evidence that perceiving the climate change is not necessary or prerequisite to take adaptation decisions. Therefore, the question might come that weather adaptation determinant are different or not to those farmers who did not perceive the changes than those who perceived. To explore this, a probit regression was estimated considering only those farmers who did not perceived the climate changes. The result of the estimates is shown in Table 6.7. Effect of *education*, *experience*, *fertility of land*, *extension advice* and *irrigation facility* are in the same direction like to those who perceive the changes. However, if we compare the marginal effect of these with the main model considering all farmers (shown in Table 6.5) it is seen that *experience*, *extension advice* and *irrigational facility* are influencing more. Moreover, it is worth mentioning that it is the *extension advice* that is influencing more to them, around 1.5 times more. This again indicates the importance of extension advice to the farmers to promote climate change adaptation.

Among the other factors, we may expect that influence from being a farmer group would affect their adaptation decision but this is not found here significance. However, influence of some other factors are also found in the estimate. Number of literate members in the household has positive influence, which again indicates the importance of education. Farm asset have positive influence whereas household's agricultural income has negative influence (shown in Table 6.7) which indicates that small but wealthy farmers are taking adaptation. These determinants are associated with only to those farmers who did not perceive the climate change. Apart from these, influence of distance to market is found positive which is completely opposite than those who perceive climate change.

Table 6.6 : Adaptation determinants: The Heckman Probit Selection model

	Adaptation decision		Perception as selection model	
	Coefficient	S.E	Coefficient	SE
Farmer's Characteristics				
Education	0.219***	(0.0562)	0.0546**	(0.0269)
Experience	0.0689***	(0.0196)	0.0150*	(0.00837)
Group	0.915**	(0.364)	-0.0696	(0.236)
Household Characteristics				
Household's own labour	-0.0217	(0.117)	0.00114	(0.0729)
Household has electricity	0.379	(0.448)	0.569***	(0.178)
Number of literate members	-0.00554	(0.0829)	0.0190	(0.0552)
Household's asset	-0.0708	(0.237)	0.265**	(0.135)
Household's Agri. income	0.0887	(0.294)	0.141	(0.161)
Household's Non-agri. income	-0.107	(0.130)	-0.00948	(0.0940)
Farm Characteristics				
Farm size	0.0394	(0.119)	-0.103	(0.0709)
Fertility of land	-0.767***	(0.161)	0.0483	(0.0900)
Tenure status	0.393	(0.274)	0.133	(0.160)
Livestock owned	0.577	(0.411)	0.454**	(0.220)
Farm asset	-0.262*	(0.154)	-0.0727	(0.104)
Institutional Accessibility				
Extension advice	1.202***	(0.380)	0.331*	(0.182)
Weather info	0.0766	(0.263)	-0.00238	(0.187)
Credit	-0.158	(0.312)	0.299*	(0.175)
Irrigation	-0.0110**	(0.00542)	-0.00161	(0.00327)
Market	-0.213**	(0.0925)	-0.0279	(0.0594)
constant	-0.615	(1.994)	-1.192*	(0.667)
Zone fixed effect	Yes			
Total Observations	432			
Censored	104			
Uncensored	328			
Wald Chi-square (26)	76.03***			
Wald Chi-square (independent equations)	0.00, *P*=0.9459			

Note: *** p<0.01, ** p<0.05, * p<0.1; this table shows the results for the Heckman Probit model for adaptation. It may be argued that adaptation to climate change is a two-step process where in the first step farmers require to perceive a change in climate and then in the second step they would act through adaptation. In that case, a standard probit model would be inappropriate to explain the factors that affect the adaptation to climate change (shown in Table 6.5). That is why here the Heckman probit model is used to test the two-step process as well as the appropriateness of the model used. The results show that although the likelihood function of the overall model is significant (Wald Chi-square=76.03, with $P < 0.001$) it does not show any correlation between the error terms of the outcome and selection models (as indication of a sample selection problem). The rho is not significantly different from zero (Wald Chi-square=0.00, with $P = 0.9459$). Although the results here do not show the superiority of the model than the standard probit model (shown in Table 6.5) it shows the robustness of the analysis to explain climate change adaptation. Full table with the zone dummies are shown in Appendix 6.

Table 6.7 : Adaptation determinants to those who does not perceive climate change

Explanatory variables	Independent variable: Adaptation decision			
	Coefficient	S.E	Marg. Effect	SE
Farmer's Characteristics				
Education	0.138**	(0.0616)	0.0197**	(0.00822)
Experience	0.0702***	(0.0237)	0.0100***	(0.00297)
Group	-0.0287	(0.842)	-0.00410	(0.121)
Household Characteristics				
Household's own labour	-0.190	(0.280)	-0.0271	(0.0410)
Household has electricity	0.306	(0.515)	0.0437	(0.0713)
Number of literate members	0.562***	(0.194)	0.0804***	(0.0293)
Household's asset	0.404	(0.313)	0.0577	(0.0451)
Household's Agri. income	-1.645**	(0.663)	-0.235**	(0.0954)
Household's Non-agri. income	-0.379	(0.269)	-0.0542	(0.0370)
Farm Characteristics				
Farm size	-0.190	(0.212)	-0.0272	(0.0299)
Fertility of land	-0.519**	(0.258)	-0.0742**	(0.0357)
Tenure status	0.740	(0.567)	0.106	(0.0829)
Livestock owned	-0.0403	(0.505)	-0.00576	(0.0721)
Farm asset	0.417**	(0.205)	0.0597**	(0.0299)
Institutional Accessibility				
Extension advice	2.143***	(0.465)	0.307***	(0.0513)
Weather info	0.379	(0.486)	0.0542	(0.0716)
Credit	0.0305	(0.570)	0.00436	(0.0817)
Irrigation	-0.0188**	(0.00769)	-0.00269**	(0.00110)
Market	0.316**	(0.150)	0.0452**	(0.0205)
Perceive climate change				
constant	-1.956	(1.774)		
Zone fixed effect	Yes			
Observations	104			
Percent correctly predicted	86.54			
Wald Chi-square (26)	101.78			
Log likelihood	-27.02			
Pseudo R^2	0.6187			

Note: *** p<0.01, ** p<0.05, * p<0.1; This table shows the result of Probit model coefficient and marginal effect of adaptation decision for those farmers' who does not perceive the climate change. The coefficient shows the direction of probability and the marginal effect indicates the marginal change on the probability, while dy/dx is for discrete change of dummy variable from 0 to 1. It is seen that the effect of education, experience, fertility of land, extension advice and irrigation facility are in the same direction like to those who perceive the changes (shown in Table 6.6). Apart from these, some new factors are found as significant to affect their adaptation decision. Number of literate members in the household and Farm asset have positive influence whereas household's agricultural income has negative influence. Influence of distance to market is found positive which is completely opposite than those who perceive climate change.

6.4.4.3 The Determinants of Adaptation Decision: The Multinomial Logit (MNL) Model

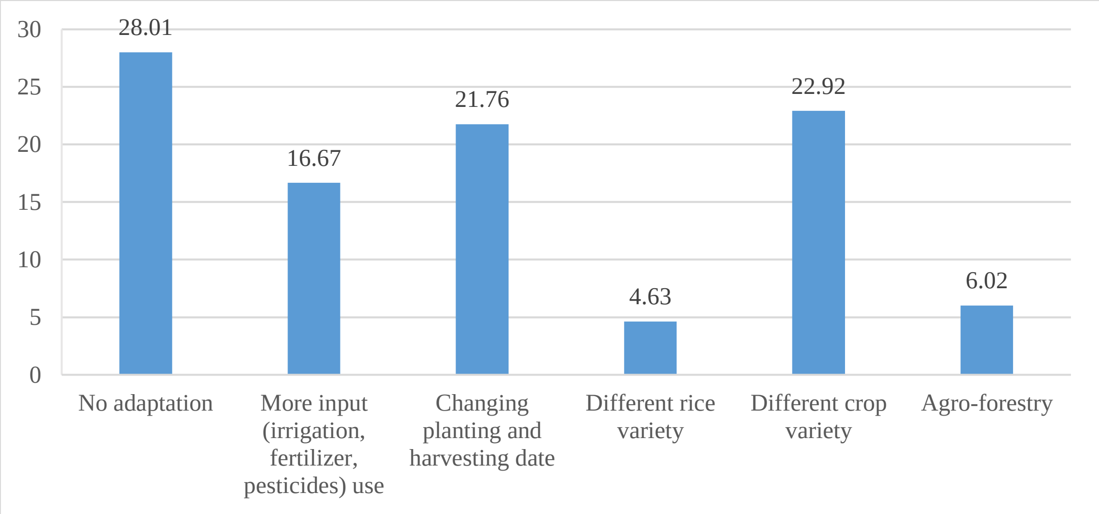
The MNL model, as shown in Figure 6.3, fails to produce statistically significant results with 11 choices because of very limited observations for some adaptation strategies. Therefore, following a standard procedure, the choices were re-organized by grouping closely related strategies, which is a standard procedure in the literature (Gbetibouo, 2009; Sarker et al., 2013; Alam, 2015). The re-specification and grouping of those closely related strategies were as follows:

1. 'More Irrigation' was merged with 'Supplementary irrigation for Aman rice' and termed *more input use*;
2. '*Changing planting and harvesting date*' is unchanged;
3. 'Cultivation of direct seeded rice' is merged with 'Use of different rice varieties (drought/flood tolerant)' and named as *different rice variety*;
4. 'Cultivation of pulses' is merged with 'Cultivation of jute/wheat/other crop' and named as d*ifferent crop variety*;
5. 'Conversion of agricultural land into orchard' is merged with 'agro forestry' and named as *Agro-forestry*;
6. The 'other' option is also merged with closely related strategies individually[19].

Consequently, the options were reduced to five main adaptation strategies taken by farmers, along with *no adaptation*. Therefore, the dependent variable for the MNL model used here is the adaptation choices made by farmers, in six categories (Figure 6.7).

[19] There were a total of five observations for other strategies. They were 'less duration rice' (two observations) which is merged with *different rice variety*, 'more use of fertilizer and pesticides' (one observation) which is merged with *more input use*; and 'cultivation of vegetables' (two observations) which is merged with *different crop variety*.

Figure 6.7 : Adaptation taken by farmers (reduced)



Numbers shown in the figure indicate percentage

The validity of the MNL model requires the IIA (Independence of Irrelevant Alternatives) to be satisfied. According to McFadden (1974: 113) this model should be used only when the outcome categories "can plausibly be assumed to be distinct and weighted independently in the eye of each decision maker". Amemiya (1981) also suggested that when the alternatives are dissimilar then the MNL is the most useful model. This IIA assumption can be tested using a Hausman test (Cameron & Trivedi, 2005) so it was applied to check the validity of the IIA assumption. The Hausman test results are shown in Table 6.8. The results failed to reject the null hypothesis of the IIA assumption. Therefore, it does not indicate inappropriateness of the use of MNL model for the analysis.

Table 6.8 : The results of the Hausman tests of IIA assumption for the MNL model

Omitted adaptation choices	χ^2	df	$p > \chi^2$
No adaptation	2.364	9	0.984
More input (irrigation, fertilizer, pesticides) use	6.653	12	0.880
Changing planting and harvesting date	1.429	8	0.994
Different rice variety	-0.000	2	-
Different crop variety	1.006	7	0.995
Agro-forestry	-0.000	4	-

Note: This table shows the results for the Hausman test result for the MNL model with six adaptation choices (shown in Table 6.9). The *p* values for omitted adaptation choices shows that the choices are independent. The chi-square value for two of the alternatives are showing negative. Cheng and Long (2007) suggested that it is common to have negative test statistics. Moreover, Hausman and McFadden (1984) noted this possibility and even concluded that a negative result is evidence that IIA has not been violated. Overall, probabilities as well as chi-square values indicating here that the IIA assumption has not been violated here.

Table 6.9 presents the estimated coefficient as well as the marginal effect from the MNL model. The coefficient estimates of the MNL model provide only the direction of the effect due to the change in independent variable on the particular dependent variable (adaptation strategy) but it does not represent any magnitude. On magnitude, the marginal effect is useful as it provides the expected change in probability of a particular adaptation strategy choice due to the change in an explanatory variable. Here, the reference category is the *no adaptation* choice and results are compared with this base category for all the adaptation strategies. For instance, the first two columns compare the *more input for all crops* with *no adaptation*. The coefficient shows the directional effect, whereas the marginal effect and its sign shows the expected change in probability of adopting more input use to no adaptation with per unit change in a given explanatory variable.

The results suggest that *education* has a positive impact on the probability of taking all five adaptation choices; all the coefficients are statistically significant and positively signed. The marginal effect shows that educated farmers are more likely to choose a different rice variety and different crop variety as an adaptation strategy. It also indicates that a one-year increase in education (in number of years schooling from its mean as 5.41 years) would increase the probability of choosing a different crop variety by 2% and a different rice variety by 0.7% as an adaptation strategy. Educated farmers are more likely to change crop and rice variety in Bangladesh, whereas soil conservation and changing planting dates were found to be preferred adaptation strategies in Ethiopia (Deressa et al., 2009).

Experienced farmers have an increased likelihood of using more inputs for crops, changing planting dates, selecting a different crop variety and agro-forestry. Other studies in African countries also found that farmers' experience increases the probability of taking different adaptation strategies (Hassan & Nhemachena, 2008; Gbetibouo et al., 2010). In a study of maize farmers in west Africa, Yegbemey et al. (2013) also found that farmers' experience determines the adoption of land use strategies. They argued that to change the land use or to allocate land among different crops, farmers need to have a high level of knowledge and that only comes from years of farming experience. In the same way, it can be argued here that through experience farmers gain the skills in management and technique, which influences their choice of adaptation strategies.

The estimated coefficient of *electricity* suggests that households' access to electricity influence the probability positively in taking more input use, changing planting dates and different crop variety as climate change adaptations. Hassan and Nhemachena (2008) also found a strong association between electricity and use of irrigation in 11 African countries. In Bangladesh, this finding could be because access to electricity may encourage farmers to use groundwater irrigation, as the cost of an electricity-operated pump is less than that of a diesel pump. Other studies in Africa also found evidence that electricity is an important determinant of livestock choices (Seo & Mendelsohn, 2008c; Seo et al., 2009) and crop choice (Kurukulasuriya & Mendelsohn, 2008a).

One of the implications of climate change (temperature and rainfall change) in agriculture is the water shortage for crop production (Mancosu et al., 2015). Therefore, irrigation is the first and easiest adaptation option for farmers. It is logical that if farmers have that facility, then they would choose that option over others. It is found here that access to *electricity* influences farmers negatively on taking adaptation strategies like changing planting date and switching to a different crop variety. This finding confirms the result of Alauddin and Sarker (2014) in a study in drought-prone areas of Bangladesh. They argued that access to electricity gave farmers access to groundwater irrigation as a dependable adaptation option for their rice crops. Consequently, it may discourage farmers from taking other strategies like changing planting dates and switching to other non-rice crops. In this present study, the coefficient of *irrigation* validated this argument, showing that farmers having more land under irrigation were less likely to take changing planting date and different crop variety as adaptation strategies.

The present study found that *fertility* of land discourages farmers from adopting all five strategies. Overall, it suggests that farmers' own perceptions about the fertility of their farmland negatively influences their adaptation decision. This finding is consistent with what has been found in African economies (Gbetibouo et al., 2010; Di Falco & Veronesi, 2014). It can be argued that farmers' sense of high fertility of the land gives them confidence in their production and, as a result, they may have less concern for climate change risk and be reluctant to take an adaptation decision. That may be why Chatzopoulos and Lippert (2015) found that farmers with productive soil are more likely to stay with permanent crops over forage farming. Conversely Gbetibouo et al. (2010) argued that owners of infertile land would take adaptation to improve the productivity of the land. Less productive soil leads farmers to take different adaptation strategies, such as mixed cropping and livestock fattening (Chatzopoulos & Lippert, 2015). From the marginal effect, the present study found that an increase in fertility perception by one unit (from its mean 2.34) will decrease the probability of changing planting date by around 6% and agro-forestry by around 3%.

Land ownership is believed to encourage technology adoption (Kpadonou et al., 2017; Senanayake & Rathnayaka, 2017). The results from this study also suggest that *tenure status* (i.e. the ownership of the land) positively influences the adoption of more input use and different crop variety. It may be because the landowner adopts technologies linked with improvement of land quality, like improvement of drainage and irrigation (Gbetibouo et al., 2010). Tenure insecurity also leads to poor agricultural practices, where input use is lower or less efficient than on owned land (Gray & Kevane, 2001). The marginal impact shows here that ownership of land is likely to reduce the adoption of agro-forestry as an adaptation decision by around 4.6%.

It is also apparent from the results that wealthier farmers are less likely to select a different rice variety and changing planting date as their adaptation strategies. A one unit increase in household assets and agricultural income decreases the probability of adopting a different rice variety by around 8% and 9% respectively. Although *farm assets* has a positive impact of around 3% for different rice variety, it has a bigger negative impact on changing planting date of around 6%. However, farmers' increase in agricultural income shows an increase in probability of adopting more input for all crops by around 6%. It seems that wealthier farmers are more likely to choose *use of more inputs* as their adaptation strategy. This suggests that when farmers can afford the cost of irrigation and other inputs, then they are less likely to select the agronomic practices like soil conservation and different crop variety (Deressa et al., 2009).

The present study also found that non-agricultural income significantly increases the likelihood of adopting agro-forestry as an adaptation strategy. It is seen that an increase in non-agricultural income by one unit would increase the probability of adopting an agro-forestry strategy by around 3.5%. On the other hand, non-agricultural income has a negative impact on the probability of adopting more inputs use, changing planting date and different crop variety, although these results are not statistically significant. It seems that non-agricultural income discourages strategies that are more labour intensive. These results are very similar to the findings of Deressa et al. (2009). In the same line of argument with Deressa et al. (2009) it can be argued here that because of non-agricultural income, farmers can afford to make the investment required for agro-forestry and so are less likely to follow other strategies. Moreover, non-agricultural income favours those options which do not require continuous full-time operator labour (Chatzopoulos & Lippert, 2015).

Access to extension advice is positively related to most of the adaptation strategies, even though the results for marginal impacts do not show the significance. The impact of access to extension advice positively influences the adoption of more input use, changing planting date, different rice variety and different crop variety. These findings are similar to the findings of the study by Tazeze et al. (2012) in Ethiopia. Farmers having access to extension advice are more likely to have information and knowledge about various management practices (Gbetibouo et al., 2010). Although the extension advice is more biased towards concerns for profitability rather than climatic risk (Tesfaye & Seifu, 2016), it enhances farmer's capacity to adopt climate change adaptation strategies (Yegbemey et al., 2013).

Weather information is another important factor found to influence farmer's decisions to adopt different adaptation strategies. The marginal impact suggests that having weather information leads farmers' adaptation decisions toward more input use and agro-forestry increases by around 9% and 4% respectively. This positive effect could be because weather information help them to use inputs (like irrigation, fertilizer and pesticides) as necessary. For instance, if farmers receive information of no rain forecast when the crop required water then they go for irrigation. Weather information encourage them to use necessary inputs, which happened to be more here. As a result, they are reluctant to take other adaptation strategies. That may be why the marginal impact result shows that access to weather information decreases the probability of adopting changing planting date by 8.4%. Overall, the effect of this variable on farmers' choice of adaptation strategies is in line with other research (Deressa et al., 2009; Tazeze et al., 2012; Di Falco & Veronesi, 2013; Alauddin & Sarker, 2014).

Awareness of changes in the climate variables (temperature and rainfall) is important for influencing farmers' adaptation decision (Maddison, 2007; Deressa et al., 2011). The results of this study suggest that *perceiving the changes in temperature* influences farmer's decision to adopt use of more inputs, changing planting date and switching to a different crop variety. Temperature change has effect on the moisture content of the field, plant nutrition and disease. Therefore, more use of inputs like irrigation, fertilizer and pesticides are obvious choices for farmers. They may choose to change the planting date as well as crop variety, according to the suitability of the temperature. Similarly, *perceiving the changes in rainfall* is associated with an increased likelihood of adopting changing planting dates or agro-forestry. The marginal effect suggests that perceiving temperature change increases the farmer's probability of adopting the use of more inputs for all crops as an adaptation strategy by around 11%.

These results also show evidence of the influence of other variables on adopting particular strategies. For instance, belonging to a *group* (i.e. farmer's club) has a positive impact on changing planting date, and *livestock ownership* on selection of a different crop variety.

Other empirical studies also found that in places where information is scarce and markets are not functioning well, farmers' social networks facilitate information exchange and have impact on technology adoption decisions, especially water conservation techniques (Di Falco & Bulte, 2013; Kassie et al., 2015). Marginal impact results in the present study shows that livestock ownership increases the likelihood of adopting a different crop variety by 11%. This result may be because livestock is also an important source of income in order to purchase other crop variety. Involvement with livestock in farming may lead farmers to be more involved with other people, the environment, and the market. It may also encourage them to diversify their production by adopting a different crop variety. This finding is in line with the findings of other studies in African countries related to climate change adaptation (Nhemachena & Hassan, 2007; Deressa et al., 2009; Tazeze et al., 2012) as well as technology adoption (Marenya & Barrett, 2007; Kassie et al., 2015).

Table 6.9 : Multinomial logit model estimation for different adaptation

Independent variable	Dependant variable: adaptation strategies									
	More inputs for all crops		Changing planting date		Different rice varieties		Different crop varieties		Agro-forestry	
	Coefficient	Marg. effect	Coefficient	Marg. effect	Coefficient	Marg. effect	Coefficient	Marg. effect	Coefficient	Marg. effect
Farmer's Characteristics										
Education	0.345***	0.0034	0.290***	-0.00487	0.521***	0.00721**	0.440***	0.0204***	0.392***	0.002
Experience	0.149***	0.00746***	0.0878***	-0.000404	0.0305	-0.00191	0.0987***	7.82E-07	0.167***	0.00303**
Group	0.393	-0.0502	1.292*	0.0983	0.957	0.00548	0.728	-0.0197	1.684	0.0379
Household's Characteristics										
Own Labour	-0.0804	-0.0116	0.0230	0.00144	0.383	0.0126	0.0693	0.0121	-0.281	-0.0129
Electricity	0.978*	0.0164	1.205**	0.0628	1.171	0.0136	1.206**	0.0594	-0.764	-0.0718**
Literacy	-0.0166	-0.00167	-0.00253	0.000628	-0.153	-0.00491	0.0200	0.0054	-0.0222	-0.000521
Household Asset	-0.145	-0.00454	0.0273	0.0314	-2.575**	-0.0818**	-0.00191	0.0292	-0.0407	0.00743
Agri. Income	0.220	0.0595**	-0.178	0.0158	-2.904*	-0.0885*	-0.396	-0.027	-0.0117	0.014
Non-agri. Income	-0.229	-0.0055	-0.398	-0.0383	0.160	0.0104	-0.294	-0.0196	0.638*	0.0352***
Farm's Characteristics										
Farm Size	-0.144	-0.0208	0.0153	-0.00107	0.560	0.0179	0.0630	0.0093	-0.0435	-0.00326
Fertility of land	-1.238***	-0.0092	-1.472***	-0.0596***	-1.182***	-0.00149	-1.294***	-0.00968	-1.829***	-0.0259*
Tenure Status	0.815*	0.0343	0.674	0.0231	-0.146	-0.0208	0.871*	0.0583	-0.517	-0.0464*
Livestock	0.0564	-0.0424	0.110	-0.0505	1.349	0.0332	0.932	0.110*	-0.0381	-0.0203
Farm Asset	-0.0394	0.0207	-0.595**	-0.0760**	0.841*	0.0344**	-0.180	0.00417	-0.162	-0.000241
Institutional Accessibility										
Extension advice	2.038***	-0.109	1.726***	-0.171	2.171**	-0.0349	2.443***	-0.116	18.28	0.657
Weather info	0.618	0.0886**	-0.528	-0.0840*	-0.670	-0.0205	-0.230	-0.0354	0.961	0.0437*
Credit	-0.272	-0.0207	-0.444	-0.058	-0.608	-0.0167	0.149	0.059	0.292	0.0184
Irrigation	-0.0126	0.000751	-0.0302***	-0.00223***	-0.00465	0.000412	-0.0262***	-0.00142	0.00172	0.000863

Market	0.0301	0.0204	-0.193	-0.0138	0.0866	0.00699	-0.229	-0.021	-0.165	-0.002
Climate Change Perception										
Perceive temp change	2.493***	0.108**	2.084***	0.0797	0.808	-0.0246	1.887***	0.0199	1.052	-0.0295
Perceive rain change	0.647	-0.0818	1.992**	0.137	1.855	0.0186	1.262	-0.0186	2.761*	0.0616
Constant	-6.231***		-3.223*		-25.50		-5.791***		-41.01	
District fixed effect	Yes									
Base Category	No Adaptation									
LR Chi-square	533.13***									
Log likelihood	-440.174									
Pseudo R^2	0.3772									

Note: N= 432; *** p<0.01, ** p<0.05, * p<0.1; This table shows the estimations of multinomial logit model (MNL) coefficient and marginal effect for different adaptation strategies. The full table is given in the Appendix 6. The coefficient estimates of MNL model provide only the direction of the effect due to the change in independent variable on the particular dependent variable (adaptation strategy). It does not represent any magnitude. For that, the marginal effect is useful, which provides the expected change in probability of a particular adaptation strategy choice due to the change in an explanatory variable. Here the reference category is the *no adaptation* choice and results are compared with this base category for all the adaptation strategies.

Further analysis is undertaken by categorizing some variables to see the effect of this on the adoption of different adaptation strategies. Education is categorized into three classes, *illiterate* (0 year of schooling), *primary* (1-5 years of schooling), *secondary* (6-10 years of schooling) and *above secondary* (above 10 years of education). Similarly, experience is categorized into three types, < = 15 years of experience, 16-25 years of experience and above 25 years of experience. In case of climate change perception, instead of using two separate perception variables (summer temperature increase and rainfall in rainy season decrease), one variable is created as *perceive climate change correctly*. In this case, whatever the meteorological evidence from a particular district shows, farmers' perception on both summer temperature and rainfall in the rainy season consistent with that district are considered. It is argued that farmers' use of different adaptation strategies differs as they live in different agro-ecological settings. This is because of climatic conditions influencing farmers' perceptions of climate change and influencing their decisions to adapt (Deressa et al., 2009). To see this effect, a climate-zone variable is created by merging some of the climate zones in accordance with similarity in their rainfall and temperature characteristics. They are: *good climate zone* (merging A and B) with more rainfall and lower temperature, *dry climate zone* (merging zones E and F) with less rainfall and high temperature, and *moderate climate zone* (merging C, D and G) with rainfall and temperature between those of the good and dry climate zones.

The estimation results of the MNL model to determine the adaptation determinant using the specifications specified above are reported in **Error! Reference source not found.**. The result does not vary substantially from the previous analysis, which also confirms the robustness of our results. Among all variables, the effect of education and experience are more clearly seen. For instance, education positively influences farmers to cultivate different crop varieties. Both the coefficients and marginal effects are significantly and positively increased with higher levels of education compared to the illiterate group (the reference category) in the case of *different crop variety*. The marginal impact suggests that the probability of adopting a different crop variety increases by 16.5% for the farmers with secondary education compared to illiterate farmers. The probability further increases to 30.6% for farmers with above secondary level education. Similarly, more experienced farmers are also more likely to take *different crop variety* as their adaptation strategy, as the probability of adoption is increased by 16.6% and 17.5% for subsequent increase in experience (16-25 years and 25+ years) from the reference category (<= 15 years).

The *livestock* variable is insignificant here and the *farm size* variable becomes significant. This suggests that adopting *different rice variety* is positively influenced by the farm size. From the marginal impact it can be seen that a one unit increase in farm land (from its mean value 2.35 acres) increases the probability of adopting different rice variety by around 2.4%. The argument could be that having more capital and resources, farmers may be able to grow a different variety of rice on different land. Moreover, as rice is the main crop in Bangladesh, farmers with larger farms are likely to investigate different rice varieties before looking into other options. Other studies in African countries also found evidence that farm size influences the adaptation decision (Bryan et al., 2009; Gbetibouo et al., 2010)

As expected, it is also found here that farmers living in different climatic settings employ different adaptation strategies, a finding similar to that of Deressa et al. (2009). For instance, farmers living in the *moderate climate zone* adopt *more input use* and *changing planting date* significantly, compared with farmers living in the *dry climate zone*. However, farmers in the *good climate zone* are less inclined to take different adaptation strategies; most of the coefficients are negative, although some of them are not statistically significant. It can also be seen that one strategy, *agro-forestry*, is less likely to be taken in moderate or good climate zones. The marginal impact suggests that the probability of adopting agro-forestry as an adaptation strategy significantly decreases for farmers in the moderate and good climate zones by 13.2% and 12.4% respectively, compared with farmers in the dry climate zone. It may be because the agro-forestry (conversion of cropland into fruit orchard or planting wood trees) strategy requires less water in terms of irrigation and is more temperature tolerant than other crops.

Table 6.10 : Estimated results (categorizing some variable) from MNL model

Independent variable	Dependant variable: adaptation strategies									
	More inputs for all crops		Changing planting date		Different rice varieties		Different crop varieties		Agro-forestry	
	Coefficient	Marg. effect	Coefficient	Marg. effect	Coefficient	Marg. effect	Coefficient	Marg. effect	Coefficient	Marg. effect
Farmer's Characteristics										
Education										
Illiterate										
Primary	1.279*	0.0716	0.743	-0.00466	1.179	0.0145	1.368**	0.0862	-0.129	-0.0427
Secondary	2.820***	0.0789	2.454***	0.0208	3.171***	0.0370	3.325***	0.165***	2.299*	-0.00759
Above Secondary	4.039***	0.0804	3.604***	0.000101	3.622**	0.0106	4.996***	0.306***	3.167**	-0.0281
Experience										
<= 15 years										
16-25 years	16.65	0.118***	1.638	-0.0100	3.199**	0.105*	3.152**	0.166**	-0.648	-0.0856
25+ years	18.32	0.184***	3.549***	0.110	2.004	-0.0177	4.473***	0.175***	2.651*	-0.0245
Group	0.538	-0.0430	1.338*	0.0907	1.162	0.0120	0.945	0.00863	1.246	0.0161
Household's Characteristics										
Own Labour	-0.119	-0.0200	0.0145	-0.00214	0.347	0.0107	0.141	0.0260	-0.244	-0.0125
Electricity	0.708	0.0139	0.954**	0.0596	1.183	0.0204	0.703	0.00919	-0.135	-0.0364
Literacy	0.0813	-0.00355	0.0983	-0.00198	0.145	0.00141	0.178	0.0141	0.121	0.000186
Household Asset	-0.242	-0.0112	-0.0437	0.0263	-2.322**	-0.0727**	-0.0669	0.0299	-0.158	0.00211
Agri. Income	0.578	0.0860***	0.0195	0.0127	-4.211***	-0.140***	0.107	0.0399	-0.365	-0.0136
Non-agri. Income	0.0588	0.00425	-0.171	-0.0370	0.206	0.00589	0.0333	-0.000607	0.683**	0.0294**
Farm Characteristics										
Farm size	-0.221	-0.0228	-0.0543	0.00117	0.651*	0.0236**	-0.113	-0.0121	0.0610	0.00563
Fertility of land	-0.969***	-0.00845	-1.216***	-0.0545**	-0.752*	0.00375	-1.022***	-0.00912	-1.474***	-0.0228
Tenure Status	0.902*	0.0379	0.753*	0.0182	0.0231	-0.0193	0.970**	0.0656	-0.166	-0.0391
Livestock	-0.128	-0.0460	0.0183	-0.0360	1.663	0.0490	0.501	0.0619	0.0574	-0.00826
Farm Asset	0.0104	0.0227	-0.556*	-0.0779**	1.126**	0.0425***	-0.132	0.00292	-0.148	-0.000790
Institutional Accessibility										
Extension advice	1.770***	-0.122	1.819***	-0.139	2.542***	-0.000375	2.353***	-0.116	16.23	0.612

Weather info	0.538	0.0779**	-0.542	-0.0981**	-1.026	-0.0338	-0.00726	0.00115	1.050	0.0479**
Credit	-0.275	-0.0241	-0.427	-0.0575	-0.629	-0.0181	0.0741	0.0429	0.744	0.0389
Irrigation	-0.000831	0.00156*	-0.0219**	-0.00188**	0.00250	0.000470	-0.0178**	-0.00119	-0.0128	-0.0000208
Market	0.0861	0.0159	-0.101	-0.0150	0.410*	0.0147**	-0.0752	-0.0119	-0.102	-0.00372
Climatic change Perception										
Perceive climate change correctly	2.043***	0.0534	2.430***	0.133**	1.574*	0.0000863	1.998***	0.0456	0.502	-0.0590*
Climatic Settings										
Dry climate										
Moderate	1.244*	0.0902	1.254*	0.125	-0.275	-0.0192	0.585	-0.00550	-1.970*	-0.132***
Good climate	-0.225	0.0447	-0.725	-0.0254	0.903	0.0717	-0.717	-0.0198	-2.753**	-0.124***
Constant	-20.19		-2.803		-14.05***		-6.353***		-14.58	
Base Category	No Adaptation									
LR Chi-square	458.44***									
Log likelihood	-477.519									
Pseudo R^2	0.3243									

Note: For some categories values are missing, this indicates as the reference category among all other relevant categories; *N*= 432, *** p<0.01, ** p<0.05, * p<0.1; this table shows the estimations of multinomial logit model (MNL) coefficient and marginal effect for different adaptation strategies. The difference between this table and the **Error! Reference source not found.** is that in this case, some variables are categorize (education, experience, climatic zone) and some variables are merged into one (Climate change perception). Education is categorize into three classes, illiterate (0 year of schooling), primary (1-5 years of schooling), Secondary (6-10 years of schooling) and Above Secondary (above 10 years of education). Experience is categorize into three, <= 15 years of experience, 16-25 years of experience and above 25 years of experience. In case of climate change perception instead of using two separate perception variable (temperature and rainfall) one variable is created as *perceive climate change correctly* considering correct perception (consistent with meteorological data) about both summer temperature and rainfall in the rainy season. For the climatic zone variable, three zones are created by merging some of the zones in accordance with similar rainfall and temperature situation. They are: the good climate zone (merging A and B) with more rainfall and less temperature, the dry climate zone (merging zones E and F) with less rainfall and high temperature, and the moderate climate zone (merging C, D and G) with rainfall and temperature between the good and dry climate zones.
The coefficient estimates of MNL model provide only the direction of the effect due to the change in independent variable on the particular dependant variable (adaptation strategy). It does not represent any magnitude. For that, the marginal effect is useful, which provides the expected change in probability of a particular adaptation strategy choice due to the change in an explanatory variable. Here the reference category is the *no adaptation* choice and results are relative to this base category for all the adaptation strategies.

6.4.4.4 Exploring Adaptation Determinants by Categorizing Strategies in Accordance with Difficulties

It has been found that there are several constraints that farmers face while doing adaptation and they need to make several adjustments. Therefore, the analysis proceeds by categorizing the adaptation strategies in accordance with the difficulties. It is assumed that difficulties may arise from increasing costs as well as a lack of information, knowledge, skills and inputs, which may be required for a particular strategy. Accordingly, the adaptation options from the previous five strategies are re-categorized into three classes: low, medium and high obstacle strategies. Although category names are given in obstacle term, the categorization is undertaken considering the costs involved and the difficulties that arise regarding information, training, and input requirements.

The *low obstacle* adaptations are those that involve less cost and are easy to adopt; they do not require any further knowledge. For instance, c*hanging planting and harvesting date* is a *low obstacle* strategy as for this strategy, no extra cost is involved and no extra knowledge, training, or information is required. On the other hand, *high obstacle* adaptations are those where farmers need to spend some time to learn about them and which involve greater costs. High obstacle adaptations are *different crop variety* and *agro-forestry*. For rice farmers in Bangladesh, switching to a different crop variety or agro-forestry is not so easy as farmers need to know the cultivation system, require all the inputs necessary, incur some cost and possibly require some specialist training. *More input use* and *different rice variety* are considered as *medium obstacle* adaptation strategy as taking these strategies involves some cost and knowledge, but the intensity is not as high as in the high obstacle strategies. The results from the multinomial logit model for these three adaptation choices are shown in Table 6.11.

It is argued that *education* can make a farmer more resilient in difficult situations and able to overcome the obstacles related to climate change adaptation. The results here show evidence in favour of this proposition and suggest that the probability of *high obstacle* adaptation strategies is positively influenced by the increase in farmers' years of schooling. From the marginal impact, it is seen that having secondary level education increases the probability of taking medium obstacle and high obstacle adaptations by 11.5% and 16.6% respectively, compared to no adaptation. Above secondary level education increases the probability of taking high obstacle adaptation by 28.4%.

Experienced farmers are also more likely to be able to overcome the obstacles related to adaptation. Experienced farmers have more knowledge about crop management practices and usually are leaders in farming practices in rural communities (Nhemachena & Hassan, 2007). Although the results here suggest that *experience* positively influences the likelihood of adopting all adaptations, it is more prominent toward *medium* and *high obstacle* adaptation options. It is seen that having more than 25 years of experience increases farmers' probability of taking medium and high obstacle adaptation strategies by around 14% and 17.5% respectively. It suggests that the probability increases more for high obstacle strategies than others.

Wealthy farmers are able to overcome the difficulties related to adopting climate change adaptation because of their resource capacity. The marginal effect of *agricultural income* and *farm asset* provide some supporting evidence of that. It is suggested here that increasing *agricultural income* and *farm assets* by one unit (from their mean) will increase the probability of taking *medium obstacle* adaptations by around 5.7% and 4.3% respectively. However, it is also seen that *farm assets* is likely to decrease the adoption of *low obstacle* adaptation, as both coefficient and marginal effect are statistically significant. Conversely, it seems that poor farmers are more likely to take *low obstacle* adaptation. Because of their resource limitation, low obstacle adaptations are their first choice. Moreover, poor farmers mainly produce a single staple food crop (in the case of Bangladesh it is the rice) and it is difficult for them to completely switch to a *different crop variety* (i.e. *high obstacle*) or use *more irrigation* (i.e. *medium obstacle*) (Nhemachena & Hassan, 2007). Rather, it is easier for them to incorporate the *changing planting date* (i.e. *low obstacle*) option. Provision of cheap technologies and adaptation options is an important policy prescription from this finding for resource poor counties like Bangladesh to promote adaptation.

Farmers' perceptions about the high *fertility* of their land discourages all three categories of adaptation; all coefficients and marginal effects are negative although some of them are not statistically significant. It can be argued that it is not the difficulties related to adaptations that prevent farmers from adopting the strategies but the perception related to their cropland, which makes them feel secure from climate risk and so less likely to adapt. On the other hand, owners of infertile land would make adaptation in the first place to improve the productivity of the land (Gbetibouo et al., 2010).

Access to *extension advice* and *perceiving climate change* is likely to increase adoption of all three options. However, farmers who are aware of climate change are most likely to take the *low obstacle* adaptation in response to climate change, as the marginal impact and coefficient are statistically significant. Perceiving climate change is likely to increase by 14.4% the probability of low obstacle adaptation. For extension advice, technology adoption literature suggests that access to extension services positively influences farmers' decision to adopt new technology by providing them with information and technical skills (Adesina & Zinnah, 1993; Adesina & Baidu-Forson, 1995; Doss, 2006; Abdullah & Samah, 2013). It is also found here that extension advice can help farmers to overcome the obstacles related to climate change adaptation. It is shown here that access to extension advice increases the probability of adopting *high obstacle* adaptation strategies by 16.4%.

Access to *weather information* decreases the probability of adopting *low obstacle* adaptation by 10.5%. However, both the coefficient and marginal effects of weather information suggest a positive effect on *medium* and *high* obstacle adaptation, although they are not statistically significant. Moreover, *perceiving climate change* shows a positive association with all three types of adaptation. Although weather information and climate change perception do not help farmers to overcome the obstacles related to adaptation, several studies show the importance of these variables for adaptation decisions (Maddison, 2007; Deressa et al., 2009; Deressa et al., 2011; Di Falco & Veronesi, 2014). Therefore, it is apparent here that having access to weather information and perceiving climate change may not contribute a lot in terms of overcoming obstacles but they help to motivate farmers to go for medium or high obstacle adaptation.

Security of land tenure is widely believed to contribute to farmers' adoption behaviour. Technology adoption literature frequently found that landowners tend to adopt new technology more than tenants (Feder et al., 1985; Godoy et al., 2000). Climate change adaptation literature also suggests that land ownership is likely to influence adaptation if it requires considerable investments in the land (Gbetibouo, 2009; Gbetibouo et al., 2010). In terms of obstacles, the result from this study also confirms that *tenure status* (i.e. farm ownership) is likely to help farmers to overcome the problems related to adaptation. The positive and statistically significant coefficient of *high obstacle* adaptation suggests that owner farmers are more likely to take the *high obstacle* adaptation compared to no adaptation. This is because *high obstacle* adaptation like *agro-forestry* and *different crop variety* requires investment, extra information, and inputs, which are more easy to secure by the owner occupier farmer. Thus, to facilitate climate change adaptation, reduction of tenure insecurity is an important policy action.

There are also some noteworthy findings with respect to some of the explanatory variables. Being a member of any farmers' club or *group* does not offer much help but may provide information. As a result, membership may affect positively the adoption of *low obstacle* adaptation, since the results indicate only this coefficient to be statistically significant. This finding is in sharp contrast to farmers in Kenya, where membership of a group increases the likelihood of adopting *high obstacle* adaptation like agro-forestry (Bryan et al., 2013). Bryan et al. (2013) argued that the required knowledge and investment for adaptation (like agro-forestry) might be facilitated by group membership. In the case of Bangladesh, it is apparent that whereever farmers' groups exist and whatever they are facilitating do not offer farmers substantial support to overcome the obstacles related to climate change adaptation. It is likely that most of the groups identified by the surveyed farmers were supported by NGOs and these groups are formed especially around micro-credit programmes.

The effect of access to *electricity* is similar to the effect of *group* found here. One of the most important uses of electricity in rural households is television[20]. Most of the surveyed farmers who had access to the electricity are also reported having television in their household. Access to electricity increases television viewing, which can be a useful medium for farmers to acquire information related to climate change and adaptation. Studies on rural electrification projects in developing countries found that access to electricity has a significant impact on knowledge but very little on household poverty or income (IEG, 2008; Bernard, 2010). Therefore, interpreting the result from this study can be argued that access to electricity may provide farmers with knowledge but does not help them to overcome the obstacles related to adaptation. Consequently, the easy option with low obstacles is the obvious choice for them to adopt in response to climate change.

[20] The main use of electricity in rural households is lighting. The second most common use of electricity is television. Lighting and television account for at least 80% of rural electricity consumption in developing countries (IEG, 2008).

Table 6.11 : Estimates for selecting adaptation of different obstacle level strategies using Multinomial Logit Model

Independent variable	Dependant variable: adaptation strategies in accordance with obstacle					
	Low obstacle		Medium obstacle		High obstacle	
	Coefficient	Marg. effect	Coefficient	Marg. effect	Coefficient	Marg. effect
Farmer's Characteristics						
Education						
Illiterate						
Primary	0.749	-0.00842	1.260**	0.0847	1.092*	0.0546
Secondary	2.380***	0.0136	2.823***	0.115*	3.048***	0.166**
Secondary+	3.579***	-0.00369	3.950***	0.0944	4.652***	0.284***
Experience						
<= 15 years						
16-25 years	1.416	-0.0181	2.882**	0.188**	2.286**	0.101
25+ years	3.450***	0.103	3.877***	0.139**	3.917***	0.175**
Group	1.280*	0.0790	0.753	-0.0149	0.984	0.0215
Household's Characteristics						
Own Labour	0.0385	-0.000710	-0.0469	-0.0167	0.119	0.0201
Electricity	0.933**	0.0621	0.726	0.0273	0.537	-0.0261
Literacy	0.119	-0.00259	0.129	0.0000476	0.196	0.0152
Household Asset	-0.0723	0.0150	-0.369	-0.0420	-0.126	0.00963
Agri. Income	-0.0174	-0.0146	0.359	0.0569*	-0.0557	-0.0326
Non-agri. Income	-0.154	-0.0332	0.0285	0.000965	0.147	0.0329
Farm Characteristics						
Farm Size	-0.0276	0.00277	-0.130	-0.0169	-0.0123	0.00882
Fertility of land	-1.231***	-0.0540**	-0.968***	-0.0102	-1.105***	-0.0303
Tenure Status	0.670	0.0172	0.640	0.0151	0.704*	0.0256
Livestock	-0.0294	-0.0303	0.0333	-0.0182	0.355	0.0582
Farm Asset	-0.611**	-0.0720**	0.00890	0.0430*	-0.211	0.00704

Institutional Accessibility						
Extension advice	1.834***	-0.00287	1.891***	0.0182	2.557***	0.164***
Weather info	-0.563	-0.105**	0.335	0.0633	0.154	0.0415
Credit	-0.452	-0.0577	-0.334	-0.0371	0.125	0.0750*
Irrigation	-0.0221***	-0.00184**	-0.00207	0.00186**	-0.0172**	-0.00115
Market	-0.0865	-0.0149	0.147	0.0291*	-0.0555	-0.0132
Climatic Change Perception						
Perceive climate change correctly	2.421***	0.144**	1.743***	0.0270	1.734***	-0.00196
Constant	-2.671		-5.758***		-4.895**	
Climatic settings fixed effect	Yes					
Base Category	No Adaptation					
LR Chi-square	347.24***					
Log likelihood	-421.035					
Pseudo R^2	0.29					

Note: For some categories values are missing, this indicates as the reference category among all other relevant categories; N= 432, *** p<0.01, ** p<0.05, * p<0.1; This table shows the estimated coefficients and marginal effects for different adaptation in accordance with obstacle. All the adaptation strategies (five adaptation strategies shown in **Error! Reference source not found.**7) are categorized into three classes: low, medium and high obstacle adaptation strategies. Although the name is given in obstacle terms, the categorization is done by considering the cost involved and the difficulties regarding information, training, and inputs requirement. The *low obstacle* adaptations are those that involve less cost and are easy to adopt, as they do not require any further knowledge. For instance, c*hanging planting and harvesting date* is a *low obstacle* strategy. For this strategy no extra cost is involved; no extra knowledge, training, information is required. On the other hand, the *high obstacle* adaptations are those where farmers need to spend some time to learn and which involve more cost. High obstacle adaptations are *different crop variety* and *agro-forestry*. For rice farmers in Bangladesh, switching to a different crop variety or agro-forestry is not so easy. For these strategies, farmers need to know the cultivation system, require all the inputs necessary, incur some cost and even require some special training. In the same notion, *more input use* and *different rice variety* are considered as *medium obstacle* adaptation strategy. Taking these strategies involves some cost and knowledge but the intensity is not as high as for high obstacle strategies. Climatic zone might influence the adaptation choice apart from the difficulties involved. To control for that, a dummy for climatic settings fixed effects is also used here. The full table is available in the Appendix 6.

6.5 Conclusion and Policy Implications

Farmers are unlikely to recognise the effect of climate change on their farm production or to respond to it immediately. Literature on technological adoptions during the green revolution in agriculture provides evidence of the slow uptake of technologies by farmers (Maddison, 2007). In the growing body of literature on climate change adaptation, there are gaps in the understanding of likely uptake of adaptations by farmers. Difficulties in taking adaptation arise due to several complications, such as behavioural variability, climatic variability, variability in socio-economic conditions, and variability of farmers' exposure. This research has sought to contribute to the empirical literature on climate change adaptation by assessing adaptation strategies that farmers are taking, the barriers that farmers are facing and the factors that affect their decision to adapt in the case of Bangladesh rice farms. Analysing current adaptation strategies in response to climate change by Bangladesh rice farmers can offer insights that will help us to refine our current knowledge related to farm level adaptation for developing countries. Moreover, it will enable policy makers and other stakeholders to support climate change adaptation at the farm-level.

Based on farm-household level survey data from seven climatic zones in Bangladesh, this research investigates several aspects of farmers' climate change adaptation. Descriptive statistics (percentages) are used to characterize farmers' perception on crop damage, the adaptation they made, barriers they face and adjustment they need to make while taking the adaptation. It indicates that although the majority of the farmers are aware of the crop damage caused by climate change, a considerable proportion of farmers did not make any changes (adaptation) in their farming system in response to climate change. Farmers also identified lack of knowledge about appropriate adaptation, lack of credit, lack of information on future climate change and lack of irrigation facility as the important constraints related to climate change adaptation. To facilitate climate change adaptation, policy should attempt to address these issues.

Important adaptation strategies used by farmers in Bangladesh are changing planting and harvesting dates, more irrigation, cultivation of different crops and cultivation of a different rice variety. It seems that the adaptations are mainly autonomous (strategies taken by farmers themselves) rather than planned. From a production perspective, it seems that farmers take strategies mainly to escape adverse climate conditions through crop management practices. Strategies that transform the production system, like switching to a different rice or crop variety, or changing from cropland to agro-forestry, are less frequently found.

Switching to a different crop variety or cultivating different crops in different plots may serve as an insurance against climate variability (Nhemachena & Hassan, 2007). It may reduce the risk of crop damage or even reduce the risk of complete crop failure because climatic events affect different crops differently. For planned adaptation, a caveat should be borne in mind regarding ‘maladaptation’ (McCarl et al., 2016). Some strategies can pay-off better in the long run but some may be effective in the short run. Moreover, one strategy may influence net revenue positively if implemented with other strategies but not in isolation (Di Falco, 2014). Therefore, future research is needed to understand the suitability of these adaptations for Bangladesh in accordance with its changing climate, as well as their impact on farm net revenue.

The results here show that farmers face some obstacles while taking the adaptation strategies. Farmers identified that lack of credit and lack of knowledge are two important barriers. It is also found that those who have taken the adaptations had to make several adjustments, mainly related to their credit situation. Apart from selling or mortgaging assets (i.e. land, livestock and other valuables), informal sources (i.e. input sellers, friends and relatives) are their main source of credit. Farmers also acknowledged that lack of information about future climate change, lack of irrigation facility, labour shortage in need are important obstacles they need to overcome while taking adaptation. Government policies are therefore needed to provide affordable and easy credit to farmers. There is also a need to provide support to develop and to diffuse knowledge about appropriate technology as well as future climate information to increase farmers’ ability and willingness to take adaptation strategies.

Ensuring access to irrigation facilities is another important measure the government should undertake because it will make farmers more resilient to climate variability. In Bangladesh, groundwater is the main source for irrigation. The water table for groundwater is falling and consequently problems for irrigation are increasing. The severity of the problem will increase through the growing use of water as well as reduced recharge (as the rainfall is less). Irrigation investment needs should be reconsidered in the face of climate change. In this respect, the possibilities of surface water irrigation should be explored, because rivers and tributaries flow throughout the country. However, more efficient water use at the farm level, and less irrigation-dependent strategies (like switching to crops which require less water) for adaptation, should not be ignored.

Simple probit model, Heckman probit selection model and multinomial logit models have been applied in this research to examine the determinants of farmers' adaptation decision to climate change. The results indicate that farmer and farm-household characteristics such as education, experience, perception of climate change, access to electricity and tenure status have a significant impact on the adaptation decision. Thus, policy direction should be directed towards improving the education system, increasing the electricity infrastructure and securing farmers' property right to facilitate climate change adaptation. The results also revealed that institutional factors such as access to extension advice and advance weather information enhance farmers' adaptation decision. Therefore, policies should give importance to the role of extension services in providing information about appropriate adaptation strategies and climate information.

It is also found that the climatic setting of the farm location also has an influence on choosing farmers' adaptation strategies. For instance, farmers in the *dry climate* zone are more likely to adopt *agro-forestry* whereas, *more input use* and *changing planting date* are adopted by those in a *moderate climate*. Of course, this does not mean that whatever farmers perceive and adopt is appropriate. In this respect, government intervention may be required to promote appropriate adaptation for a particular zone. Therefore, the government needs to initiate research to find appropriate strategies for different climatic settings.

This research also investigates whether, and to what extent, farmers' socio-economic characteristics play a role in explaining how to overcome the obstacles related to adaptation. The adaptation strategies taken by farmers are categorised in accordance with the obstacle involved (considering cost and difficulties that arise regarding information, training and input requirements). The analysis indicates that education, experience, extension advice, farm income and credit accessibility are the main factors that help farmers to overcome the obstacles related to climate change adaptation. This again highlights the importance of government policy intervention to improve education, extension advice and affordable credit availability to enhance farmers' capacity to adapt in the face of climate change.

Chapter 7: Conclusions and Recommendations

7.1 Introduction

This thesis is concerned with an investigation of the impact of climate change on agriculture and farmers' adaptation in Bangladesh, which is one of the most vulnerable countries in the world in the face of climate change. The empirical analysis and findings contained in this thesis are principally based on evidence collected from a survey undertaken in 2015/16 of randomly selected farm households located across the seven different climatic zones of Bangladesh. The purpose of this chapter is to summarise the thesis and draw conclusions about the methodological and empirical issues arising from this investigation. A summary of the findings and any implications that these might have for policy-makers, farmers and others is presented. The limitation of this research and implications for future research are highlighted.

7.2 Summary of this Research

Chapter 1, the introductory chapter of this thesis, contained a discussion of the background and motivation, research focus, the aims, rational for choosing Bangladesh as the context for this study and outline of this thesis. To explain the background and motivation of this study, scientific knowledge about climate change, its probable cause of impact on agriculture and the concept of adaptation to reduce the negative effect of climate change are discussed here.

Scientific evidence indicates that the global climate has altered considerably over the last century. The changes in temperature and precipitation are greater since 1950 and projected to change further in future. The agricultural sector will feel the effects of climate change most because of its sensitivity to temperature and rainfall. For developing countries this is very concerning as agriculture is the most important sector contributing significantly to GDP and provides employment to a large proportion of the labour force. Any change in temperature and precipitation will affect the agriculture and consequently national income and employment in those countries, as they rely heavily on agriculture.

The scientific and policy communities have recognized that adaptation is one solution to reduce the detrimental effects of climate change. From farmers' perspective, any action or strategic decision taken at the farm level to reduce the adverse effects or to take the benefit in response to changes in climate variables is adaptation to climate change. Therefore, from the policy perspective, quantifying the effects of climate change on agriculture as well as understanding different issues related to farmers' adaptation in developing counties are important research issues. With this background and motivation, this research investigated the impact of climate change on agriculture and farmers' adaptation in the setting of a developing country, Bangladesh. This research particularly focused on a rain-fed rice crop, Aman, which grows all over the country.

Chapter 2 provides a brief overview of Bangladesh, where this research was based. The general features of the economy, agriculture and its importance in the economy, natural calamities and their effect on the economy are discussed. The descriptions draw on reviewed books, journal articles, documents of the Bangladesh government and international development agencies. Apart from those, using the last fifty year's temperature and rainfall data, the climate change situation in Bangladesh is analysed.

Bangladesh is situated on the Indian subcontinent between India and Southeast Asia. It is the eighth most populous country in the world with a population density of 1077 per square kilometre in 2015. Three-quarters of its population live in rural areas, making Bangladesh a predominantly rural society. Low GDP per capita, underdeveloped financial market, bad infrastructure and growing inequality are some main characteristics of the Bangladesh economy.

Bangladesh is predominantly dependent on its agriculture. A huge population with limited land has no doubt created an extremely unfavourable land-man ratio in Bangladesh. The agricultural sector employs about half of the country's labour force and contributes close to one-quarter of its total GDP. Historically, it is evidenced that agricultural growth fluctuations are contributing to the fluctuations of the GDP growth rate of the country. Moreover, agricultural growth and consequently the total GDP growth decreased in those years when climatic disasters occurred in Bangladesh. Overall, it is also found that although agriculture is at the heart of the Bangladesh economy, it is of relatively low importance to government in terms of budgetary allocation.

Current predictions of climate change suggest that climatic hazards like drought, flood and cyclones will become more frequent and severe in future. Moreover, in 2015 the country was ranked as the most risk-prone country among 198 countries in the world considering the sensitivity of the population, physical exposure and government capacity to adapt to climate change over the next 30 years.

The Bangladesh climate is markedly seasonal and there are differences across the regions of the country. Through investigating the temperature and rainfall situation over the last fifty years it is found that yearly temperature has a rising trend, whereas the rainfall is falling. Although the trends are similar in the case of all three seasons (summer, rainy and winter season), they are more pronounced in the rainy season compared to the other seasons.

Chapter 3 introduced the data on which the empirical analysis was to be based. This research used the survey method to collect the required data from rice farm-households from all seven climatic zones in Bangladesh using multi-stage random sampling technique. The chapter presented the questionnaire design, sampling procedure, the study areas and procedure followed in the field while administering the survey. The questionnaire used to collect the data was structured and finalized through a pilot survey before being used in the final survey. The total number of farm-households surveyed by the researcher was 432 during the period of October 2015 to February 2016.

The chapter summarised the main characteristics of the sample and some statistics about the collected data. The average farm size of the households was 2.35 acres with the largest farm size being 13.6 acres and the smallest being 0.22 acres. Around 56% of farms were owner-occupiers and the remaining 44% were tenant farmers who had no farm land or the majority of their farm land was rented. Although majority of the farmers had access to formal agricultural extension advice and agricultural credit, 30% and 41% were still not getting these services respectively. Moreover, only 34% of the farm households had regular access to advance weather information and 29% are did not have access to electricity facility. Similarities between different statistics of this survey data and the available national statistics evidenced the representativeness of the data for Bangladesh.

The empirical analysis of the impact of climate variables on net revenue, yield and cost of production of Aman rice were undertaken in Chapter 4. To assess the impact of climate change, temperature and rainfall corresponding to the whole growth period (July-December) of Aman rice as well as the three growth stages (July-August as sowing stage, September-October as flowering stage, and November-December as ripening period) were considered by taking the mean values of those months' climate values. Using these two specification of climate variables, separate regression for each was undertaken on each of the interested dependent variables (i.e. net revenue, yield and cost of production). Farm household level control variables and unobserved regional factors that could confound the climate effects also considered in the regression analysis.

The empirical evidence shows that the changes in temperature and rainfall have no effect on net revenue. However, in the case of quantity of output produced, both the climate variables have mixed impacts at different stages of crop growth (sowing, flowering and ripening). The results are similar in case of cost of production. Temperature increase in the sowing stage contributes to an increase in rice yield as well as cost of production. Although temperature in the ripening stage increase the yield, it has no effect on cost of production. In the case of rainfall, increase in sowing and ripening stage rainfall contribute to both an increase in yield and cost of production. In contrast, both the climate variables in the flowering stage have a decreasing effect on yield but no effect on cost of production.

It is also derived from the findings that although the increase or decrease in yield is because of climate variables, climate variables also have an impact on the increase or decrease in cost of production. Moreover, empirically it is evidenced that the temperature effect is much larger than that of rainfall on both yield and cost of production.

The next empirical chapter, Chapter 5, analysed the extent and determinant of farmers' perception of climate change. The importance of climate change perception to influence agents to take the adaptation decision is not well developed in the literature. Therefore, before the empirical analysis, the importance of perception in the decision making process was explored from a theoretical perspective. Considering both theoretical and empirical evidence, a simple conceptual model of climate change adaptation was developed from an individual farmer's perspective. Based on this framework, determinants of farmers' climate change perceptions were empirically examined.

It is found that the majority of farmers believed that temperature has increased, whereas rainfall has decreased over the years. In most cases, farmers' perceptions were consistent with the meteorological data. It is also found that their perceptions are not spatially correlated. Therefore, it is argued that farmers are independent from the neighbourhood effect regarding their perceptions and it is they themselves who perceived the changes.

The study also identified several factors that are responsible to influence farmers to perceive that the climate is changing. Education and experience show a positive influence on the perception of climate change. It is also found that wealthier farmers are less likely to perceive climate change. However, it is found that access to higher levels of technology and market help farmers to recognize the changes in climate. The results also confirm the importance of agricultural extension, as farmers with extension advice are more likely to perceive the changes in temperature and rainfall.

The third empirical chapter, Chapter 6, investigated farmers' adaptation to climate change. Before the empirical investigation, a conceptual model for farm level adaptation was developed from theoretical and empirical evidence related to climate change adaptation literature. Then the strategies that farmers are taking, the barriers that farmers face while taking adaptation and the factors that affect their decision to adapt were explored.

The majority of the farmers who identified the occurrence of climate change were also aware that their crop production was affected because of the changing climate. Despite having perceived changes in climate as well as their negative effect on crop production, this study also identified that a considerable portion of farmers did not make any adaptations to their farming system in response to climate change. Farmers identified several constrains such as lack of information on both appropriate adaptation and future climate change, lack of credit, lack of irrigation facilities, availability of labour, and lack of irrigation facilities. It can be argued that lack of information about adaptation and climate change limit options to adapt. Lack of credit limits ability to get the necessary resources and technologies to adapt. Finally, farmers' lack of ownership of land, irrigation facilities and labour shortage limit the ability to implement their adaptation decisions. Important adaptation strategies taken by farmers are changing planting and harvesting dates, more irrigation, cultivation of a different crop variety and cultivation of a different rice variety.

Determinants of farmers' adaptation decisions were explored using both simple binary Probit model and the Heckman Probit selection model. Although the results from Heckman Probit model did not show evidence of a sample selection bias, they do support the robustness of the findings. Moreover, the determinants of different adaptation strategies were also explored using the Multinomial Logit Model (MNL). Overall, empirical evidence from both the models indicated that farmer and farm-household characteristics such as education, experience, perception of climate change, access to electricity, tenure status and extension advice have significant positive impact on the adaptation decision. Apart from those impacts, it is also found that farms with highly fertile land and more irrigation facilities are less likely to take an adaptation decision.

The empirical analysis was continued to explore the determinants to overcome barrier related to adaptation. Difficulties related to a particular adaptation strategy are associated cost, lack of information, knowledge, skills and inputs, which may be required to adopt that strategy. Categorising different adaptation strategies in accordance with difficulties, determinants of those adaptation were analysed using Multinomial Logit Model. The results suggest that several factors helped farmers to overcome obstacles or difficulties related to adaptation. The reported empirical analysis indicates that education, experience, extension advice, farm income and credit accessibility are the main factors that help farmers to overcome the obstacles related to climate change adaptation.

7.3 Implications of Findings and Policy Recommendations

The empirical results from this research provide a rich understanding about climate change impact and adaptation issues related to the Aman rice crops in Bangladesh. The findings have important implications for a wider range of stakeholders in developing countries. For researchers, policy-makers and development practitioners, the findings provide new insights into the impact of climate change and adaptation in agriculture. The implications of the findings as well as policy recommendations are discussed below.

From the findings on the climate change situation in Chapter 2, it can be said that the climate of Bangladesh has changed considerably over the last fifty years. This is expected to have an effect on the economy especially on the agricultural sector. Moreover, as the changes are more pronounced in the rainy season compared to the other seasons, crops grown in the rainy season would be more effected than others.

Based in the findings from this chapter, it can also be said that because of its importance in the economy, the agricultural sector needs to be accorded more importance than it is currently receiving from government. Given the vulnerability of the country in the face of climate change, for the development of the agricultural sector consideration should be given to raising the budgetary allocations to improve resilience in the face of climate change effects. More specific policy recommendations are given further in line with the findings related to each empirical chapter in the subsequent paragraph.

Chapter 3 provides a detailed description about the survey procedure and techniques employed to collect data step by step. This provides practical evidence regarding primary data collection for agricultural research in a developing country. The same steps can be followed for collecting data from farm-households in Bangladesh or other developing countries of a similar background for future research.

The empirical results from Chapter 4 on *climate change impact* show that increase in temperature or rainfall do not have any effect on the net revenue but increases both yield and cost of production. The effect of rainfall is similar to but much less in magnitude that the temperature effect. The evidence suggested that to see the impact of climate change, analysis using only net revenue or yield does not provide the real scenario. When we consider the cost of production and compare the results with those of the other impacts then the real effect can be understood.

Several issues then arise here from the policy perspective. The association of climate change impact with cost of production suggests that policy should be focused on the reduction of cost of production related to Aman rice. Although it is a more general suggestion but it can be said that policy should be focused on reducing the cost of important inputs like fertilize, irrigation and labour, so that farmers may reduce the adverse effects of climate change at less cost and consequently increase net benefit. The results here also provide evidence that climate change impact on cost of production varies in each stage of rice crop development (i.e. sowing, flowering and ripening). The inputs required for each stage of rice crop development are different in quantity as well as quality. Policy direction in this respect has to ensure the proper use of those inputs to reduce cost as on effect of climate change. In this respect, farmers' training as well as extension advice need to be available to them.

As the effect of temperature is more than that of rainfall, adaptation related to reducing the effect of temperature should be prioritised. For instance, the temperature tolerant rice varieties, if available, should be promoted to farmers. Moreover, future agricultural research should focus on the development of rice varieties that are more temperature tolerant. Apart from that, other adaptation options that are suitable for temperature increase should be given priority and promoted them among farmers.

The findings from Chapter 5 on *farmers' perceptions of climate change* provide a rich understanding about farmers' perceptions on climate change. An important element of any policy is to understand how farmers would respond to climate change and the basis for this understanding would be farmers' prevailing perception to climate change. The results from this study would help policy makers to anticipate the effects of a policy from management and planning perspective. Moreover, the empirical results showing the determinants of farmers' perception might help policy makers to understand where and how to intervene. Overall, these results will help policy makers to make sure that farmers are well aware of climate change risk and ready to take actions in the form of adaptation to reduce the impact of climate change.

Several policy recommendations can be suggested from the findings of this chapter. It is found that a considerable portion of farmers, around 40%, who did not have any opinion, or their perceptions on changes in climate variables, temperature and rainfall, were inconsistent with the actual meteorological data. Therefore, in general, the policy focus needs to ensure that all farmers understand climate change and the associated potential risks. There is a need to provide scientific information about climate change from different sources like climate science, agricultural science, social science, to influence farmers' perceptions about climate change risks. In this respect, extension workers may need to be trained to convey climate change information to farmers.

The empirical results from this chapter also suggest that several variables influence, some positively and some negatively, farmers' perceptions of climate change. Among different variables, agricultural extension advice plays a positive role in enhancing farmers' perceptions about climate change. Therefore, availability of agricultural extension advice to farmers needs to be ensured. More specifically, targeted and farmer-specific extension advice needs to be provided to specific farmer groups to enrich their climate change understanding. In this respect, provision of extension advice should be targeted towards less educated and less experienced farmers. The results also suggest the need for extension advice provision to large farmers, farmers with a higher proportion of land having irrigation facilities and farmers who have less access to credit facilities.

Moreover, factors identified in this research as affecting the perception of climate change are related to infrastructure and institutions in general. More specifically, there should be a policy focus on improving education facilities, electricity facilities, extension advice and credit facilities to farmers.

The findings from the last empirical chapter, Chapter 6, on *rice farmers' adaptation to climate change* provide insights into farmers' adaptation issues that help us to refine our current knowledge related to farm level adaptation for developing countries. Specifically, the findings from this chapter helps policy makers to understand the current state regarding farm level adaptation and associated problems in Bangladesh. Moreover, these will ultimately help policy makers to identify where to intervene and how, to facilitate farm level adaptation to reduce the impact of climate change.

The findings show that although farmers were aware of the crop damage being caused through climate change, a considerable proportion of them had not adopted an adaptation strategy. This finding indicates that there is need for a policy intervention to promote farmers' adaptation to climate change. Important adaptation strategies used by farmers in Bangladesh are changing planting and harvesting date, more irrigation, cultivation of different crop varieties and cultivation of a different rice variety. It seems that the adaptations are mainly autonomous (strategies taken by farmers themselves) and not planned. In terms of production perspective, it seems that farmers are taking strategies mainly to escape adverse climate conditions through crop management practices. Strategies that transform the production system, like switching to a different rice/crop variety, or changing cropland to agro-forestry are very less. Moreover, suitability of these strategies in the changed climate has to be checked and policy actions should be taken to promote those accordingly.

The empirical results indicate that several farmer and farm-household characteristics such as education, experience, perception to climate change, access to electricity and tenure status, influence farmers' adaptation decision. Therefore, improved education system, electricity infrastructure and farmers' property rights should be addressed in policy to facilitate climate change adaptation. Moreover, the results also revealed that institutional factors such as access to extension advice and advance weather information enhance farmers' adaptation decision. Therefore, policies should give importance to the role of extension services in providing information about appropriate adaptation strategies and climate information.

Several obstacles are identified here that are faced by farmers while in taking adaptations. Important obstacles are lack of knowledge about appropriate adaptation, lack of credit, lack of information on future climate change and lack of irrigation facility. From the policy perspective, these barriers need to be removed to facilitate climate change adaptation. The empirical findings also showed that education, extension advice, farm income and credit accessibility are the main factors that helps farmers to overcome the obstacles related to climate change adaptation. The importance of policy direction to improve education, extension advice and credit availability is again supported by these findings.

7.4 Contributions of this Research

This research contributes in several ways to the literature, practice and policymaking. This research uses primary data collected by the researcher himself, using a survey questionnaire from farm-households from seven climatic zones in Bangladesh. The collected data set contains a rich set of information related to farmers' socio-economic conditions, institutional accessibility, cost and production, perception of climate change, the adaptation strategies farmers have so far taken, barriers they face while taking adaptation and so on. This data set is itself a contribution that can be further used for other research latter on.

Previous studies on the impact of climate change estimated the climate change effect on either net revenue (Ricardian approach) of farms or yield of a crop (production function approach). Moreover, in the literature on climate change impact, research on rice crops is very limited. Moreover, to the best of our knowledge, no study has ever been investigated on rice crop considering the Ricardian approach. In the present research, along with these two approaches, climate change effect on cost of production was also estimated. To the best of our knowledge, this study is the first of its kind where climate change impact on agriculture is explored with reference to the cost of production. Therefore, this research contributes to the climate change impact analysis by opening a new avenue of analysis considering the cost of production.

The study on *farmers' perception of climate change* also contribute to knowledge in several ways. A solid foundation for adaptation decisions related to perception was missing in the climate change literature. In this research, a theoretical grounding for the importance of perception of climate change in farmers' adaptation decision was developed using rational agent and behavioural economics literature. Empirical work from this research also contributes to the limited literature on farmers' perception of climate change and its determinants. Moreover, this research is the first of its kind to examine farmers' perception of climate change and its determinants in the context of Bangladesh. Apart from these, the research focuses on rice farmers. In this respect, this research is also the first of its kind where rice farmers' perceptions of climate change and its determinants are analysed.

This research also contributes to the literature on adaptation to climate change. The empirical work on farmers' adaptation here is done considering a particular crop, the rice crop. In this respect, consideration of rice farmers' adaptation strategies, the barriers they face and factors influencing their decision to adapt is very limited in the literature. This study then adds to the existing knowledge on rice farmers' adaptation literature. Moreover, although there is some literature on the factors that determine farmers' adaptation strategy, so far there has been no study on the determining factors for overcoming the obstacles involved with adaptation strategies. The empirical work on farmers' adaptation in the present research has investigated the determinants to overcome the obstacles related to adaptation strategies. As a contribution of this study, this research is the first of its kind where factors that help to overcome the obstacles related to adaptation strategies are explored.

Overall, this research contributes to the literature on climate change impact on agriculture and farmers' adaptation in developing countries. Moreover, this research is conducted in the context of Bangladesh, which is one of the most vulnerable countries in the world in the face of climate change. Therefore, the contribution of this research is not only to the knowledge (i.e. related to climate change impact, perception of climate change and adaptation to climate change) related to developing countries but also for Bangladesh specifically.

7.5 General Limitations and Suggestions for Future Research

This research is not free from limitations and the main limitation is related to the data used. The data used here are from a farm-household level survey conducted in 28 villages. These villages are situated in 14 sub-districts in 7 districts (two in each district) in Bangladesh. The intention was to cover all seven climatic zones in Bangladesh with fair representation of the data, taking into account the duration feasible for a PhD thesis and the cost involved. Overall, it is acknowledged here that the study sample is limited when compared to the 544 sub-district in 64 district in Bangladesh. Moreover, the climate data used here are district level which is a general limitation for most of developing countries where one weather station covers a wide geographical area. If the survey data had covered more villages from more districts and sub-districts then it would have been better.

One of the results from climate change impact estimates shows that temperature increase in the sowing and flowering stages increases the cost of production. Future research can be done on the detailed composition of the inputs' cost. Further investigation can show the effect of climate change on the cost associated with different inputs. Furthermore, investigation on prices of inputs as well as availability of those inputs can be a research agenda for future.

The present research particularly focused on Aman rice, which is a rain-fed crop. Another rice crop, Boro, which is an irrigated crop is also grown in Bangladesh. Similar types of investigation can be done in future considering the Boro rice crop. In addition, it would be valuable to conduct separate studies on important non-rice crops such as on jute, potato, wheat, vegetables and others, as well as studies on non-crop such as on livestock and fishery. With all these, a more comprehensive understanding of the impact of climate change on agriculture as well as adaptation issues can be gained for Bangladesh, which will have some relevance to other developing countries.

Several adaptation options were found in this research that had already taken by farmers in Bangladesh. Future research can be undertaken to investigate the suitability of these adaptations from an economic point of view in accordance with climate change. Particularly, the effect of a particular adaptation on the cost of production as well as on the net revenue can be a new avenue of research for the future.

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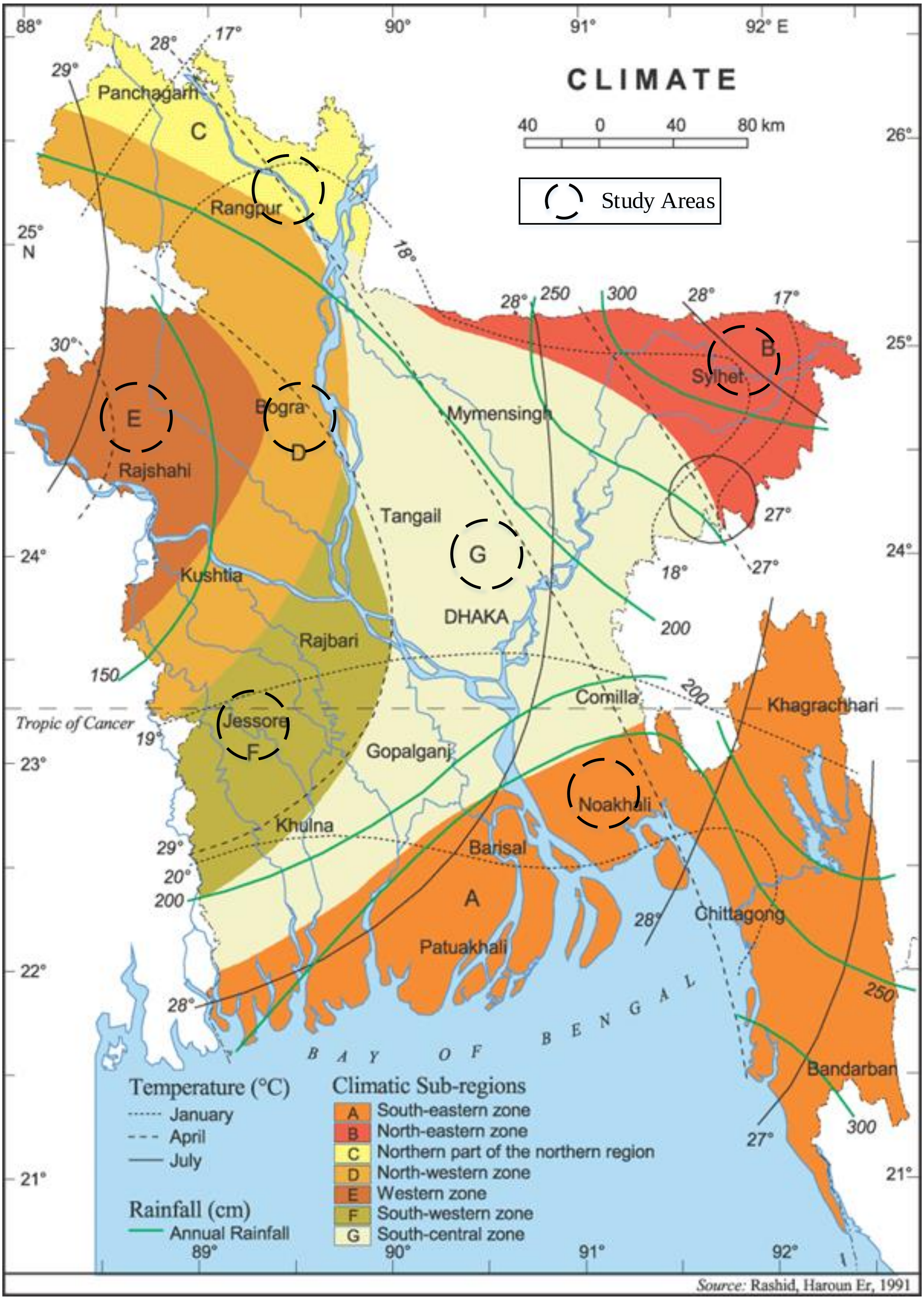
Appendices

Appendix 1: Map of Bangladesh showing climate zones and the study areas



Source: Rashid (1991)) (http://www.poribesh.com/Maps/Climate.htm, Accessed [27/01/ 2015])

Appendix 2: Detailed description of data collection in the field

This study was in Bangladesh. The whole procedure started from the first week of August 2015. First, I finalized my questionnaire from the preliminary questionnaire and then embarked on the final survey. The preliminary questionnaire included questions related to farmers' socio-economic conditions, perceptions about the climate change and its impact on their production, cost of production and revenue.

There were eight sections in the questionnaire: household's general information, socio-economic information, farm characteristics, institutional accessibility, farmers' perceptions, farmers' adaptation, cost of production and quantity produce of farm and household's total yearly income. In order to finalize the questionnaire, I discussed those with several academics and experts involved in agricultural research or with farmers, to identify any ambiguity in the questionnaire as well as obtain their suggestions. The academics were from the University of Rajshahi, Bangladesh and the experts were the Upazila Agriculture Officer (UAO), and Sub Assistant Agricultural Officer (SAAO) from Godagari Upazila, in Rajshahi district, Bangladesh. Their suggestions were incorporated in the preliminary questionnaire. Then this questionnaire was tested on the same type of respondent, proposed by this research in the field, as a pilot survey, where I interviewed 20 farmers. Based on the outcome, the questionnaire was modified by accommodating new questions as well as removing some irrelevant ones. Through this process finally the questionnaire was ready for collecting data from farmers.

The final survey for the data collection was done from October 2015 to February 2016 and I personally did it, visiting each and every places, interviewing each and every farmer. A multi-stage random sampling technique was used for selecting the respondent farmers for this research. In the first stage the seven districts were selected purposively from the seven climatic zones, one from each climatic zone, in accordance with the climate data availability. Then in the second stage, two sub-districts were randomly selected from each district. For selecting the respondent farmers the Upazila Agriculture Extension Office was the key point at this stage. For the convenience of their work the Upazila Agriculture Extension Office divide the area into several blocks and in each block there are several villages. One block from these several blocks and inside that block two villages were selected subsequently and randomly from each sub-district. Farmers from each village were then randomly selected from the list of farmers available to the concerned SAAO. A standard random numbers table was used to conduct the random sampling.

I first contacted with the selected district agricultural office from where I got the address for the selected Upazila Agriculture Office. From the Upazila Agriculture Office I got the information about the blocks as well as villages in that particular selected Upazila. The Agriculture Officers at each and every level whom I needed to contact were very helpful and gave me all sorts of support at their disposal. At this point if I did not mention this then it would be very ungrateful on my part. Before going to their place I communicate with them and they were very kind and supportive to what I needed. The Upazila Agriculture Officers even helped me to find a place to stay, as I had to stay there for several days during my data collection in the villages.

When I get the names from the list of farmers kept with the SAAO, I went to the village to do the interviews. As all the places and peoples were new to me, I had to look for location as well as the farmer by asking whoever I found on my way. At the beginning, I would locate one farmer first, then do interview with him and later go to the next one. I faced several difficulties at this stage. Firstly, it was difficult to find the farmers from my list. Although the list contained their names, father's name and address, but there was no house numbers/names or any other particular location indicators to identify their houses. Consequently, when I asked people about someone through their names, sometimes I was been directed to a wrong people because of similarities of names. After going there to the location I was told, when I checked with the farmer's father's name, I found that he was not the person I was looking for. Secondly, when I was looking for someone, asking other people about him attracted a lot of attention from the other people. Although they helped me to locate the person I was looking for, they also stayed nearby while I did the interviews. Of course, I separated the person during the interview from the others and I had to ask for that very politely, because only if the respondent was alone would be answer freely, without bias, and be comfortable to give his answer, which is very important for research. Thirdly, after finishing an interview, when going to the next ones sometimes found that the house was far away, but near to one I did visited earlier. All these problems took lot of time and effort collecting my data. I decided to change my strategy to locate the farmers and complete the interviews in a more quickly and in the best possible way.

First I talked to the concerned SAAO regarding the location of the village, how to get there, and a rough idea about the houses of the farmers I was looking for. I also asked him whether or not there was a school in the village. Moreover, I also asked for someone he might know in the village who could help me to locate the farmers on my list. I did not take the SAAO with me to the village, as it might have given the wrong impression about me to the farmers. They might think my data collection was related with government and so I might not get the real data. I had to be very careful about that also. In most of the cases, I talked with the headmaster of the school located in the village. Sometimes I also obtained help from the owner of any shop selling agricultural inputs (like fertilizer and pesticides) in the village. When I visited them they understood the purpose of my visit and cordially helped me to locate the farmer. In this way I was able to locate my farmers very easily. I talked with them, explained the purpose of my visit, and asked for their time. When I revisited the farmers at the agreed time I found them more prepared and comfortable about talking to me.

When I first met the farmers, in most cases they were very co-operative and cordially agreed to give an interview. There were some instances, however, when I was not greeted well at the beginning. Different types of questions they asked and some individuals showed a dismissive attitude towards me. In these cases, I had to talk with them a bit longer and answered all their questions very calmly and politely. Once I explaining the purpose of my visit, where I come from, what type of information I required and what I would do with it, they were happy and their attitude changed. I am happy to say that not a single person refused to give me an interview and they even apologised for their early mistrust. Sometimes they even offered homemade cookies as a gesture of apology.

Other difficulties I faced during the field visits were related to transport, food and accommodation. In rural areas, at the sub-district level, there are no hotels. Usually I stayed in the Upazila Rest House, maintained by the Upazila Nirbahi Officer (UNO). The Upazila Agriculture Officers helped me to arrange this for which I am really grateful. So, for each sub-district I made the sub-district headquarter my base and each day I went to the respective village and came back in the evening. No shop to buy food is available in the villages, so during the interviews I always had to carry some snacks with me. Sometimes, I had to do the interviews very early in the morning or in the evening because of the farmer's convenience. In those cases, getting transport to go or come back was difficult. In most cases I had to walk a long distance. Moreover, in some cases, the respondent arranged an appointment but when I got there he was not home or had urgent work to do so, I had to wait or visit him again later on.

Picture 1: Some photos of the researcher during the field survey

Walking to the village road

Interviewing at the back-yard of the house

Interview beside the house

Interview inside the house

Interview near field beside the house

Interview inside the house

Picture 2: Informal talk after the interview with the farmers and others

During the interview, it was one to one correspondence. In case of data, I asked the question and I wrote their response and marked in the questionnaire immediately. Always the interview was in a place where no one around apart from the respondent and me. In case of the production and cost data some maintained record in the notebook or some kept the buying slips or some said from their memory. Sometimes, other member of the family (like son or brother) who is educated kept the record of expenses. In that case, for that part, their involvement also allowed but that is at the last part of the interview. In this way, the data collection was done to its best possible way to have accurate and unbiased data from the farmers.

Appendix 3: The overview of the survey data

Zone/District	No. of Sub-district the district have	Name of the Selected Sub-districts	No. of Blocks the sub-district has	No. of Villages the selected block has	Name of selected villages	Total Farmers in the village	Sample taken from each village	Total sample
A Noakhali	9	Companiganj	25	6	Manikpur	109	16	32
					Sirajpur	107	16	
		Kabirhat	14	5	Malipara	96	14	28
					Rajurgaon	92	14	
B Sylhet	12	Gowainghat	27	7	Pokas	111	17	34
					Abdulmahal	110	17	
		Kanaighat	28	6	Dargimati	103	15	30
					Bisnopur	97	15	
C Kurigram	9	Nageshwari	33	4	Baniapara	93	14	28
					Koiyapara	90	14	
		Ulipur	30	5	Gorai Panchpir	102	15	30
					Jharbhanga	98	15	
D Bogra	12	Sonatola	22	4	Mundumala	136	20	40
					Chocknondon	130	20	
		Dupchanchia	20	4	Alohali	132	20	40
					Dimshohor	135	20	
E Rajshahi	9	Godagari	29	5	Tilibari	116	17	34
					Gonigram	112	17	
		Tanor	23	4	Pachondor	107	16	32
					Chuniapara	105	16	
F Jessor	8	Abhaynagar	25	4	Arpara	105	16	32
					Digholia	104	16	
		Keshabpur	28	6	Baisa	107	16	32
					Mojidpur	104	16	
G Gagipur	5	Kapasia	33	8	Chinaduli	67	10	20
					Borhor	66	10	
		Sripur	32	7	Kewa	65	10	20
					Tongra	67	10	
Total								432

Appendix 4: Table (in full) from Chapter 4

Table 4.5: Models considering the climate variables for whole Aman rice growth period (Dependant variable: log of Aman rice net revenue)

VARIABLES	1	2	3	4	5	6
Temp	-	-			-	-
Temp sq.		-				-
Rain			-	-	-	-
Rain sq.				-		-
Temp*fsize	-0.00169	0.00139			-0.0142	-0.00162
	(0.00587)	(0.00597)			(0.0138)	(0.0356)
Temp sq. * fsize		-5.52e-05				8.84e-06
		(0.000208)				(0.00116)
Rain * fsize			4.90e-07	5.02e-05	-8.95e-06	4.78e-05
			(3.77e-06)	(3.02e-05)	(9.86e-06)	(9.27e-05)
Rain sq. * fsize				-1.59e-08		-1.54e-08
				(9.62e-09)		(2.35e-08)
Experience	0.00142	0.00142	0.00141	0.00144	0.00144	0.00144
	(0.000989)	(0.000989)	(0.000980)	(0.000985)	(0.00101)	(0.00101)
Education	0.000544	0.000544	0.000537	0.000451	0.000515	0.000453
	(0.00203)	(0.00203)	(0.00203)	(0.00202)	(0.00201)	(0.00203)
HH agri. Labour	0.0108	0.0108	0.0108	0.0109	0.0108	0.0109
	(0.00646)	(0.00646)	(0.00647)	(0.00649)	(0.00645)	(0.00650)
Farm size	0.0430	-	-0.00572	-0.0410*	0.412	-
	(0.168)		(0.00458)	(0.0204)	(0.403)	
Fertility of land	0.0269***	0.0269***	0.0269***	0.0270***	0.0269***	0.0270***
	(0.00342)	(0.00342)	(0.00342)	(0.00343)	(0.00342)	(0.00345)
Tenure status	-0.00879	-0.00879	-0.00874	-0.00884	-0.00864	-0.00883
	(0.0169)	(0.0169)	(0.0169)	(0.0168)	(0.0169)	(0.0168)
Ext. advice	0.00931	0.00931	0.00935	0.00914	0.00896	0.00912
	(0.0163)	(0.0163)	(0.0163)	(0.0164)	(0.0165)	(0.0164)
Climate info.	0.00160	0.00160	0.00155	0.00142	0.00185	0.00144
	(0.0162)	(0.0162)	(0.0162)	(0.0163)	(0.0163)	(0.0161)
Credit facility	0.00661	0.00661	0.00667	0.00597	0.00641	0.00597
	(0.0133)	(0.0133)	(0.0132)	(0.0136)	(0.0135)	(0.0136)
Irrigation facility	-0.000193	-0.000193	-0.000193	-0.000204	-0.000195	-0.000204
	(0.000234)	(0.000234)	(0.000233)	(0.000236)	(0.000236)	(0.000237)
Constant	10.09***	10.09***	10.09***	10.09***	10.09***	10.09***
	(0.0349)	(0.0349)	(0.0350)	(0.0347)	(0.0351)	(0.0350)
Model Summary						
Observations	432	432	432	432	432	432
R-squared	0.777	0.777	0.777	0.777	0.777	0.777
Adj. R-squared	0.7680	0.7681	0.7680	0.7677	0.7676	0.7671
AIC	-545.4953	-545.4971	-545.4671	-543.8581	-543.6385	-541.8584
BIC	-496.6742	-496.6760	-496.6460	-490.9685	-490.7490	-484.9004

Note: "-" denotes as omitted because of collinearity. Standard errors are in parentheses; *** p<0.01, ** p<0.05, * p<0.1; Regression results for log of net revenue of Aman rice is shown here. Climate variables are temperature and rainfall for the Aman rice complete growing period. Different columns show the different possible combinations of climate variables to cover all possible functional relationships between net revenue and climate. In columns 1 & 2 only the temperature variable is considered but they use linear and quadratic form respectively. Column 3 & 4 are like the previous two but here, instead of temperature only the rainfall variable is also considered. In columns 5 & 6 the temperature and rainfall variables are both considered with linear and quadratic forms respectively.

Table 4.6: Models considering the climate variables for three phases of Aman rice growth period (Dependant variable: log of Aman rice net revenue)

VARIABLES	1	2	3	4	5	6
Temp: sow	-	-			-	-
Temp: sow sq.		-				-
Temp: flower	-	-			-	-
Temp: flower sq.		-				-
Temp: ripe	-	-			-	-
Temp: ripe sq.		-				-
Rain: sow			-	-	-	-
Rain: sow sq.				-		-
Rain: flower			-	-	-	-
Rain: Flower sq.				-		-
Rain: ripe			-	-	-	-
Rain: ripe sq.				-		-
Temp: sow * fsize	-0.0159	-1.141			0.0441*	-4.346***
	(0.0140)	(1.117)			(0.0195)	(0.443)
Temp: sow sq. * fsize		0.0197				0.0717***
		(0.0194)				(0.00742)
Temp: flower * fsize	0.0110	1.229			-0.127***	3.068***
	(0.00830)	(0.972)			(0.0255)	(0.324)
Temp: flower sq. * fsize		-0.0220				-0.0556***
		(0.0175)				(0.00586)
Temp: ripe * fsize	-0.0111	-0.0589			0.0247**	2.202***
	(0.00980)	(0.301)			(0.00697)	(0.212)
Temp: ripe sq. * fsize		0.00122				-0.0514***
		(0.00705)				(0.00492)
Rain: sow * fsize			8.55e-05***	0.000456***	0.000161***	-0.000232***
			(1.40e-05)	(4.05e-05)	(2.85e-05)	(1.94e-05)
Rain: sow sq. * fsize				-2.01e-07***		-
				(2.84e-08)		
Rain: flower * fsize			-0.000199***	-0.00119***	-0.000662***	-
			(4.15e-05)	(0.000226)	(9.98e-05)	

Rain: Flower sq. * fsize				9.60e-07**		-
				(2.68e-07)		
Rain: ripe * fsize			-0.000476***	-0.00185*	0.00128**	-
			(8.67e-05)	(0.000839)	(0.000380)	
Rain: ripe sq. * fsize				2.58e-05		-
				(1.49e-05)		
Experience	0.00143	0.00143	0.00139	0.00142	0.00142	0.00142
	(0.00102)	(0.00101)	(0.000999)	(0.00101)	(0.00101)	(0.00101)
Education	0.000567	0.000542	0.000468	0.000362	0.000362	0.000362
	(0.00205)	(0.00204)	(0.00204)	(0.00203)	(0.00203)	(0.00203)
HH agri. Labour	0.0111	0.0114	0.0113	0.0114	0.0114	0.0114
	(0.00627)	(0.00638)	(0.00639)	(0.00638)	(0.00638)	(0.00638)
Farm Size	0.387	-	0.0348***	0.141**	1.884***	-
	(0.420)		(0.00898)	(0.0552)	(0.186)	
Fertility of land	0.0268***	0.0266***	0.0260***	0.0260***	0.0260***	0.0260***
	(0.00327)	(0.00312)	(0.00318)	(0.00319)	(0.00319)	(0.00319)
Tenure status	-0.00916	-0.00885	-0.00846	-0.00876	-0.00876	-0.00876
	(0.0168)	(0.0169)	(0.0170)	(0.0169)	(0.0169)	(0.0169)
Ext. advice	0.00887	0.00891	0.00993	0.00971	0.00971	0.00971
	(0.0165)	(0.0167)	(0.0167)	(0.0168)	(0.0168)	(0.0168)
Climate info.	0.00187	0.00152	0.00166	0.00184	0.00184	0.00184
	(0.0164)	(0.0163)	(0.0162)	(0.0163)	(0.0163)	(0.0163)
Credit facility	0.00618	0.00682	0.00795	0.00693	0.00693	0.00693
	(0.0134)	(0.0138)	(0.0133)	(0.0138)	(0.0138)	(0.0138)
Irrigation facility	-0.000203	-0.000222	-0.000218	-0.000228	-0.000228	-0.000228
	(0.000230)	(0.000239)	(0.000240)	(0.000241)	(0.000241)	(0.000241)
Constant	10.09***	10.10***	10.10***	10.10***	10.10***	10.10***
	(0.0353)	(0.0345)	(0.0357)	(0.0363)	(0.0363)	(0.0363)
Model Summary						
Observations	432	432	432	432	432	432
R-squared	0.778	0.778	0.778	0.779	0.779	0.779
Adj. R-squared	0.7673	0.7665	0.7681	0.7668	0.7668	0.7668
AIC	-542.1745	-538.8641	-543.7295	-538.4795	-538.4796	-538.4783
BIC	-485.2165	-473.7693	-486.7716	-469.3163	-469.3163	-469.3151

Note: "-" denotes as omitted because of collinearity. Standard errors are in parentheses; *** p<0.01, ** p<0.05, * p<0.1 ; This table is like Table 4.5 but here the climate variable is for three growth phases of Aman rice. See the explanation in the note for Table 4.5.

Table 4.8: Models considering the climate variables for whole Aman rice growth period
(Dependant variable: log of Aman rice yield)

VARIABLES	1	2	3	4	5	6
Temp	-	-			-	-
Temp sq.		-				-
Rain			-	-	-	-
Rain sq.				-		-
Temp*fsize	-0.0132	0.0127			0.0392	0.0371
	(0.0135)	(0.0133)			(0.0376)	(0.108)
Temp sq. * fsize		-0.000453				-0.00109
		(0.000472)				(0.00351)
Rain * fsize			1.14e-05	-0.000185*	3.73e-05*	-0.000240
			(7.40e-06)	(9.22e-05)	(1.87e-05)	(0.000272)
Rain sq. * fsize				6.26e-08*		7.50e-08
				(3.03e-08)		(6.93e-08)
Experience	0.00326*	0.00326*	0.00325**	0.00313**	0.00317*	0.00316*
	(0.00134)	(0.00134)	(0.00132)	(0.00127)	(0.00136)	(0.00135)
Education	0.00511*	0.00511*	0.00517*	0.00551*	0.00523*	0.00553*
	(0.00258)	(0.00258)	(0.00258)	(0.00258)	(0.00256)	(0.00261)
HH agri. Labour	-0.00655	-0.00656	-0.00649	-0.00695	-0.00662	-0.00695
	(0.0115)	(0.0115)	(0.0116)	(0.0118)	(0.0116)	(0.0118)
Farm size	0.370	-	-0.0202	0.119*	-1.171	-
	(0.379)		(0.0154)	(0.0597)	(1.092)	
Fertility of land	0.0226**	0.0226**	0.0226**	0.0224**	0.0227**	0.0224**
	(0.00892)	(0.00891)	(0.00896)	(0.00896)	(0.00896)	(0.00887)
Tenure status	0.0110	0.0110	0.0107	0.0111	0.0104	0.0113
	(0.0252)	(0.0252)	(0.0252)	(0.0256)	(0.0256)	(0.0262)
Ext. advice	0.0429	0.0429	0.0433	0.0441	0.0444	0.0436
	(0.0237)	(0.0237)	(0.0238)	(0.0237)	(0.0229)	(0.0226)
Climate info.	0.00842	0.00841	0.00818	0.00871	0.00735	0.00934
	(0.0190)	(0.0190)	(0.0188)	(0.0190)	(0.0191)	(0.0204)
Credit facility	-0.0137	-0.0137	-0.0136	-0.0108	-0.0129	-0.0108
	(0.0204)	(0.0204)	(0.0202)	(0.0192)	(0.0206)	(0.0190)
Irrigation facility	-3.62e-06	-3.81e-06	-1.06e-06	4.37e-05	6.40e-06	4.73e-05
	(0.000368)	(0.000368)	(0.000373)	(0.000363)	(0.000366)	(0.000372)
Constant	3.779***	3.779***	3.778***	3.775***	3.778***	3.774***
	(0.0623)	(0.0623)	(0.0630)	(0.0626)	(0.0643)	(0.0635)
Model Summary						
Observations	432	432	432	432	432	432
R-squared	0.656	0.655	0.656	0.659	0.657	0.659
Adj. R-squared	0.6414	0.6414	0.6420	0.6440	0.6417	0.6433
AIC	-309.4605	-309.4273	-310.1526	-311.6847	-308.9063	-309.8687
BIC	-260.6394	-260.6062	-261.3315	-258.7952	-256.0168	-252.9108

Note: "-" denotes as omitted because of collinearity. Standard errors are in parentheses; *** p<0.01, ** p<0.05, * p<0.1; Regression results for log of yield of Aman rice are shown here. Climate variables are temperature and rainfall for the whole Aman rice growing period. Different columns show the different possible combinations of climate variables to cover the full possible range of functional relationships between net revenue and climate. In columns 1 & 2 the temperature variable only is considered but using linear and quadratic form respectively. Columns 3 & 4 are just like the previous two but here instead of temperature, only the rainfall variable is considered. In columns 5 & 6 the temperature and rainfall variables are both considered with linear and quadratic form respectively.

Table 4.9: Models considering the climate variables for three phases of Aman rice growth period (Dependant variable: log of Aman rice yield)

VARIABLES	1	2	3	4	5	6
Temp: sow	-	-			-	-
Temp: sow sq.		-				-
Temp: flower	-	-			-	-
Temp: flower sq.		-				-
Temp: ripe	-	-			-	-
Temp: ripe sq.		-				-
Rain: sow			-	-	-	-
Rain: sow sq.				-		-
Rain: flower			-	-	-	-
Rain: Flower sq.				-		-
Rain: ripe			-	-	-	-
Rain: ripe sq.				-		-
Temp: sow * fsize	-0.0472	-4.174			0.718***	-11.27***
	(0.0388)	(2.180)			(0.0549)	(0.468)
Temp: sow sq. * fsize		0.0707				0.186***
		(0.0379)				(0.00780)
Temp: flower * fsize	0.0264	2.494			-0.948***	6.565***
	(0.0257)	(1.908)			(0.0805)	(0.399)
Temp: flower sq. * fsize		-0.0438				-0.118***
		(0.0343)				(0.00719)
Temp: ripe * fsize	-0.0287	2.459***			0.225***	7.465***
	(0.0303)	(0.645)			(0.0201)	(0.266)
Temp: ripe sq. * fsize		-0.0579***				-0.174***
		(0.0152)				(0.00619)
Rain: sow * fsize			0.000242**	0.00215***	0.00128***	-0.000513***
			(8.16e-05)	(0.000143)	(7.19e-05)	(2.80e-05)
Rain: sow sq. * fsize				-1.10e-06***		-
				(7.40e-08)		
Rain: flower * fsize			-0.000533**	-0.00806***	-0.00425***	-

			(0.000179)	(0.000414)	(0.000289)	
Rain: Flower sq. * fsize				7.40e-06***		-
				(4.15e-07)		
Rain: ripe * fsize			-0.00125*	-0.0116***	0.0137***	-
			(0.000639)	(0.00105)	(0.00119)	
Rain: ripe sq. * fsize				0.000194***		-
				(1.78e-05)		
Experience	0.00328*	0.00312*	0.00318*	0.00310*	0.00310*	0.00310*
	(0.00139)	(0.00132)	(0.00132)	(0.00131)	(0.00131)	(0.00131)
Education	0.00517	0.00571*	0.00498*	0.00531*	0.00531*	0.00531*
	(0.00272)	(0.00265)	(0.00249)	(0.00256)	(0.00256)	(0.00256)
HH agri. Labour	-0.00582	-0.00583	-0.00515	-0.00590	-0.00590	-0.00590
	(0.0112)	(0.0113)	(0.0110)	(0.0112)	(0.0112)	(0.0112)
Farm Size	1.247	-	0.0898**	1.286***	1.479**	-
	(1.224)		(0.0336)	(0.0717)	(0.467)	
Fertility of land	0.0224**	0.0211*	0.0201*	0.0198*	0.0198*	0.0198*
	(0.00901)	(0.00880)	(0.00899)	(0.00912)	(0.00912)	(0.00912)
Tenure status	0.00990	0.0105	0.0114	0.0107	0.0107	0.0107
	(0.0256)	(0.0267)	(0.0261)	(0.0267)	(0.0267)	(0.0267)
Ext. advice	0.0421	0.0431	0.0450	0.0449	0.0449	0.0449
	(0.0218)	(0.0233)	(0.0236)	(0.0237)	(0.0237)	(0.0237)
Climate info.	0.00885	0.0110	0.00831	0.0117	0.0117	0.0117
	(0.0205)	(0.0216)	(0.0213)	(0.0218)	(0.0218)	(0.0218)
Credit facility	-0.0148	-0.00967	-0.0102	-0.00943	-0.00943	-0.00943
	(0.0205)	(0.0177)	(0.0173)	(0.0176)	(0.0176)	(0.0176)
Irrigation facility	-3.18e-05	1.64e-05	-7.13e-05	2.76e-06	2.77e-06	2.80e-06
	(0.000364)	(0.000343)	(0.000379)	(0.000344)	(0.000344)	(0.000345)
Constant	3.779***	3.776***	3.786***	3.782***	3.782***	3.782***
	(0.0683)	(0.0687)	(0.0679)	(0.0696)	(0.0696)	(0.0696)
Model Summary						
Observations	432	432	432	432	432	432
R-squared	0.658	0.666	0.664	0.670	0.670	0.670
Adj. R-squared	0.6419	0.6494	0.6482	0.6523	0.6524	0.6523
AIC	-308.2295	-315.3883	-315.8251	-318.1324	-318.1338	-318.1210
BIC	-251.2715	-250.2934	-258.8671	-248.9692	-248.9706	-248.9578

Note: "-" denotes as omitted because of collinearity. Standard errors are in parentheses; *** p<0.01, ** p<0.05, * p<0.1 ; This table is like the same as Table 4.8 but here the climate variable is for the three phases of Aman rice growing. See the explanation at the below of Table 4.8 in note section.

Table 4.11: Models considering the climate variables for whole Aman rice growth period (Dependant variable: log of Aman rice cost of production)

VARIABLES	1	2	3	4	5	6
Temp	-	-			-	-
Temp sq.		-				-
Rain			-	-	-	-
Rain sq.				-		-
Temp*fsize	-0.105*	0.107*			-0.0852	0.406***
	(0.0488)	(0.0501)			(0.0888)	(0.0879)
Temp sq. * fsize		-0.00372*				-0.0131***
		(0.00175)				(0.00285)
Rain * fsize			7.04e-05	-0.000355	1.39e-05	-0.00110***
			(3.75e-05)	(0.000374)	(8.49e-05)	(0.000260)
Rain sq. * fsize				1.36e-07		3.03e-07***
				(1.18e-07)		(6.93e-08)
Experience	0.000955	0.000955	0.000742	0.000467	0.000921	0.000858
	(0.00203)	(0.00203)	(0.00197)	(0.00192)	(0.00189)	(0.00187)
Education	0.0124**	0.0124**	0.0126**	0.0133**	0.0125**	0.0137**
	(0.00482)	(0.00481)	(0.00485)	(0.00540)	(0.00481)	(0.00546)
HH agri. Labour	-0.0823**	-0.0823**	-0.0826**	-0.0836**	-0.0824**	-0.0837**
	(0.0242)	(0.0242)	(0.0241)	(0.0251)	(0.0242)	(0.0258)
Farm size	3.014*	-	-0.0628	0.239	2.439	-
	(1.398)		(0.0414)	(0.265)	(2.627)	
Fertility of land	0.0113	0.0113	0.0115	0.0112	0.0113	0.0101
	(0.0123)	(0.0123)	(0.0123)	(0.0123)	(0.0122)	(0.0125)
Tenure status	0.0361	0.0361	0.0353	0.0362	0.0359	0.0395
	(0.0526)	(0.0526)	(0.0521)	(0.0525)	(0.0520)	(0.0524)
Ext. advice	0.0512	0.0512	0.0541	0.0558	0.0517	0.0486
	(0.0445)	(0.0445)	(0.0451)	(0.0452)	(0.0464)	(0.0456)
Climate info.	-0.0122	-0.0122	-0.0144	-0.0132	-0.0126	-0.00468
	(0.0401)	(0.0402)	(0.0405)	(0.0383)	(0.0399)	(0.0363)
Credit facility	-0.0289	-0.0290	-0.0270	-0.0210	-0.0286	-0.0202
	(0.0179)	(0.0179)	(0.0200)	(0.0195)	(0.0188)	(0.0183)
Irrigation facility	0.00221**	0.00221**	0.00223**	0.00233***	0.00221**	0.00237***
	(0.000613)	(0.000611)	(0.000613)	(0.000611)	(0.000626)	(0.000622)
Constant	8.977***	8.977***	8.976***	8.969***	8.976***	8.961***
	(0.124)	(0.124)	(0.128)	(0.120)	(0.126)	(0.105)
Model Summary						
Observations	432	432	432	432	432	432
R-squared	0.628	0.628	0.627	0.631	0.628	0.640
Adj. R-squared	0.6127	0.6125	0.6119	0.6152	0.6118	0.6230
AIC	225.8297	226.0609	226.7999	223.9975	227.7713	216.0985
BIC	274.6508	274.8820	275.6210	276.8870	280.6609	273.0565

Note: "-" denotes as omitted because of collinearity. Standard errors are in parentheses; *** p<0.01, ** p<0.05, * p<0.1 ; Regression results for log of cost of Aman rice are shown here. Climate variables are temperature and rainfall for the whole Aman rice growing period. Different columns show the different possible combinations of climate variables to cover all possible functional relationships between cost of production and climate. In columns 1 & 2 the temperature variable only is considered but using linear and quadratic form respectively. Columns 3 & 4 are like the previous two but here instead of temperature, the rainfall variable is considered. In columns 5 & 6 the temperature and rainfall variables are both considered with linear and quadratic form respectively.

Table 4.12: Models considering the climate variables for three phases of Aman rice growth period (Dependant variable: log of Aman rice cost of production)

VARIABLES	1	2	3	4	5	6
Temp: sow	-	-			-	-
Temp: sow sq.		-				-
Temp: flower	-	-			-	-
Temp: flower sq.		-				-
Temp: ripe	-	-			-	-
Temp: ripe sq.		-				-
Rain: sow			-	-	-	-
Rain: sow sq.				-		-
Rain: flower			-	-	-	-
Rain: Flower sq.				-		-
Rain: ripe			-	-	-	-
Rain: ripe sq.				-		-
Temp: sow * fsize	0.0214	2.441			1.230***	8.036***
	(0.0655)	(2.077)			(0.0702)	(1.163)
Temp: sow sq. * fsize		-0.0450				-0.136***
		(0.0360)				(0.0194)
Temp: flower * fsize	-0.124	-5.569**			-1.430***	-8.779***
	(0.0705)	(1.842)			(0.0763)	(0.879)
Temp: flower sq. * fsize		0.0994**				0.158***
		(0.0330)				(0.0159)
Temp: ripe * fsize	0.0358	4.205***			0.364***	0.258
	(0.0474)	(0.720)			(0.0230)	(0.547)
Temp: ripe sq. * fsize		-0.0979***				-0.00607
		(0.0168)				(0.0127)
Rain: sow * fsize			-0.000179	0.00217***	0.00155***	0.000405***
			(0.000163)	(5.65e-05)	(9.31e-05)	(5.09e-05)
Rain: sow sq. * fsize				-1.31e-06***		-
				(2.56e-08)		
Rain: flower * fsize			0.000764*	-0.00863***	-0.00493***	-

			(0.000382)	(0.000357)	(0.000290)	
Rain: Flower sq. * fsize				9.01e-06***		-
				(4.40e-07)		
Rain: ripe * fsize			-0.000189	-0.00925***	0.0227***	-
			(0.00104)	(0.00200)	(0.00115)	
Rain: ripe sq. * fsize				0.000176***		-
				(3.46e-05)		
Experience	0.00112	0.000856	0.00116	0.000872	0.000872	0.000872
	(0.00194)	(0.00191)	(0.00194)	(0.00190)	(0.00190)	(0.00190)
Education	0.0124**	0.0135**	0.0129**	0.0138**	0.0138**	0.0138**
	(0.00503)	(0.00536)	(0.00518)	(0.00536)	(0.00536)	(0.00536)
HH agri. Labour	-0.0835**	-0.0859**	-0.0839**	-0.0859**	-0.0859**	-0.0859**
	(0.0254)	(0.0256)	(0.0255)	(0.0257)	(0.0257)	(0.0257)
Farm Size	2.118	-	-0.188**	1.289***	-2.956***	-
	(1.469)		(0.0738)	(0.116)	(0.579)	
Fertility of land	0.0112	0.0114	0.0130	0.0124	0.0124	0.0124
	(0.0123)	(0.0127)	(0.0130)	(0.0127)	(0.0127)	(0.0127)
Tenure status	0.0395	0.0380	0.0379	0.0379	0.0379	0.0379
	(0.0528)	(0.0528)	(0.0531)	(0.0530)	(0.0530)	(0.0530)
Ext. advice	0.0480	0.0494	0.0467	0.0480	0.0480	0.0480
	(0.0462)	(0.0469)	(0.0460)	(0.0472)	(0.0472)	(0.0472)
Climate info.	-0.00861	-0.00262	-0.00839	-0.00319	-0.00319	-0.00319
	(0.0377)	(0.0368)	(0.0371)	(0.0370)	(0.0370)	(0.0370)
Credit facility	-0.0275	-0.0246	-0.0296	-0.0248	-0.0248	-0.0248
	(0.0173)	(0.0192)	(0.0166)	(0.0193)	(0.0193)	(0.0193)
Irrigation facility	0.00226**	0.00248***	0.00232***	0.00249***	0.00249***	0.00249***
	(0.000644)	(0.000561)	(0.000620)	(0.000555)	(0.000555)	(0.000555)
Constant	8.972***	8.957***	8.963***	8.953***	8.953***	8.953***
	(0.114)	(0.0972)	(0.108)	(0.0948)	(0.0948)	(0.0948)
Model Summary						
Observations	432	432	432	432	432	432
R-squared	0.632	0.643	0.636	0.644	0.644	0.644
Adj. R-squared	0.6151	0.6246	0.6190	0.6245	0.6245	0.6245
AIC	225.0839	216.1394	220.7087	217.2881	217.2871	217.2834
BIC	282.0419	281.2342	277.6666	286.4513	286.4504	286.4466

Note: "-"denotes as omitted because of collinearity. Standard errors are in parentheses; *** p<0.01, ** p<0.05, * p<0.1 : This table is like Table 4.11 but here the climate variable is for three growth phases of Aman rice. See the explanation in the footnote for Table 4.11.

Appendix 5: Table (in full) from Chapter 5

Table 5.6: Determinant of correctly perceived changes in summer temperature and rainy season rainfall

Independent variables						
	Temperature		Rainfall		Both	
	Coefficient	Marginal effect	Coefficient	Marginal effect	Coefficient	Marginal effect
Farmer's Characteristics						
Education	0.118**	0.0161**	0.140*	0.00987*	0.140**	0.0161**
Experience	0.0294**	0.00401**	0.0645***	0.00455***	0.0328*	0.00376*
Group	-0.217	-0.0297	-0.0867	-0.00611	-0.194	-0.0222
Household's Characteristics						
Own labour	-0.0495	-0.00676	-0.191	-0.0134	-0.0867	-0.00995
Electricity	0.813**	0.111**	0.841	0.0593	1.134***	0.130***
Literacy	0.0335	0.00458	0.000413	0.0000292	-0.105	-0.0120
Household Asset	0.555**	0.0759**	0.480	0.0338	0.409	0.0469
Agri. Income	0.115	0.0157	0.584	0.0412	0.219	0.0251
Non-agri. Income	-0.0440	-0.00601	-0.112	-0.00787	0.0133	0.00152
Farm Characteristics						
Farm size	-0.177	-0.0242	-0.340**	-0.0239**	-0.216	-0.0247
Fertility of land	0.133	0.0183	-0.343	-0.0242	-0.0843	-0.00967
Tenure Status	0.163	0.0222	0.198	0.0139	-0.116	-0.0133
Livestock	0.669*	0.0915*	0.579	0.0408	0.581	0.0667
Farm Asset	-0.0240	-0.00328	-0.378	-0.0266	-0.305	-0.0350
Institutional Accessibility						
Extension advice	0.732**	0.100**	0.932*	0.0657*	0.107	0.0123
Weather info	-0.109	-0.0149	0.280	0.0198	0.166	0.0190
Credit	0.555**	0.0759**	0.276	0.0195	0.739**	0.0848**
Irrigation	-0.00265	-0.000362	-0.0138*	-0.000977*	-0.00769	-0.000882

Market	-0.0833	-0.0114	-0.146	-0.0103	-0.224	-0.0257
Zones						
Zone B	0.338	0.0521	0.281	0.0289	0.959*	0.153*
Zone C	0.272	0.0425	0	0	0	0
Zone D	0.634	0.0922	1.197*	0.0991	1.144**	0.177**
Zone E	0.867	0.120	0.450	0.0445	0.719	0.120
Zone F	1.277**	0.161**	-6.022***	-0.780***	-4.616***	-0.614***
Zone G	-0.937	-0.172*	-6.884***	-0.804***	-5.245***	-0.629***
Constant	-1.736		0.880		-0.390	
Observations	432		374		374	
Percent correctly predicted	80.79		91.18		83.16	
Wald Chi-square (25)	66.64***		122.49***		105.45***	
Log pseudolikelihood	-184.93		-90.24		-136.1488	
Pseudo R^2	0.1734		0.6293		0.4695	

Note: *** p<0.01, ** p<0.05, * p<0.1 ; The econometric estimates of the logit regression model for perception are shown here considering three correct perception variables. To create the correct perception variables, the meteorological data evidence for each zone is used. Whatever directional change the meteorological evidence shows (shown in Figure 5.6 and Figure 5.7) farmers' perception in that direction is taken as a *correct perception* for each zone for each variable (summer temperature as *temperature* and rainfall in the rainy season as *rainfall*). The *both* variable is where both *temperature* and *rainfall* are perceived correctly. Overall, the results indicate that some explanatory factors are related to all three categories of climate change perceptions and some are relevant only to a certain category. The explanatory variables that are statistically significant at least at the 10% level are education, experience, electricity, household assets, farm size, extension advice, credit and irrigation. *Farm size* and proportion of land that has *irrigation* facilities are only negatively related to climate change perception apart from all those significant variables. The zone/district fixed effect is considered using the dummy variable. The estimated models have pseudo R^2 value of 0.17, 0.63 and 0.47 with quite high Wald Chi-square value significant at the 1% level. The models are also able to predict around 81, 91 and 83 per cent of the dependent variable correctly. All these statistics imply that the model used here is quite reliable and appropriate.

Appendix 6: Table (in full) from Chapter 6

Table 6.4: Determinant of adaptation decision: Probit model

Explanatory variables	Independent variable: Adaptation decision			
	Coefficient	S.E	Marg. Effect	S.E
Farmer's Characteristics				
Education	0.197***	(0.0315)	0.0291***	(0.00403)
Experience	0.0559***	(0.0116)	0.00824***	(0.00162)
Group	0.441	(0.298)	0.0651	(0.0433)
Household Characteristics				
Household's own labour	-0.0297	(0.0956)	-0.00438	(0.0141)
Household has electricity	0.476**	(0.220)	0.0703**	(0.0321)
Number of literate members	0.0332	(0.0695)	0.00489	(0.0103)
Household's asset	-0.0521	(0.156)	-0.00769	(0.0230)
Household's Agri. income	-0.0521	(0.209)	-0.00768	(0.0308)
Household's Non-agricultural income	-0.0962	(0.100)	-0.0142	(0.0147)
Farm Characteristics				
Farm size	-0.0338	(0.0913)	-0.00499	(0.0135)
Fertility of land	-0.670***	(0.117)	-0.0989***	(0.0156)
Tenure status	0.252	(0.211)	0.0372	(0.0308)
Livestock owned	0.173	(0.283)	0.0254	(0.0416)
Farm asset	-0.115	(0.118)	-0.0170	(0.0174)
Extension advice	1.193***	(0.212)	0.176***	(0.0277)
Weather info	-0.0392	(0.228)	-0.00578	(0.0336)
Credit	-0.132	(0.214)	-0.0194	(0.0313)
Irrigation	-0.0113***	(0.00404)	-0.00166***	(0.000588)
Market	-0.0389	(0.0780)	-0.00574	(0.0115)
Perceive climate change	1.025***	(0.226)	0.151***	(0.0305)
Zone				
Zone B	-0.108	(0.380)	-0.0158	(0.0553)
Zone C	0.567	(0.397)	0.0736	(0.0529)
Zone D	0.307	(0.445)	0.0418	(0.0606)
Zone E	0.0692	(0.431)	0.00982	(0.0614)
Zone F	-0.346	(0.418)	-0.0527	(0.0627)
Zone G	-1.091**	(0.434)	-0.187***	(0.0715)
constant	-1.251	(0.765)		
Observations	432			
Percent correctly predicted	87.04			
Wald Chi-square (26)	163.26***			
Log likelihood	-115.86			
Pseudo R^2	0.5478			

Note: *** p<0.01, ** p<0.05, * p<0.1; This table shows the result of Probit model coefficient and marginal effect for farmers' adaptation decision. The coefficient shows the direction of probability and the marginal effect indicates the marginal change on the probability, while dy/dx is for discrete change of dummy variable from 0 to 1. It is seen that education, experience, electricity facility, fertility of land, extension advice, irrigation facility and perception of climate change have influence on farmers adaptation decision (statistically significant at least 5%). Among these factors, fertility of the land and irrigation facilities (proportion of land have irrigation facility) are only negatively related to adaptation decision. Perception about climate change is positively related to adaptation decision and statistically significant at 1% level.

Table 6.5: Adaptation Determinant: Heckman Probit Selection Model

	Adaptation decision		Perception as selection model	
	Coefficient	S.E	Coefficient	S.E
Farmer's Characteristics				
Education	0.219***	(0.0562)	0.0546**	(0.0269)
Experience	0.0689***	(0.0196)	0.0150*	(0.00837)
Group	0.915**	(0.364)	-0.0696	(0.236)
Household Characteristics				
Household's own labour	-0.0217	(0.117)	0.00114	(0.0729)
Household has electricity	0.379	(0.448)	0.569***	(0.178)
Number of literate members	-0.00554	(0.0829)	0.0190	(0.0552)
Household's asset	-0.0708	(0.237)	0.265**	(0.135)
Household's Agri. income	0.0887	(0.294)	0.141	(0.161)
Household's Non-agricultural income	-0.107	(0.130)	-0.00948	(0.0940)
Farm Characteristics				
Farm size	0.0394	(0.119)	-0.103	(0.0709)
Fertility of land	-0.767***	(0.161)	0.0483	(0.0900)
Tenure status	0.393	(0.274)	0.133	(0.160)
Livestock owned	0.577	(0.411)	0.454**	(0.220)
Farm asset	-0.262*	(0.154)	-0.0727	(0.104)
Institutional Accessibility				
Extension advice	1.202***	(0.380)	0.331*	(0.182)
Weather info	0.0766	(0.263)	-0.00238	(0.187)
Credit	-0.158	(0.312)	0.299*	(0.175)
Irrigation	-0.0110**	(0.00542)	-0.00161	(0.00327)
Market	-0.213**	(0.0925)	-0.0279	(0.0594)
Zone				
Zone B	0.522	(0.545)	0.313	(0.306)
Zone C	0.668	(0.579)	0.297	(0.344)
Zone D	-0.0792	(0.643)	0.509*	(0.301)
Zone E	0.0165	(0.566)	0.327	(0.352)
Zone F	-0.292	(0.678)	0.774**	(0.337)
Zone G	-1.117*	(0.625)	-0.391	(0.337)
constant	-0.615	(1.994)	-1.192*	(0.667)
Total Observations	432			
Censored	104			
Uncensored	328			
Wald Chi-square (26)	76.03***			
Wald Chi-square (independent equations)	0.00, *P*=0.9459			

Note: *** p<0.01, ** p<0.05, * p<0.1; this table shows the results for the Heckman Probit model for adaptation. It may argued that adaptation to climate change is a two-step process where in the first step farmers require to perceive a change in climate and then in the second step they would act through adaptation. In that case, standard probit model would be inappropriate to explain the factors affect the adaptation to climate change (shown in table 6.4). That is why here the Heckman probit model is used to test the two-step process as well as the appropriateness of the model use. The results show that although the likelihood function of the overall model is significant (Wald Chi-square=76.03, with P < 0.001) but does not show any correlation among the error terms of outcome and selection models (indication of sample selection problem). The rho is not significantly different from zero (Wald Chi-square=0.00, with P = 0.9459). Although the results here does not shows the superiority of the model than the standard probit model (shown in table 6.4) but it can shows the robustness of the analysis to explain climate change adaptation.

Table 6.7: Multinomial Logit Model Estimation for Different Adaptation

Independent variable	Dependant variable: adaptation strategies									
	More inputs for all crops		Changing planting date		Different rice varieties		Different crop varieties		Agro-forestry	
	Coefficient	Marg. effect	Coefficient	Marg. effect	Coefficient	Marg. effect	Coefficient	Marg. effect	Coefficient	Marg. effect
Farmer's Characteristics										
Education	0.345***	0.0034	0.290***	-0.00487	0.521***	0.00721**	0.440***	0.0204***	0.392***	0.002
Experience	0.149***	0.00746***	0.0878***	-0.000404	0.0305	-0.00191	0.0987***	7.82E-07	0.167***	0.00303**
Group	0.393	-0.0502	1.292*	0.0983	0.957	0.00548	0.728	-0.0197	1.684	0.0379
Household's Characteristics										
Own labour	-0.0804	-0.0116	0.0230	0.00144	0.383	0.0126	0.0693	0.0121	-0.281	-0.0129
Electricity	0.978*	0.0164	1.205**	0.0628	1.171	0.0136	1.206**	0.0594	-0.764	-0.0718**
Literacy	-0.0166	-0.00167	-0.00253	0.000628	-0.153	-0.00491	0.0200	0.0054	-0.0222	-0.000521
Household Asset	-0.145	-0.00454	0.0273	0.0314	-2.575**	-0.0818**	-0.00191	0.0292	-0.0407	0.00743
Agri. Income	0.220	0.0595**	-0.178	0.0158	-2.904*	-0.0885*	-0.396	-0.027	-0.0117	0.014
Non-agri. Income	-0.229	-0.0055	-0.398	-0.0383	0.160	0.0104	-0.294	-0.0196	0.638*	0.0352***
Farm Characteristics										
Farm size	-0.144	-0.0208	0.0153	-0.00107	0.560	0.0179	0.0630	0.0093	-0.0435	-0.00326
Fertility of land	-1.238***	-0.0092	-1.472***	-0.0596***	-1.182***	-0.00149	-1.294***	-0.00968	-1.829***	-0.0259*
Tenure Status	0.815*	0.0343	0.674	0.0231	-0.146	-0.0208	0.871*	0.0583	-0.517	-0.0464*
Livestock	0.0564	-0.0424	0.110	-0.0505	1.349	0.0332	0.932	0.110*	-0.0381	-0.0203
Farm Asset	-0.0394	0.0207	-0.595**	-0.0760**	0.841*	0.0344**	-0.180	0.00417	-0.162	-0.000241
Institutional Accessibility										
Extension advice	2.038***	-0.109	1.726***	-0.171	2.171**	-0.0349	2.443***	-0.116	18.28	0.657
Weather info	0.618	0.0886**	-0.528	-0.0840*	-0.670	-0.0205	-0.230	-0.0354	0.961	0.0437*
Credit	-0.272	-0.0207	-0.444	-0.058	-0.608	-0.0167	0.149	0.059	0.292	0.0184

Irrigation	-0.0126	0.000751	-0.0302***	-0.00223***	-0.00465	0.000412	-0.0262***	-0.00142	0.00172	0.000863
Market	0.0301	0.0204	-0.193	-0.0138	0.0866	0.00699	-0.229	-0.021	-0.165	-0.002
Climate Change Perception										
Temperature change	2.493***	0.108**	2.084***	0.0797	0.808	-0.0246	1.887***	0.0199	1.052	-0.0295
Rainfall change	0.647	-0.0818	1.992**	0.137	1.855	0.0186	1.262	-0.0186	2.761*	0.0616
Zone										
B	-1.925*	-0.243***	-0.0815	0.0192	16.41	0.128*	-0.0656	0.0429	15.89	0.0282
C	1.133	-0.182	2.832**	0.111	1.679	-1.49E-08	2.909**	0.207	16.94	0.00846
D	-0.455	-0.178**	1.198	0.109	-3.399	-4.23E-08	0.759	0.0523	17.67	0.0595**
E	-1.004	-0.158*	-0.375	-0.0105	15.60	0.0726**	-0.700	-0.0836	18.46	0.155***
F	-0.492	-0.191*	1.944	0.274**	15.42	0.0347	-0.236	-0.136	18.19	0.0802
G	-2.177*	-0.238**	0.483	0.204*	-2.727	-3.93E-08	-2.513*	-0.197**	18.19	0.174*
Constant	-6.231***		-3.223*		-25.50		-5.791***		-41.01	
Base Category	No Adaptation									
LR Chi-square	533.13***									
Log likelihood	-440.174									
Pseudo R^2	0.3772									

N= 432; *** p<0.01, ** p<0.05, * p<0.1

This table shows the estimations of multinomial logit model (MNL) coefficient and marginal effect for different adaptation strategies. The model was tested for the validity of the independent of the irrelevant alternatives (IIA) assumptions using the Hausman test for IIA. The test result did not show any evidence to reject the null hypothesis of independence of adaptation strategies (Chi-square ranges from 6.65 to 17.54, with probability values ranging from 0.68 to 0.88). This result suggesting that MNL specification used here is appropriate to model adaptation strategies. Moreover, the likelihood ratio statistics as shown by Chi-square statistics is highly significant, indicating that the model is quite a good fit with strong explanatory power. The coefficient estimates of MNL model provide only the direction of the effect due to the change in independent variable on the particular dependant variable (adaptation strategy). It does not represent any magnitude. For that, the marginal effect is useful, which provide the expected change in probability of a particular adaptation strategy choice due to the change in an explanatory variable. Here the reference category is the *no adaptation* choice and results are comparable with this base category for all the adaptation strategies.

Table 6.9: Estimated for selecting adaptation of different obstacles using MNL model

Independent variable	Dependant variable: adaptation strategies in accordance with cost					
	Less obstacle		Medium obstacle		High obstacle	
	Coefficient	Marg. effect	Coefficient	Marg. effect	Coefficient	Marg. effect
Farmer's Characteristics						
Education						
Illiterate						
Primary	0.749	-0.00842	1.260**	0.0847	1.092*	0.0546
Secondary	2.380***	0.0136	2.823***	0.115*	3.048***	0.166**
Secondary+	3.579***	-0.00369	3.950***	0.0944	4.652***	0.284***
Experience						
<= 15 years						
16-25 years	1.416	-0.0181	2.882**	0.188**	2.286**	0.101
25+ years	3.450***	0.103	3.877***	0.139**	3.917***	0.175**
Group	1.280*	0.0790	0.753	-0.0149	0.984	0.0215
Household's Characteristics						
Own labour	0.0385	-0.000710	-0.0469	-0.0167	0.119	0.0201
Electricity	0.933**	0.0621	0.726	0.0273	0.537	-0.0261
Literacy	0.119	-0.00259	0.129	0.0000476	0.196	0.0152
Household Asset	-0.0723	0.0150	-0.369	-0.0420	-0.126	0.00963
Agri. Income	-0.0174	-0.0146	0.359	0.0569*	-0.0557	-0.0326
Non-agri. Income	-0.154	-0.0332	0.0285	0.000965	0.147	0.0329
Farm Characteristics						
Farm size	-0.0276	0.00277	-0.130	-0.0169	-0.0123	0.00882
Fertility of land	-1.231***	-0.0540**	-0.968***	-0.0102	-1.105***	-0.0303
Tenure Status	0.670	0.0172	0.640	0.0151	0.704*	0.0256
Livestock	-0.0294	-0.0303	0.0333	-0.0182	0.355	0.0582
Farm Asset	-0.611**	-0.0720**	0.00890	0.0430*	-0.211	0.00704

Institutional Accessibility						
Extension advice	1.834***	-0.00287	1.891***	0.0182	2.557***	0.164***
Weather info	-0.563	-0.105**	0.335	0.0633	0.154	0.0415
Credit	-0.452	-0.0577	-0.334	-0.0371	0.125	0.0750*
Irrigation	-0.0221***	-0.00184**	-0.00207	0.00186**	-0.0172**	-0.00115
Market	-0.0865	-0.0149	0.147	0.0291*	-0.0555	-0.0132
Climatic change Perception						
Perceive correctly both temperature & rainfall	2.421***	0.144**	1.743***	0.0270	1.734***	-0.00196
Climatic Settings						
Dry climate						
Moderate	1.184*	0.141*	0.659	0.0316	0.0761	-0.120
Good climate	-0.796	-0.0245	-0.279	0.0622	-1.015	-0.101
Constant	-2.671		-5.758***		-4.895**	
Base Category	No Adaptation					
LR Chi-square	347.24***					
Log likelihood	-421.035					
Pseudo R^2	0.29					

Note: For some categories values are missing indicates as the reference category among all other relevant categories; *N*= 432, *** p<0.01, ** p<0.05, * p<0.1; This table shows the estimated coefficients and marginal effects for different adaptation in accordance with obstacle. All the adaptation strategies (five adaptation strategies shown in Figure 6.7) are categorize into three classes: low, medium and high obstacle adaptation strategies. Although name is given in obstacle term but the categorization is done by considering the cost involve and the difficulties arises regarding information, training, and inputs requirement. The *low obstacle* adaptations are those, which involve less cost as well as easy to adopt, does not require any further knowledge. For instance, c*hanging planting and harvesting date* is the *low obstacle* strategy. For this strategy no extra cost is involved; no extra knowledge, training, information is required. On the other hand, the *high obstacle* adaptations are those where farmers need to spend some times to know and involve more cost. High obstacle adaptations are *different crop variety* and *agro-forestry*. For rice farmers in Bangladesh, switching to different crop variety or agro-forestry is not so easy. For these strategies, farmers need to know the cultivation system, require all the inputs necessary, involve some cost and even require some special training. In the same notion, *more input use* and *different rice variety* are considered as *medium obstacle* adaptation strategy. Taking these strategy involves some cost and knowledge but the intensity is not too high as like high obstacle one. Climatic zone might influence the adaptation choice apart from the difficulties involve. To control for that dummy for climatic settings fixed effects are also used here.

Appendix 7: Derivation of equation 4.13 in Chapter 4

The regression model of equation 4.10 is

$$\log(X_i) = \alpha + \beta_1 T + \beta_2 R + \beta_3 T f_i + \beta_4 R f_i + \sum \gamma_{FH} FH_i + \mathcal{E}_i$$

Marginal impact of temperature is the derivatives of the above equation with respect to *T* become

$$\frac{dlog(X)}{dT} = \beta_1 + \beta_3\, f$$

The farm size (*f*) is in the equation. Therefore, to make it a meaningful interpretation taking expectations on the both side of the equation

$$E\left[\frac{dlog(X)}{dT}\right] = \beta_1 + \beta_3\, E(f) \qquad 4.13$$

This show the marginal impact of temperature evaluated at the average farm size. The interpretation of the result would be percentage change in X due to 1 unit change in temperature for an average farm.

Appendix 8: Derivation of marginal impact for section 4.5.2.1 in Chapter 4

The full empirical model considered for the marginal impact analysis is Model 5 in Table 4.9. The empirical model is

$$\begin{aligned}\log(X) = \alpha &+ \beta_1 T_{sow} + \beta_2 T_{flow} + \beta_3 T_{ripe} + \beta_4 R_{sow} + \beta_5 R_{flow} \\ &+ \beta_6 R_{ripe} + \beta_7 T_{sow}(f) + \beta_8 T_{flow}(f) + \beta_9 T_{ripe}(f) \\ &+ \beta_{10} R_{sow}(f) + \beta_{11} R_{flow}(f) + \beta_{12} R_{ripe}(f) \\ &+ \sum \gamma_{FH} FH + \mathcal{E}\end{aligned}$$

Where X is the yield per acre, T and R are temperature and rainfall respectively, f is the farm size.

The regression results showed that variables related to coefficients β_2 to β_6 are not identified because of correlation between district fixed effects. Therefore the empirical model become

$$
\begin{aligned}
\log(X) = \alpha &+ \beta_7 T_{sow}(f) + \beta_8 T_{flow}(f) + \beta_9 T_{ripe}(f) \\
&+ \beta_{10} R_{sow}(f) + \beta_{11} R_{flow}(f) + \beta_{12} R_{ripe}(f) \\
&+ \sum \gamma_{FH} FH + \mathcal{E}
\end{aligned}
$$

Marginal impact of sowing period temperature on yield is the derivatives of the above equation with respect to T_{sow}. It become

$$\frac{dlog(X)}{dT} = \beta_7\,(f)$$

In the above expression farm size (*f*) is there. Therefore, to make it a meaningful interpretation taking expectations on the both side of the equation

$$E\left[\frac{dlog(X)}{dT_{sow}}\right] = \beta_7\,E(f)$$

The above expression show the marginal impact of sowing period temperature evaluated at the mean firm size.

Therefore, the interpretation of marginal impact result will be for an average farm the percentage change in yield due to 1^0C increase in temperature in sowing period.

The derivation and interpretation of marginal impact for other climate variables (temperature and rainfall for sowing, flowering and ripening phase) will be in the same manner.

Appendix 9: Derivation of marginal impact for section 4.5.3.1 in Chapter 4

The full empirical model considered for the marginal impact analysis is Model 11 in Table 4.12. The empirical model is

$$
\begin{aligned}
\log(X) = \alpha &+ \beta_1 T_{sow} + \beta_2 T_{flow} + \beta_3 T_{ripe} + \beta_4 R_{sow} + \beta_5 R_{flow} \\
&+ \beta_6 R_{ripe} + \beta_7 T_{sow}(f) + \beta_8 T_{flow}(f) + \beta_9 T_{ripe}(f) \\
&+ \beta_{10} R_{sow}(f) + \beta_{11} R_{flow}(f) + \beta_{12} R_{ripe}(f) \\
&+ \sum \gamma_{FH} FH + \mathcal{E}
\end{aligned}
$$

Where X is the cost of production per acre, T and R are temperature and rainfall respectively, f is the farm size.

The regression results showed that variables related to coefficients β_2 to β_6 are not identified because of correlation between district fixed effects. Therefore the empirical model become

$$\begin{aligned}\log(X) = \alpha + \beta_7 T_{sow}(f) + \beta_8 T_{flow}(f) + \beta_9 T_{ripe}(f) \\ + \beta_{10} R_{sow}(f) + \beta_{11} R_{flow}(f) + \beta_{12} R_{ripe}(f) \\ + \sum \gamma_{FH} FH + \mathcal{E}\end{aligned}$$

Marginal impact of sowing period temperature on yield is the derivatives of the above equation with respect to T_{sow}. It become

$$\frac{dlog(X)}{dT} = \beta_7\ (f)$$

In the above expression farm size (*f*) is there. Therefore, to make it a meaningful interpretation taking expectations on the both side of the equation

$$E\left[\frac{dlog(X)}{dT_{sow}}\right] = \beta_7\ E(f)$$

The above expression show the marginal impact of sowing period temperature evaluated at the mean firm size.

Therefore, the interpretation of marginal impact result will be for an average farm the percentage change in cost due to 1^0C increase in temperature in sowing period.

The derivation and interpretation of marginal impact for other climate variables (temperature and rainfall for sowing, flowering and ripening phase) will be in the same manner.

Appendix 10: Questionnaire for Survey on Farm Household

ID	

A. General Information

Date of Interview Taken	
Name of Respondent	
Name of Village, Union, Upazilla	
Name of District	

B. Socio-economic information

1. Is the respondent head of household: [ ] Yes [ ] No
2. Age of the household head (in years):
3. Gender of household head: [ ] Male [ ] Female
4. Year of schooling of the household head (in years):
5. Occupation of the household head

Primary occupation	Secondary occupation
KEY: 1. Farmer; 2. Agricultural Labourer; 3. Service holder; 4. Trader; 5. Other	

6. Household size (in number):
   Adult member (above 15 years of age):
   Child member (under 15 years of age):
   Income earning member:
   Literate member:
7. Does the household have electricity: [ ] Yes [ ] No
8. Household assets

Items	Quantity	Brand	Market value
TV			
Radio			
Mobile Phone			
Motor Cycle			
Bicycle			
Refrigerator			
Other (please specify)			

C. Farm characteristics

9. Farm size

Type of land	Size (in Bigha*)
Own cultivable land	
Rented-in land	
Rented-out land	
Homestead land	

(*1 Bigha = 0.1338 hectare/0.3306 acre)

10. Do you have tenure status? [ ] Yes [ ] No
11. How many of your family members work farm activities?
    Adult members: …………………….. Child member: …………………

12. How long have you been involved in farming (in years)?: …………………years.
13. Major soil type of your farm: [ ] Clay [ ] Clay-loamy [ ] Loamy [ ] Sandy
14. What do you think about the fertility of your farm land:
    [ ] Very fertile [ ] Fertile [ ] Medium fertile [ ] Low fertile
15. What crops (other than rice) grown in your farm over the last 12 months?

Name of the crops	Area cultivated

16. Please state the average yield of these crops in a normal year:

Crop	Normal year average yield (kg per bigha)

17. Do you own any livestock, poultry or other animals?: [ ] Yes [ ] No
    If yes, yearly net income from that. ………………………………………
18. Farm assets

Asset type	Quantity	Price	Value
Tractor			
Power tiller			
Thresher			
Swallow tube-well			
Bullocks power			
Cart			
Other (Please specify)			

19. If this farm (including land, equipment and livestock) were for sale, what is its approximate value?.................................... (If difficult to answer go to next question)

19.1 If you were to purchase a farm identical to yours. What would you have to pay for it? ……………………………

D. Institutional Accessibility

20. Do you get information and advice from extension workers?: [ ] Yes [ ] No
    If yes then which sources?
    [ ] Government [ ] Non-government [ ] other (please specify)
21. If you get any technical assistance and advice from other sources apart from extension workers, from where do you receive the necessary information? ………………….
    (Key: 1=Media; 2=Neighbouring farmer; 3=shopkeepers in village; 4=Others (Please specify); 5=None)
22. Do you get any advance climate (e.g. temperature, rainfall drought and flood) information from any sources? [ ] Yes [ ] No

If yes, then which sources? …………………………………
(Key: 1=Media; 2=Neighbouring farmer; 3= Union Information Centre (UIC), 4=Others (Please specify); 5=None)

23. Do you have access to agricultural credit from Bank or NGOs? [ ] Yes [ ] No
24. Did you borrow agricultural credit over the last 12 months? [ ] Yes [ ] No
If yes, which sources? [ ] Friends/Relatives [ ] Commercial Banks; [ ] Farmer association/co-operative [ ] NGOs [ ] other (please specify).............
25. Does your cultivable land have accessed to irrigation? [ ] Yes [ ] No
If yes, who is the service provider? [ ] Deep-tube well by government agencies
[ ] Own shallow tube-well [ ] other (please specify)
26. What percentage of your cultivable land have accessed to irrigation? ………..%
27. How far is it to the nearest market where you sell your harvest? ....km
28. What transport do you use to get to market? ....
(Key: 1=walk; 2=cart; 3=truck or other motorized vehicle; 4=other (please specify))
29. How far is it to the nearest market where you obtain your inputs? ....km
30. Are you a member of any institutional group/farmers' co-operative/ farmers' society? [ ] Yes [ ] No, If yes, what is the name of the group? ....
If yes, how long have you engaged with this? ....years.

E. Farmers' perceptions

31. Have you noticed any changes in climate since you start cultivating? [ ] Yes [ ] No
If yes, identify the changes

Climate components	Period or season	Increase	Decreased	No change	Do not know
Temperature	Annual				
	Winter				
	Summer				
Rainfall	Annual				
	Winter				
	Summer				
	Rainy Season				
Occurrence of drought	Annual				
Occurrence of flood	Annual				
Severity of heat wave/hot days	Annual				
Severity of cold wave/cold days/foggy days	Annual				
Availability of groundwater	Annual				
Availability of surface water	Annual				
Others, if any (please specify)					

32. Do you think that rice production is damaged due to these changes you identified?
[ ] Yes [ ] No
If yes, what is your opinion on the production loss due to that?

Rice Type	1	2	3	4	5
Aman					
Boro					
Aus					
Overall					

1=Very adversely affected; 2=Adversely affected; 3=Moderately affected; 4=Slightly affected; and 5=Not affected at all.

33. What percentage of your production loss are incurred?

	Aman	Boro	Aus	Overall
% loss				

F. Farmers' adaptation

34. Have you made any changes to your farm operations due to changes that you identified at question 31? [ ] Yes [ ] No ; If yes then from which year? ………………………
35. What are those measures (adjustment) that you have taken to reduce crop yield loss?

Adaptive measures	Please put 1 for main measure and tick (√) for others
More Irrigation	
Cultivation of direct seeded rice	
More Aman rice with supplementary irrigation	
Changing planting and harvesting date	
Conversion of agriculture land into orchard	
Agro-forestry	
Use of different crop varieties for each crop Drought Tolerant Varieties (Bina7/14,Biri28/56) Flood Tolerant Varieties (Bina12)	
Cultivation of pulses	
Cultivation of jute, wheat and other crop	
Others (Please specify)	

36. Please indicate the reasons why you chose the above adaptive measures. (1 = saving cost, 2 = more suitable for the changed climate, 3 = more selling price of crops, 4 = others)

Adaptive measures	Main reasons. If none of the above reasons apply, please write down the specific reasons here.
More Irrigation	
Cultivation of direct seeded rice	
More Aman rice with supplementary irrigation	
Changing planting and harvesting date	
Conversion of agriculture land into orchard	
Agro-forestry	
Use of different crop varieties for each crop Drought Tolerant Varieties (Bina7/14,Biri28/56) Flood Tolerant Varieties (Bina12)	
Cultivation of pulses	
Cultivation of jute, wheat and other crop	
Others (Please specify)	

37. While doing those adaptation, what adjustment do you need to do?

Adjustment to adaptation	Please put 1 for main measure and tick (√) for others
Credit taken from Commercial Bank	
Credit taken from Micro-credit institution	
Credit taken from shopkeeper (input seller)	
Credit taken from friends/relatives	
Sale/mortgage of some land area	
Sales of livestock	
Sales of other assets	
Family members migrated to other areas	
Others (Please specify)	
Nothing	

38. What are your constraints while taking adaptation (that mentioned answering question 34)?

Constraints	Please put 1 for main measure and tick (√) for others
Lack of irrigation facility	
Lack of knowledge about appropriate adaptation	
Lack of information on future climate change	
Lack of credit/saving	
Labour shortage in need	
Lack of own land	
Others (Please specify)	

G. Costs & production of farm, and Household total yearly income

39. Costs and return in some previous production years

Rice	Items	Costs per bigha (in taka)	
		2014-15	2013-14
Aman	Total cultivated land (in bigha)		
	Labour cost		
	Seedbed preparation (1)		
	Pulling of seedling and transplanting (2)		
	Land preparation (3)		
	Weeding (4)		
	Fertilizer application (5)		
	Pesticide application (6)		
	Harvesting (7), Threshing (8), Packing and storage (9)		
	Total labour cost (1-9)		
	Other Input cost		
	Animal power (10)		
	Power tiller (11)		
	Seed (12)		
	Chemical Fertilizer (13)		
	Organic Fertilizer (14)		
	Irrigation (15)		
	Pesticides (16)		
	Others (Please specify) (17)		
	Total other input cost (10-17)		
	Total cost (1-17)		
	Output		
	Production		
	Straw		
	Return		
	Selling price of rice		
	Selling price of straw		
	Gross return		
	Total Net Return		
Boro	Total cultivated land (in bigha)		
	Labour cost		
	Seedbed preparation (1)		
	Pulling of seedling and transplanting (2)		

	Land preparation (3)		
	Weeding (4)		
	Fertilizer application (5)		
	Pesticide application (6)		
	Harvesting (7), Threshing (8), Packing and storage (9)		
	Total labour cost (1-9)		
	Other Input cost		
	Animal power (10)		
	Power tiller (11)		
	Seed (12)		
	Chemical Fertilizer (13)		
	Organic Fertilizer (14)		
	Irrigation (15)		
	Pesticides (16)		
	Others (Please specify) (17)		
	Total other input cost (10-17)		
	Total cost (1-17)		
	Output		
	Production		
	Straw		
	Return		
	Selling price of rice		
	Selling price of straw		
	Gross return		
	Total Net Return		
Aus	Total cultivated land (in bigha)		
	Labour cost		
	Seedbed preparation (1)		
	Pulling of seedling and transplanting (2)		
	Land preparation (3)		
	Weeding (4)		
	Fertilizer application (5)		
	Pesticide application (6)		
	Harvesting (7), Threshing (8), Packing and storage (9)		
	Total labour cost (1-9)		
	Other Input cost		
	Animal power (10)		
	Power tiller (11		
	Seed (12)		
	Chemical Fertilizer (13)		
	Organic Fertilizer (14)		
	Irrigation (15)		
	Pesticides (16)		
	Others (Please specify) (17)		
	Total other input cost (10-17)		
	Total cost (1-17)		
	Output		
	Production		
	Straw		
	Return		
	Selling price of rice		
	Selling price of straw		
	Gross return		
	Total Net Return		
Other Crop mentioned	Total cultivated land (in bigha)		
	Labour cost		

in Q 15 (please specify)	Seedbed preparation (1)		
	Pulling of seedling and transplanting (2)		
	Land preparation (3)		
	Weeding (4)		
	Fertilizer application (5)		
	Pesticide application (6)		
	Harvesting (7), Threshing (8), Packing and storage (9)		
	Total labour cost (1-9)		
	Other Input cost		
	Animal power (10)		
	Power tiller (11)		
	Seed (12)		
	Chemical Fertilizer (13)		
	Organic Fertilizer (14)		
	Irrigation (15)		
	Pesticides (16)		
	Others (Please specify) (17)		
	Total other input cost (10-17)		
	Total cost (1-17)		
	Output		
	Production		
	Straw		
	Return		
	Selling price of rice		
	Selling price of straw		
	Gross return		
	Total Net Return		
Other Crop mentioned in Q 15 (please specify)	Total cultivated land (in bigha)		
	Labour cost		
	Seedbed preparation (1)		
	Pulling of seedling and transplanting (2)		
	Land preparation (3)		
	Weeding (4)		
	Fertilizer application (5)		
	Pesticide application (6)		
	Harvesting (7), Threshing (8), Packing and storage (9)		
	Total labour cost (1-9)		
	Other Input cost		
	Animal power (10)		
	Power tiller (11)		
	Seed (12)		
	Chemical Fertilizer (13)		
	Organic Fertilizer (14)		
	Irrigation (15)		
	Pesticides (16)		
	Others (Please specify) (17)		
	Total other input cost (10-17)		
	Total cost (1-17)		
	Output		
	Production		
	Straw		
	Return		
	Selling price of rice		
	Selling price of straw		
	Gross return		
	Total Net Return		

Other Crop mentioned in Q 15 (please specify)	Total cultivated land (in bigha)		
	Labour cost		
	Seedbed preparation (1)		
	Pulling of seedling and transplanting (2)		
	Land preparation (3)		
	Weeding (4)		
	Fertilizer application (5)		
	Pesticide application (6)		
	Harvesting (7), Threshing (8), Packing and storage (9)		
	Total labour cost (1-9)		
	Other Input cost		
	Animal power (10)		
	Power tiller (11)		
	Seed (12)		
	Chemical Fertilizer (13)		
	Organic Fertilizer (14)		
	Irrigation (15)		
	Pesticides (16)		
	Others (Please specify) (17)		
	Total other input cost (10-17)		
	Total cost (1-17)		
	Output		
	Production		
	Straw		
	Return		
	Selling price of rice		
	Selling price of straw		
	Gross return		
	Total Net Return		

40. Household yearly income:

Income from agricultural sources			*Income from non-agricultural sources*		
Items	Income		Items	Income	
	2014-15	2013-14		2014-15	2013-14
Rice			Service		
Other crops			Business		
Livestock/poultry			Pension		
Fishery			Remittance		
Others (please specify)			Others (please specify)		
Total					

Appendix 11: Correlation Coefficient of Farm-household Variables Included in the Analysis

	AGE	EDU	EXP	HHAL	HHA	HHAI	HHNAI	FS	FA	IR	IM
AGE	1										
EDU	0.1370	1									
	(0.0043)										
EXP	0.8388	-0.0364	1								
	(0)	(0.4508)									
HHAL	0.1411	-0.1638	0.1245	1							
	(0.0033)	(0.0006)	(0.0096)								
HHA	0.1692	0.3667	0.0874	-0.0987	1						
	(0.0004)	(0)	(0.0697)	(0.0404)							
HHAI	0.1349	0.1825	0.0934	0.0179	0.6292	1					
	(0.005)	(0.0001)	(0.0524)	(0.7099)	(0)						
HHNAI	0.1896	0.1627	0.1313	0.0785	0.3417	0.1401	1				
	(0.0001)	(0.0007)	(0.0063)	(0.1034)	(0)	(0.0035)					
FS	0.1811	0.2649	0.1156	-0.0462	0.6838	0.7653	0.1492	1			
	(0.0002)	(0)	(0.0162)	(0.3384)	(0)	(0)	(0.0019)				
FA	0.1624	0.1782	0.1518	0.0003	0.4417	0.4419	0.1027	0.5816	1		
	(0.0007)	(0.0002)	(0.0016)	(0.9954)	(0)	(0)	(0.0328)	(0)			
IR	-0.0663	0.0298	-0.0158	-0.0516	0.0603	-0.0472	0.0829	-0.0252	0.052	1	
	(0.1688)	(0.5374)	(0.7431)	(0.2843)	(0.2109)	(0.328)	(0.0853)	(0.6021)	(0.2805)		
IM	0.1029	0.0939	0.0206	0.0451	0.2103	0.2166	0.0653	0.2725	0.2535	-0.2881	1
	(0.0325)	(0.0512)	(0.6689)	(0.3497)	(0)	(0)	(0.1753)	(0)	(0)	(0)	

HHAL=Household Agricultural Labour, HHA=Household Asset, HHAI=Household Agricultural Income, HHNAI=Household Non-agricultural Income, FS=Farm Size, FA=Farm Asset, IR=Irrigated Land, IM=Input Market; Standard Errors are in the parentheses.