UNIVERSITY OF SOUTHERN QUEENSLAND

Impacts of Climate Change on Rice Production and Farmers' Adaptation in Bangladesh

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A dissertation submitted in fulfilment of the requirements for the

degree of Doctor of Philosophy

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University of Southern Queensland

Toowoomba, Queensland, Australia

October 2012

Abstract

Bangladesh is frequently cited as one of the countries most vulnerable to climate change, despite the country's insignificant contribution to climate change. Crop production, especially rice, the main food staple, is the most susceptible to climate change and variability. Any changes in climate will, thus, increase uncertainty regarding rice production as climate is major cause of year-to-year variability in rice productivity. This thesis is motivated partly by the susceptibility of rice farming to climate change and partly by the limited studies of Bangladesh on this topic. The overall aim of this thesis is, thus, to analyse the impact of climate change on rice production at three levels (aggregate-national, disaggregated-climate zone and micro-farm level), and to evaluate the adaptation strategies practised by farmers in a severely drought-prone area.

At the aggregate level, this thesis first investigated national data from secondary sources to examine changes in maximum temperature, minimum temperature and rainfall over the past 60 years. Results from a linear trend model reveal that the time trend is statistically significant for all three major climate variables. This implies climate has changed over the whole period. However, the findings from quantile regression indicate that the explanatory power of the time trend is higher in the higher quantiles than the lower quantiles for all three climate variables. This latter method thus offers a more complete picture of the changing climate at different points of time. Given these changes in climate and using production function theory, an evaluation of the impacts of changing climate on the yields for three rice crops in Bangladesh: Aus, Aman and Boro, was made. The findings confirm that the changes to both maximum and minimum temperatures are statistically significant for Aus and Boro rice. However, changes to the average minimum temperature are found to affect Aus rice production adversely and the average maximum temperature is also negatively related to Boro rice yield. On the contrary, the impacts of maximum temperature and rainfall are more pronounced for Aman rice compared to minimum temperature whose effects are adverse. Given these adverse effects of temperature on rice crops, policy makers should design strategies for the development and use of temperature tolerant rice varieties. However, this analysis of national level data

is unable to reveal regional level differences in climate and their differential impacts on rice yield which warrants disaggregated level analysis.

Under the theoretical framework of Just-Pope stochastic production function, the objective of the disaggregated level analysis was to assess the effects of climate change on the yield and variability of Aus, Aman and Boro rice using cross-sectional time series (panel) data. The results reveal that maximum temperature is risk increasing for Aus and Aman rice while it is risk decreasing for Boro rice yield. Minimum temperature is risk increasing for Boro rice and risk decreasing for the Aus and Aman varieties. Finally, rainfall is risk increasing for Aman rice whilst risk decreasing for Aus and Boro rice. Moreover, future climate change is expected to increase the variability of rice yield for all three rice crops. Disaggregated level analysis, thus, provided more information than aggregate level analysis. However, the disaggregated level data is unable to show how individual farmers are affected by climate change which necessities a farm level analysis of impact and adaptation.

The farm level analyses employed data from a survey of 550 farm households in a severely drought-prone area of Bangladesh. Descriptive statistics reveal that net revenue and production loss from Aman rice vary between different subsamples of farmers. For example, mean profit was significantly higher for large and medium farmers compared to small and landless farmers while the latter group of farmers faced higher mean production losses. Integrated farms have higher net revenue compared to rice only farms. Moreover, production losses for highly irrigated farms are lower than for less irrigated farms. Further, results from both mean and median regression on the determinants of profit and production loss indicate significant variables that can be targeted to increase profit or decrease production loss. These include age, years of schooling of household head, household yearly total income, household assets, land tenure, access to agricultural extension services, weather information, electricity and subsidy, percentage of land under irrigation, crop selling at local market, and distance to local or nearby urban market. Government policy initiatives should include support for integrated farming, increasing the provision of education, providing regular weather forecasts, giving subsidies to very small and landless farmers, distributing government owned fallow lands to small farmers, and adopting water saving irrigation technologies.

Farmers have taken some adaptation strategies to reduce these adverse effects on rice production. The major adaptation strategies include higher levels of irrigation, cultivation of short-duration rice varieties, changing planting dates, agro forestry, use of different crop varieties and cultivation of non rice crops. Estimates from a multinomial logit model specify that age, gender and education level of household head, household annual total income, household assets, farm size, tenure status, farming experience, access to agricultural credit, availability of subsidies, electricity at home, and farmer-to-farmer extension services all affect adaptation choices. Therefore, policy makers should target these determinants to boost farmers' adaptation and thereby diminish the adverse effects of climate change.

The analytical framework used in this study has produced robust results. It should be replicated in other developing countries experiencing adverse climate change and having similar characteristics to Bangladesh.

Certification of dissertation

I hereby certify that the work embodied in this dissertation is the result of my own research. I also declare that it has not been submitted for a higher degree to any other institution or university.

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Publications from this research

Journal Papers

1. Sarker, MAR, Alam, K, Gow, J (2012), 'Exploring the relationship between climate change and rice yield in Bangladesh: An analysis of time series data', *Agricultural Systems*, vol. 112, pp. 11-16.

2. Sarker, MAR, Alam, K, Gow, J (2012), 'How does the variability of Aus rice yield respond to climate change in Bangladesh?', *Journal of Agronomy and Crop Science* (Accepted).

3. Sarker, MAR, Alam, K, Gow, J (2012), 'Assessing the determinants of rice farmers' adaptation strategies in Bangladesh', *International Journal of Climate Change Strategies and Management*, (Accepted).

4. Sarker, MAR, Alam, K, Gow, J (2012), 'Performance of rain-fed Aman rice yield in Bangladesh in the presence of climate change', *Crop and Pasture Science* (Under review).

Conference Paper

1. Sarker, MAR, Alam, K, Gow, J (2012), 'A comparison of the effects of climate change on Aus, Aman and Boro rice yields in Bangladesh: Evidence from panel data', Proceedings of the 41st Australian Conference of Economists, July 8-11, 2012, Melbourne.

Acknowledgements

Let me take this opportunity to thank Dr Khorshed Alam for being a fantastic principal supervisor throughout my study at the University of Southern Queensland (USQ). He has provided me with thought-provoking comments on each draft of this thesis. Without his encouragement, timely suggestions and proper guidance, it was impossible for me to complete this thesis. I express my sincere gratitude for everything I have learnt from him, and for everything he has done for me.

I express my heartfelt gratitude to my associate supervisor, Professor Jeff Gow, for his productive criticism, thought-penetrating comments and innovative ideas on each draft which were really crucial to the completion of this thesis. I have learnt many things from him. Without his punctuality in looking at my documents, it would have been difficult for me to submit this thesis.

Discussions with Mohammad Alauddin, Associate Professor of Economics at the University of Queensland, provided me with clear guidelines on how I should proceed with the collected data. I thank him for his intellectual instructions and mental support as well. Professor Kevin Parton of Charles Stuart University also deserves sincere thanks for his useful comments on the early draft of my PhD proposal. His comments enriched my way of thinking. Sincere thanks also go to Mann Kim, Assistant Professor of Applied Economics at Utah State University, for his guidelines on the mean and variance functions estimation and some other issues. Advice from Dr Ariful Hoque of Murdoch University has been a great source of inspiration for me in finishing this thesis.

Thanks are due to the Department of Economics, Rajshahi University and the authority of Rajshahi University for granting me study leave. Special thanks go to Professor Mohsin Ali who provided me an office and other support facilities during fieldwork which was truly helpful for data collection and entry. Special thanks are due to Professor Dilip Kumar Nath for his comments on my survey questionnaire and for his support during my study. I appreciate his regular phone calls to discuss my progress. I am forever grateful to him for his humane behaviour towards me and my family in Bangladesh. I am also thankful to Professors Abdur Rahman, Tariq Saiful Islam and Abdul Quiyum for their invaluable advice. I express my gratitude to Professor ANK Noman and Dr Elias Hossain for their ideas on my questionnaire and estimation techniques. I am also thankful to all other teachers and colleagues at the Department of Economics, Rajshahi University.

My wholehearted thanks go to Professors Sanat Kumer Saha and ATM Nurul Amin. They played a pioneering role in facilitating my higher study. Professor Saha helped in organising some issues for this research. It is impossible for me to repay their contribution in my academic career.

Other people whom I wish to thank include Dr Jahanur Rahman, Dr Mallik Akram Hossain, Md. Abdul Khaleque, Bijoy Krishna Banik, Rezaul Karim Bakshi, Kaji Julfikar Ali, Md Shahiduzzaman, Nur Azrin, and Zhen Lu. I am also grateful to the academic and administrative staff, especially Dr Mafiz Rahman, Dr. Shane Zhen, Dr Rasheda Khanam, Liz Whatson and Jean Charlish, of the University of Southern Queensland. Bernard O'Neil deserves special thanks for his proofreading.

Last but not least, sincere thanks to my mother, brothers, sisters, wife and son. The person who would be happiest with the completion of my thesis is my eldest brother who died just prior to the commencement of my PhD study. It will be my regret forever that I cannot see his proud face on my achievement. My beloved wife, Shapla, has sacrificed a lot for me to complete this thesis. She has really been a source of tremendous trust, confidence and encouragement for me. At the end, I beg pardon to my son, Tahmid, for my inability to provide him all of the time he might have wanted from me. I am indebted to you forever.

Dedication

In fond memory of my father, the late Abdul Mazid Sarker and my eldest brother, the late Abdul Khaleque Sarker.

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List of abbreviations and acronyms

ADF	Augmented Dickey Fuller
AEO	Agriculture Extension Officer
AEZ	Agro-ecological Zone
AIC	Akaike Information Criterion
ANOVA	Analysis of Variance
AWD	Alternate Wet and Drying
BADC	Bangladesh Agricultural Development Corporation
BBS	Bangladesh Bureau of Statistics
BCCSAP	Bangladesh Climate Change Strategy and Action Plan
BIC	Bayesian Information Criterion
BMD	Bangladesh Meteorological Department
BMDA	Barind Multipurpose Development Authority
BRRI	Bangladesh Rice Research Institute
CGE	Computable General Equilibrium
cm	centimetre
CO_2	Carbon Dioxide
CV	Coefficient of Variation
DAE	Department of Agricultural Extension
DOE	Department of Environment
DTW	Deep Tube Well
FAO	Food and Agriculture Organisation
FGLS	Feasible Generalised Least Squares
GCM	General Circular Model
GDP	Gross Domestic Product
GOB	Government of Bangladesh
HBT	High Barind Tract

HYVs	High yielding varieties
IFPRI	International Food Policy Research Institute
IIA	Independent of Irrelevant Alternatives
IPCC	Intergovernmental Panel on Climate Change
Kg	Kilogram
MLE	Maximum likelihood estimates
mm	millimetre
MNL	Multinomial logit
MNP	Multinomial probit
MOEF	Ministry of Environment and Forest
NAPA	National Adaptation Programmes of Actions
NGOs	Non-Government Organisations
OLS	Ordinary least squares
PP	Philips and Perron
ppm	parts per million
PVC	Polyvinyl Chloride
QR	Quantile regression
RRR	Relative risk ratio
SAAOs	Sub-Assistant Agricultural Officers
T. Aman	Transplanted Aman
UNDP	United Nations Development Programme
VIF	Variance Inflation Factor
WB	World Bank

Chapter 1 Introduction, Research Issues and Chapter Outlines

1.1 Background and motivation of this study

Climate change resulting from human activities has emerged as a global concern in the past 20 years. One particular worry is the potentially disastrous consequence for agriculture and food security in many parts of the world, particularly developing countries (FAO 2007; IPCC 2007; Mertz et al. 2009; WB 2010; Kotir 2011). Crop farming is extremely vulnerable to climate change and it has been predicted that climate change will impact negatively on agricultural yield in the 21st century through higher temperatures, more variable rainfall and extreme climate events such as floods, cyclones, droughts and rising sea levels (Molua 2002; Isik & Devadoss 2006; IPCC 2007; WB 2010). This susceptibility of agriculture to climate change has led to the scientific and policy communities questioning the capacity of farmers to adapt (Reid et al. 2007; Mertz et al. 2009). The United Nations Framework Convention on Climate Change also identifies the danger to food production as a major concern (Reid et al. 2007).

Bangladesh is one of the countries most vulnerable to climate change. The main reasons for its vulnerability are due to (i) its location in the tropics, (ii) the dominance of floodplains, (iii) its low elevation from sea level and (iv) its high population density. However, it also has limited adaptive capacities due to poor economic capacities and limited technological competency (MOEF 2005; DOE 2007; Shahid & Behrawan 2008; Pouliotte *et al.* 2009; Hossain & Deb 2011). Extreme climate events like major floods, drought and cyclones occur almost every year, and sometimes more than once a year, affecting the crop agriculture sector adversely, particularly rice production (MOEF 2005; Yamin et al. 2005).

Rice is one of the major crops to feed the world's growing population (Shimono et al. 2010). About 3 billion people consume rice daily. As one of the most common staple foods for humans, it feeds more people than any other crop (Maclean et al. 2002). In Bangladesh, rice production is very important because it is the staple diet of the Bangladeshi people and about half of the rural population is involved in its farming. Rice production needs to increase to meet future population growth. Any decline in rice production through climate change would thus critically impair food security in the country. Therefore, quantifying the effects of climate change on rice farming and assessing the potential of rice farmers to adapt to climate change are urgent research topics.

1.2 Crop agriculture and rice production in Bangladesh

The Bangladesh economy is dominated by the agricultural sector. This includes cropping, livestock, forestry and fishery. Agriculture accounts for almost 25% of gross domestic product (GDP) and almost 66% of the labour force depends on agriculture for employment (GOB 2010).

Crop production dominates Bangladesh agriculture. Crop agriculture accounts for 15% of GDP while livestock, forestry, and fisheries contributed 2.95%, 1.87% and 5.51% respectively in the 2009-10 financial year (GOB 2011). Rice is the dominant crop, and in terms of value adding, it accounts for more than 60% of total crop agriculture value (Asaduzzaman et al. 2010, Yu et al. 2010).

Overall, food grain production plays a central role in the agricultural economy. Almost 80% of the total cropped area is planted with rice which accounts for over 90% of total cereal production (Alauddin & Tisdell 1987; GOB 2009, Asaduzzaman et al. 2010). Given the percentage of the total population dependent on agriculture for their livelihoods and the contribution of agriculture to the GDP, it can be said that crop agricultural development is a key strategy in the economic development of Bangladesh into the foreseeable future.

Aman (mainly transplanted Aman or T. Aman) and Boro rice are the main crops. Aman is a rain-fed monsoon crop while Boro rice is a completely irrigated variety. The other main variety, Aus, is both directly seeded and transplanted under rain-fed or limited irrigated conditions and grown in the very hot summer season (Rahman et al. 2009). However, rain-fed farmers are the most vulnerable to climate change and they are most likely to face higher potential reductions in production (Wang et al. 2009). Therefore, though the aggregate level and greater district level analyses are focused on all three major rice varieties' sensitivity to climate change, the survey part of this research focuses only on Aman rice. Moreover, this study focuses on the High Barind Tract (HBT) of Bangladesh because of its high vulnerability to rising temperature, low rainfall and very severe droughts where Aman is the major economic activity of the majority of the population in that region.

1.3 Climate change vulnerability and the Bangladesh economy

Climate change impacts are already being experienced through increasing temperatures, variable rainfall and climate related extreme events such as floods, droughts, cyclone, sea level rise, salinity and soil erosion (Asaduzzaman et al. 2010; Yu, et al. 2010; Hossain & Deb 2011). Table 1.1 shows the sectors most affected by climate change: crop agriculture, fisheries, livestock, infrastructure, industries, biodiversity, health, human settlement and energy (MOEF 2005).

Table 1.1 Intensity of the impact of climate change on different sectors

Vulnerable Sectors	**Physical vulnerability context (climate change and climate events)**							
	Extreme temperature	Drought	Flood		Cyclone & storm surges	Sea level rise		Soil erosion
			River flood	Flash flood		Coastal inundation	Salinity intrusion	
Crop agriculture	***	***	*	**	***	**	***	-
Fisheries	**	**	**	*	*	*	*	-
Livestock	**	-	-	**	***	**	***	-
Infrastructure	*	-	**	*	*	**	-	***
industries	**	-	**	*	*	***	**	-
Biodiversity	**	-	**	-	*	***	***	-
Health	***	-	**	-	**	*	***	-
Human settlement	-	-	-	-	***	-	-	***
Energy	**	-	*	-	*	*	-	-

Source: MOEF, 2005
Notes: ***= severely vulnerable, ** = moderately vulnerable, *= vulnerable, - = not vulnerable

Crop agriculture is the most vulnerable sector to climate change and climate related events (Table 1.1). Crop agriculture is most vulnerable to extreme temperatures, droughts, cyclone, and salinity intrusion. These findings are consistent with those of Roy et al. (2009) and Karim et al. (1999) who found that rice, the single most important crop, faces the threats of both droughts and floods in Bangladesh.

1.4 Statement of the research problem

While rice production is already under pressure on the demand side due to population growth, the supply side is further exposed to natural pressures through climate change. As a result, overall rice production is forecast to decrease by 17% per annum due to climate change and climatic events (GOB 2005).

Temperatures in Bangladesh have been increasing, particularly during the monsoon season, over the past three decades (GOB & UNDP 2009). Average temperatures were found to have risen by 0.7^{o}C per decade across Bangladesh (Ahsan et al. 2011). Moreover, the country is expected to experience an increase in average temperature overall by 1°C by 2030 and by 1.4°C by 2050 (FAO 2006; IPCC 2007).

Rainfall in the country is highly variable and has demonstrated an increasingly uneven distribution (Ahsan et al. 2011). The number of days without rain is increasing, although the total annual rainfall remains almost the same. This erratic behaviour of rainfall produces extreme events like floods and droughts which have noticeably adverse impacts on rice yields. For example, the reduction of Aman rice production was 20% to 30% in the northwestern region in 2006 when a drought occurred (UNDP 2007; GOB & UNDP 2009).

Droughts appear as a recurrent phenomenon in many parts of Bangladesh. Since independence in 1971, the country has experienced 12 severe droughts, which affected nearly 50% of the land area (Ahmed 2006; Shahid & Behrawan 2008). Moreover, the frequency and severity of droughts have increased in recent years. It is forecast that by 2050, the Barind Tract (a northwest upland region with hard red clay soil) will be at greater risk of droughts, as a result of a potential temperature increase of 2°C and a 10% decrease in rainfall. This will limit irrigation water availability and decrease food security (FAO 2006; FAO 2007).

In Bangladesh, several research studies have been undertaken on the effects of climate change on rice and rural agro-based livelihoods (Ali 1996; Karim et al. 1996; Mahmood, 1998; Ali 1999; WB 2000; Mirza 2002; Mahmood et al. 2003; Mirza et al. 2003; Hutton & Haque 2004; Basak et al. 2009; Pouliotte et al. 2009; Basak et al. 2010). One strand of research has focused on crop simulation modelling or scenario based modelling (Mahmood 1998; Mahmood et al. 2003; Basak et al. 2009; Basak et al. 2010). However, these studies have been unable to reveal the effect of a slight change in climate variables on crop production (Schlenker & Roberts 2008). The other strand of research is descriptive in nature and has focused on the livelihoods of people in the southwestern coastal areas of the country, which are particularly vulnerable to cyclones, sea level rise, floods and storm surges (Ali 1996; Ali 1999; WB 2000; Mirza 2002; Mirza et al. 2003; Hutton & Haque 2004; Pouliotte et al. 2009; Paul and Routray 2011). The results from both strands of research are not comprehensive and conclusive which necessitates further studies. However, the impacts of climate change have spatial and temporal dimensions.

The spatial dimension refers to the fact that the effects of climate change are location dependent. That is, the effects of climate change are heterogeneous and region specific. For example, a rise in temperature with reduced and more variable rainfall has already affected the natural and physical ecosystems of Bangladesh, predominantly the northwest with its recurrent droughts and the southwest with rising soil salinity (Ahsan et al. 2011). The temporal dimension refers to the timeframe over which climate change effects are being considered. These two dimensions require further research focusing on time series, cross-sectional time series and farm level micro data which is absent in the existing literature. This study, therefore, has as its overall objective to assess the impacts of climate change on rice farming at the national (or aggregate), sub-national (greater district or climate zone specific) and farm levels.

1.5 Research questions and approach

Crop specific research is important given that different crops are impacted differently by climate change. Studies on the effects of climate change on rice are very limited. Based on the formulated research problem of this study, four key research questions were devised:

1. What is the impact of climate change on rice production at the aggregate level?

2. How does the change in major climate variables affect rice production across district or agro-climatic zones?

3. How do rice farmers perceive the impact of climate change on rice production and what are the determinants of net revenue changes as a result of changes in rice production?

4. What are the determinants of farmers' adaptation choices in the face of perceived climate change?

This study employs a holistic approach to answer the research questions. Holistic in the sense that it deals with all three levels of impact of climate change on rice production, namely aggregate time series data for national level, cross-sectional time series data for district level and cross-sectional survey data for farm level. First of all, it analyses time series aggregate data, both for climatic and rice variables. Secondly, it uses cross-sectional time series data to measure the effects of climate variability on rice production at the district level. Thirdly, climate change impact and farm level adaptation are examined using farm level survey data for the country's most drought-affected region, Rajshahi district in the HBT. This area has been chosen as a case study site due to its high vulnerability to rising temperature and its variable and low rainfall.

1.6 Climate change and rice crop production: a conceptual framework

Greenhouse gases emissions from human activities are responsible for climate change (IPCC 2007; Li et al. 2011). Climate change leads to increased temperatures, changing rainfall patterns and amounts, and a higher frequency and intensity of extreme climate events such as floods, cyclone, droughts, and heatwave (IPCC 2007; Tirado et al. 2010; Roudier et al. 2011). Temperature increases and erratic rainfall patterns affect crop agriculture most directly and adversely (Lansigan et al. 2000; Rosenzweig & Tubiello 2007; Almaraz et al. 2008). Changing climate over time affects rice crop production adversely (Behnassi 2011). The channels of the impacts are depicted in Figure 1.1. Changes in climate generally involve changes in two major climate variables: temperature and rainfall. The increase in temperature shortens the phenological phases of crops (such as planting, flowering and harvesting) (Liu et al. 2010; Roudier et al. 2010; Teixeira et al. 2011) and affects plant growth and development. The fluctuations and occurrence of extreme climate events reduce rice yields significantly, particularly at critical crop growth stages (Lansigan et al. 2000; Teixeira et al. 2011).

Rainfall extremes, through droughts and floods are very detrimental to rice productivity. Higher and/or heavy rainfall results in higher yield losses through flooding (Rosenzweig et al. 2002; Reid et al. 2007; Roudier et al. 2011). In contrast, insufficient rainfall leads to greater drought frequency and intensity, while increased evaporation leads to complete crop failure (Reid et al. 2007; Liu et al. 2010).

Overall, temperature and rainfall changes reduce the cropped area, production level and yield. This reduction or fluctuation in rice yield warrant farmers' adaptability to minimise these adverse effects. However, adaptation strategies at the farm level vary from area to area and from farm to farm. Farmers' adaptive capacity is determined by their socio-demographic characteristics, farm characteristics and accessibility to institutional factors.

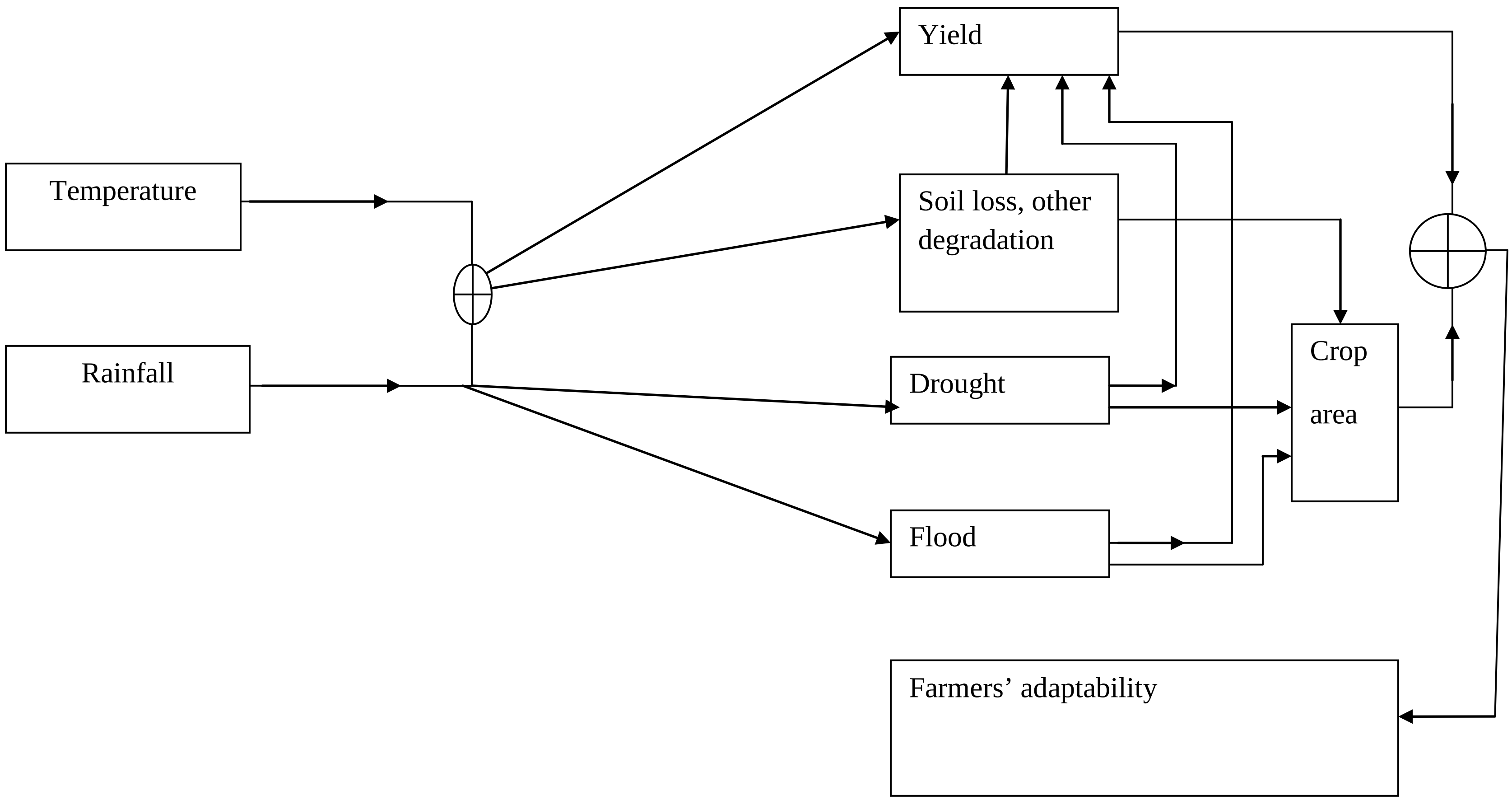


Figure 1.1 Conceptual framework of climate change impacts on rice production

1.7 Organisation of the thesis

In addition to this introductory chapter, this study is organised into seven chapters. Chapter 2 reviews the existing literature dealing with climate change and crop agriculture generally, and Bangladesh, specifically.

Chapter 3 provides an account of the methodology employed in this study. The approach is holistic since it comprises national level aggregate data, district level time series data and farm household cross sectional level data.

Chapter 4 outlines and investigates the trend of climate change and rice production in Bangladesh using aggregate time series data. In the latter part of the chapter both mean and median regression models are employed to estimate the impact of climate variables on the rice yields for three varieties. This chapter provides a more rigorous and detailed analysis in terms of technique and robustness of the results than previous studies which employed simpler regression methods.

Chapter 5 examines the effects of temperature and rainfall on the mean and variability of rice yields. A balanced panel data approach using the theoretical framework of Just and Pope (1978) is applied to estimate the effect of climate variability on rice yields in 13 districts. Results from this model are used to forecast the future impact of climate change on rice yields. Findings at every stage are compared with studies from other countries since studies of this type were not found in the literature for Bangladesh.

Chapter 6 examines farmers' perceptions about climate change impacts on rice production. It assesses the factors that affect net revenue or profit from rice production in the face of climate change. It also evaluates the determinants of rice production losses due to climate change. For this, this study utilises farm level data from 15 villages of the Rajshahi district which has been severely affected by recent droughts. In addition to bivariate analysis, both mean and median regression analysis are used to analyse the data.

Chapter 7 documents farmers' perceptions about long-term climate change, i.e., changes in temperature, rainfall and drought as extreme events. It also assesses the determinants of farm level adaptation choices. A multinomial logit model using micro-level survey data from 550 farm households is employed to determine the important factors which influence farmers' adaptation strategies.

Finally, Chapter 8 provides an overview of the results of the study and suggests policy recommendations and an agenda for additional future research.

Chapter 2 Review of the Literature

2.1 Introduction

This chapter provides a review of the pertinent literature on climate change and crop agriculture. The review focuses on the two main areas of this research: the impact of climate change on crop agriculture and farmers' adaptation to it. The organisation of this chapter is as follows. Section 2.2 provides a brief overview of climate change globally. The interplay of climate change and crop production is explained in Section 2.3. Section 2.4 evaluates the different models utilised in analysing climate change impacts on crop agriculture. Section 2.5 reviews the empirical studies on climate change impacts on crop agriculture. Section 2.6 critically examines adaptation strategies to climate change and factors influencing their adoption. Section 2.7 examines impact of climate change and adaptation studies for Bangladesh. Gaps and weaknesses in the existing literature are discussed in Section 2.8.

2.2 Evidence of global climate change

Climate change results in changes in long-term weather conditions globally. More explicitly, climate change denotes a significant statistical variation either in the average condition of the climate or in its variability that continues for long periods, typically decades or longer (Vijaya Venkata Raman et al. 2011). Due to human activities (such as burning of fossil fuel), the impacts of climate change have already been observed from rising sea levels to melting snow and ice to changing weather patterns. IPCC (2007) provided strong evidence for rapid climate change, these include:

i. Global temperature increase: Most of this warming has occurred since the 1970s, with the 20 hottest years having taken place since 1981 including 10 of the warmest years taking place in the past 12 years.

ii. Diminishing Arctic sea ice: Both the size and depth of Arctic ice has reduced quickly over recent decades.

iii. Sea level rise: Global sea levels have risen about 17 cm in the past 100 years. The rate in the last decade is almost double that for the previous century.

The increasing trend of carbon dioxide (CO_2) emissions, Arctic sea ice, CO_2 concentration, sea level rise and global surface temperature are illustrated in Figures 2.1–2.5 (Vijaya Venkata Raman et al. 2011).

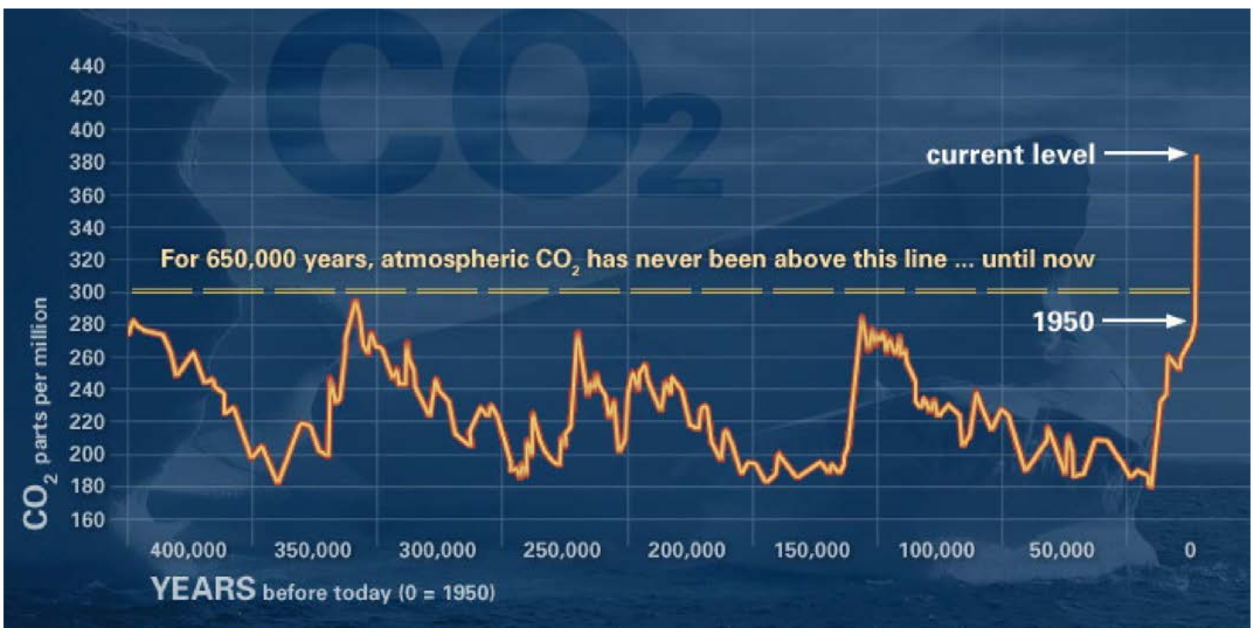


Figure 2.1 CO_2 (ppm) trend over time
Source: Adapted from Vijaya Venkata Raman et al. 2011.

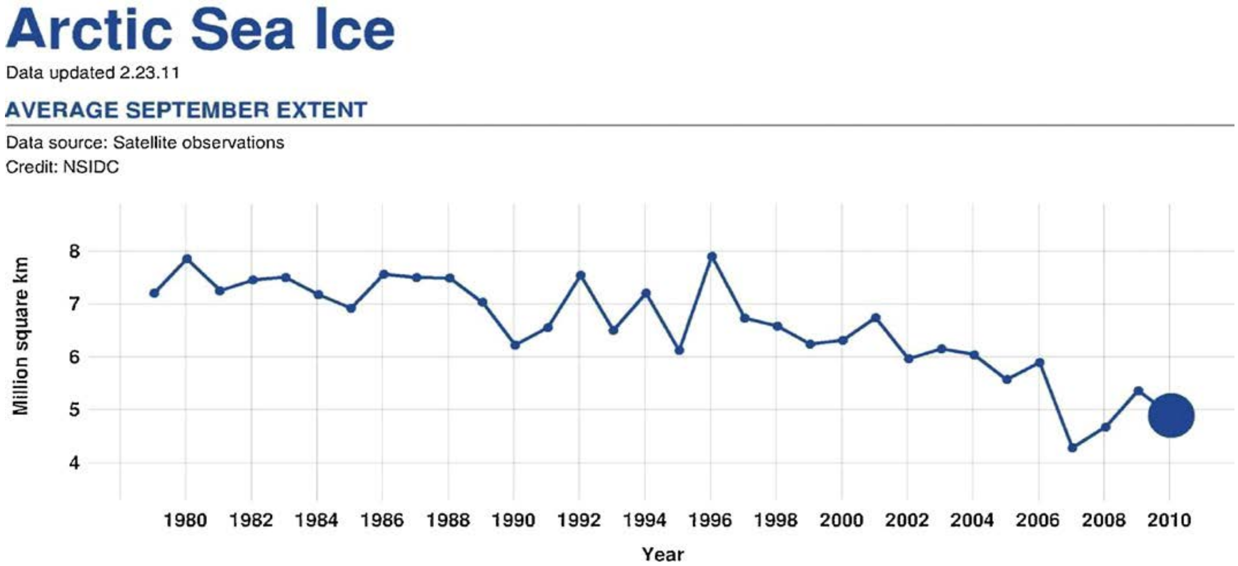


Figure 2.2 Arctic sea ice level change, 1980–2010.

Source: Adapted from Vijaya Venkata Raman et al. 2011.

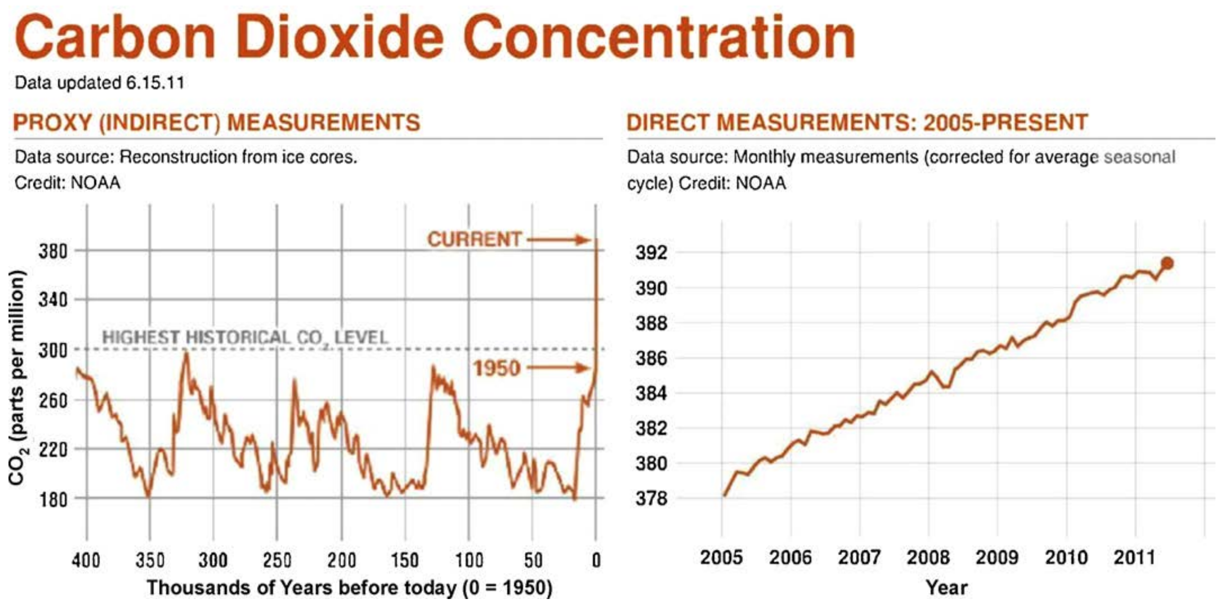


Figure 2.3 CO_2 concentration level over the millennia

Source: Adapted from Vijaya Venkata Raman et al. 2011.

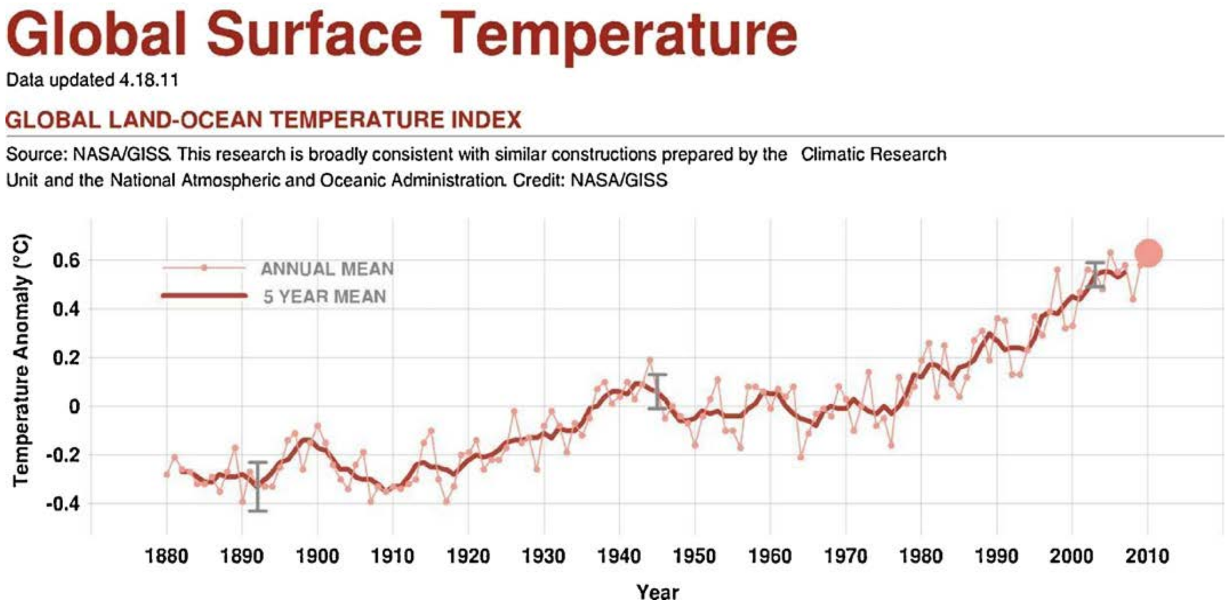


Figure 2.4 Global temperature variations, 1880–2010

Source: Adapted from Vijaya Venkata Raman et al. 2011.

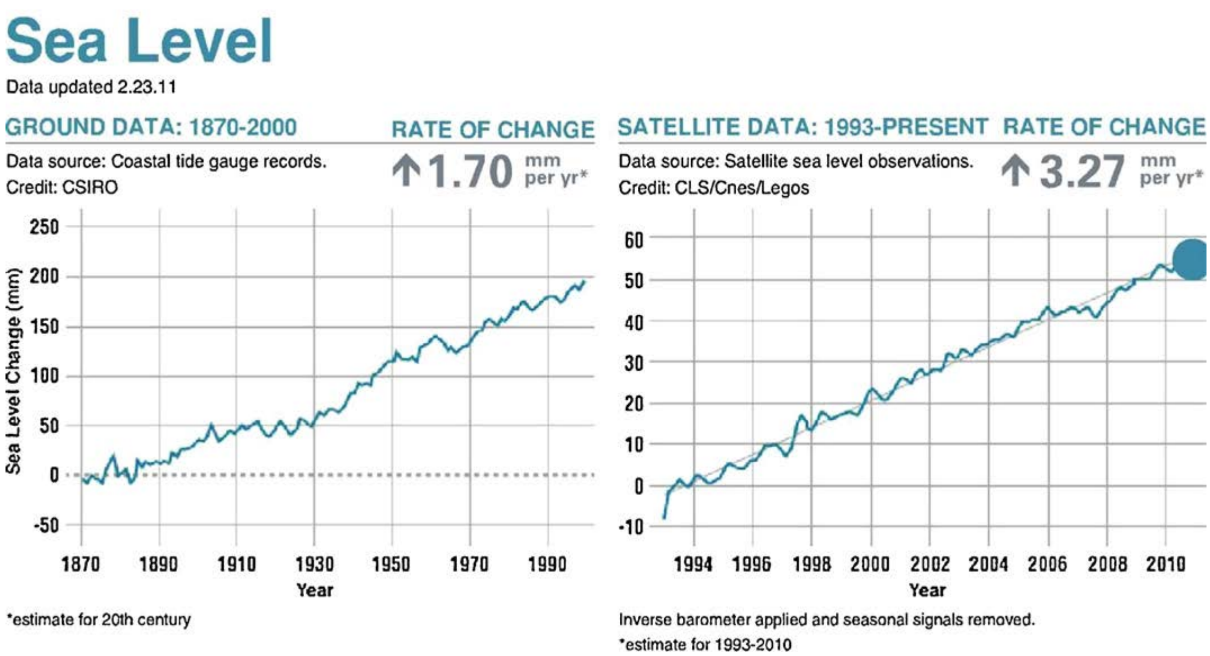


Figure 2.5 Sea level rise, 1870–2010

Source: Adapted from Vijaya Venkata Raman et al. 2011.

2.3 Interplay of climate change, crop production and food security

Climate change is expected to significantly impact on global agricultural production. This will occur because agricultural production is highly dependent on climate and is adversely affected by increasing anthropogenic climate change and climate variability (Smit et al. 2000; IPCC 2007; Chandrappa, et al. 2011). Therefore, weather patterns considerably affect crop production. Climate change represents an additional pressure on the world's food supply system and is expected to increase yields at higher latitudes and decrease yields at lower latitudes (IPCC 2007).

Much research has reported that high temperatures, variable rainfall, floods, droughts and cyclones would cause a significant decrease in world food production, especially in developing countries (Rosenzweig & Parry 1994; Parry et al. 1999; Reilly et al. 1999; Gregory et al. 2005). Some studies have demonstrated that the distribution of food supplies in different parts of the world might also be affected greatly by climate change (Gregory et al. 2005; Schmidhuber & Tubiello 2007).

Climate change directly affects all dimensions of food security: availability, accessibility, stability and utilization (Gregory et al. 2005). It affects food production directly through changes in agro-ecological conditions and, thereby, affects overall food supply (Molua 2002; Gregory et al. 2005; Ingram et al. 2008). Moreover, extreme climate events such as cyclones, floods and droughts affect food supplies severely and thus food security. The overall impact of climate change on food security differs across regions and over time (Parry et al. 1999; Gregory et al. 2005; Misselhorn 2005; Stern 2006). The impact will depend on a country's socio-economic status.

2.4 Different methods for estimating climate change impacts on crop agriculture

Different methods and approaches for estimating the impact of climate change on the agriculture sector are found in the literature. They are grouped into two broad categories: partial economic models and economy-wide models. Partial equilibrium models analyse a single market or commodity or subsets of markets or sectors whilst general equilibrium models observe the economy as a complete system of co-dependent elements (such as industries, factors of production, institutions and the rest of the world) (Sadoulet & De Janvry 1995). The most common economy-wide general equilibrium model is the computable general equilibrium (CGE) model. Partial equilibrium models encompass four approaches: crop modelling/agro-economic, Ricardian/cross-sectional, panel data (Deressa & Hassan 2009) and agro-ecological zone (AEZ).

2.4.1 General equilibrium model

2.4.1.1 Computable general equilibrium approach

The CGE model estimates the economy-wide effects of climate change (Deressa & Hassan 2009). CGE methods are based on a system of linear and non-linear equations that can be solved to simulate equilibrium. As climate change affects different sectors of an economy directly or indirectly, CGE models are required for climate change impact assessment (Winters et al. 1996). The main advantage of applying CGE models is that they take into account the economy-wide effects of climate change. However, the major disadvantages of the model are difficulties with model selection; functional forms and parameter specification; data consistency or calibration problems; the absence of statistical tests for the model specification; and the complexity of the CGE models and the high level skills required to develop and utilise them (Gilling & McCarl 2002).

2.4.2 Partial equilibrium models

2.4.2.1 Crop modelling or production function approach

Based on the climate-yield relationship, the crop modelling approach estimates the effects of climate change on agricultural production. Survey or experimental data are used to measure this relationship. This agronomic-economic method commences with a crop model that is calibrated from carefully controlled agronomic experiments (Easterling et al. 1993; Rosenzweig & Parry 1994; Adams et al. 1998). The agronomic modelling evaluates how a crop reacts to the changing environmental conditions. In this initial stage, environmental variables are employed to measure crop yields and output variations in laboratory type settings. The changes in yields are then entered into the economic model as inputs to predict the aggregate impact on crop yields and prices under various settings. Models have been developed and calibrated through repeated experiments by agronomists to forecast yield changes of specific crops under different weather settings (Adams et al. 1989; Rosenzweig & Parry 1994). Crop simulation models developed worldwide include CERES (Hawaii), CROPSYST (Washington), CROPWAT and CROP Yield Forecasting (FAO), APSIM (Australia) and SWB (Pretoria). These models have been successfully employed in many studies (Easterling et al. 1993; Rosenzweig et al. 1995; Makadho 1996; Iglesias et al. 2000; Tubiello et al. 2000; Du Toit et al. 2002).

While this approach offers a carefully controlled and randomised application of environmental conditions, the laboratory style outcomes might not incorporate the adaptive behaviour of optimising farmers. Though some adaptation is modelled, it is not clear how well this corresponds to the actual behaviour of farmers (Guiteras 2009). This approach is expected to produce estimates with a negative bias when farmers' actual practices are more adaptive. Furthermore, if the presumed adaptation does not take adjustment mechanisms into consideration, these estimates could be over optimistic (Guiteras 2009). In developing countries, most agronomic models perform an unsatisfactory job of incorporating adaptation. Incorporating new technologies has also traditionally been overlooked in agronomic models (Mendelsohn & Tiwari 2000).

2.4.2.2 Ricardian/cross-sectional approach

The cross-sectional approach examines farm performance in different climate zones. This has been named the Ricardian approach as it is based on the theoretical work of the classical economist David Ricardo. His Rent Theory states that land values or net revenue from land uses reflect land productivity at a particular site under conditions of perfect competition (Ricardo 1817, 1822). The approach explores a cross-section of farmers in various climatic settings and looks at the relationship between the land value or net revenue[1] and agro-climate factors (Mendelsohn et al. 1994; Kumar & Parikh 1998). That is, it specifies land value as a function of climate, economic, demographic and physical variables (Mendelsohn et al. 1994). The marginal contribution of each input variable to farm income is measured by regressing land value on a set of environmental input variables. The main strength of this approach is that it captures farmers' adaptations that affect the net revenue or farm income. The approach has been successfully applied in many countries: the USA (Mendelsohn et al. 1994; Mendelsohn & Dinar 2003), England and Wales (Maddison 2000), Kenya (Mariara & Karanja 2007), Taiwan (Chang 2002),

[1] Net revenues or profits instead of land values are used for applying the approach to most developing countries where efficient land markets are non-existent. The model that uses profits or net revenues is called the Semi-Ricardian method.

South Africa (Gbetibouo & Hassan 2005), Cameroon (Moula 2009), China (Wang et al. 2009), and India and Brazil (Sanghi & Mendelsohn 2008).

The major weaknesses of this approach are: (i) it assumes price is constant (Mendelsohn et al. 1994; Mariara & Karanja 2007) which leads to a bias in the welfare calculation (Cline 1996); (ii) the method does not measure the effect of climate on the yield of individual crops (Kaufmann 1998); (iii) though yield variability is found to be significant in the literature, a Ricardian model is unable to capture the impacts of climate change (Barnwal & Kotani 2010); (iv) the approach requires data from different agro-ecological zones (AEZs) or weather stations which becomes impractical for an individual researcher to collect given time and funding constraints; (v) the approach suffers from the problem of omitted variables since it does not take into consideration time independent or location specific variables such as unobservable skills of farmers and quality of soil, which has already led economists to search for new estimation techniques (Guiteras 2007) such as the panel data approach.

2.4.2.3 Panel data approach

Omitted variables bias in the cross-sectional approach has led the use of the panel data approach to study the economic effects of annual fluctuations in weather variables on agricultural output and profits (Schlenker & Roberts 2006; Deschenes & Greenstone 2007). This approach overcomes the problem of omitted variables. The panel data approach is used to estimate the effects of climate change on mean crop yield and yield variability (Barnwal & Kotani 2010). Two versions of the model are normally used to estimate panel data: fixed effects and random effects (Baltagi 2008). The fixed effect approach has the advantage of controlling for time invariant, district level and unobservable effects of omitted variables such as local soil condition, labour and fertilizer availability, infrastructure, access to markets and farmers' skills (Barnwal & Kotani 2010). The fixed effect model permits the measurement of district specific effects when there is a correlation between unobserved time invariant features and independent variables. In contrast, the random effect model firmly necessitates the assumption of no correlation between time invariant characteristics and independent variables (Baltagi 2008; Semykina & Wooldridge 2010). Therefore, the fixed effect model usually offers a better estimate.

2.4.2.4 Agro-ecological zone analysis

The AEZ approach developed by the FAO (1992), is also known as the crop suitability approach. It assesses the suitability of various land and biophysical attributes for crop production (Deressa & Hassan 2009). Like the agronomic approach, the AEZ approach depends on natural science relationships. However, the AEZ method develops a thorough eco-physiological process model and uses a simulation of crop yields rather than measured crop yields (Mendelsohn 2000). Various factors such as crop characteristics (i.e., length of growing cycle, yield formation period, leaf area index and harvest index), existing technology, soil and climate factors are included as determinants of suitability for crop production (FAO 2006). Combining these variables, the approach facilitates the identification and distribution of potential crop producing lands. As the approach contains climate as a determinant, it can be used to predict the impact of climate change (e.g., changes in temperature and rainfall) on potential agricultural output and cropping patterns (Xiao et al. 1997; Mendelsohn & Tiwari 2000; Du Toit et al. 2001).

By generating static scenarios with changes in technological parameters, adaptation to climate change specific impacts can be captured with this method (Mendelsohn & Tiwari 2000). However, the disadvantage of the AEZ methodology is that it cannot predict final outputs without clearly modelling all the related components. The exclusion of one main factor thus would considerably influence the model's predictions (Mendelsohn & Tiwari 2000).

2.5 Empirical studies on climate change effects on crop agriculture

This section examines the empirical studies on the economic effects of climate change on crop agriculture. Based on the available literature, the analyses can be grouped in three sections: the impact on world agriculture, on developed countries' agriculture and on developing countries' agriculture.

2.5.1 Evidence from world agriculture

Several studies investigated the possible effects of climate change on world agricultural production (Rosenzweig & Parry 1994, Darwin et al. 1995, Parry et al. 1999, Parry et al. 2004).

Rosenzweig and Parry (1994) assessed the likely impact of climate change on world food supply using a crop growth model. The main finding of the research is that global food production would be reduced slightly because of a two-fold increase in atmospheric CO_2 concentration. It was also found that climate change affects developed and developing countries differently. Countries in the lower latitude regions (i.e., developing countries) will bear the major brunt of the problems caused by climate change. Results from simulations of the effectiveness of adaptive options taken by farmers confirmed that these are rarely successful in alleviating the difference between developed and developing countries.

Darwin et al. (1995) reported that climate change was not likely to endanger cereal world production as a whole, but that production of non-grain crops was expected to be reduced. Farmers' adaptation will play a vital role in sustaining cereal production under climate change. Thus a severe change in climate could lead to a decline in global GDP.

Parry et al. (1999) looked at the possible impacts of climate change on crop yields, world food supply and risk of hunger using the Hardly Centre Coupled Model (HadCM2) global climate change model scenarios. The consequences for crop yields are beneficial for countries in mid and high latitude regions (i.e., the developed world) while the effects are damaging for countries in low latitude areas (i.e., the developing world, excluding China). The availability of water supplies for irrigation and the costs of adaptation appeared to be important dimensions for further research.

Parry et al. (2004) projected the impact of climate change scenarios, developed from the HadCM3 global climate model, on crop production, yield and the risk of hunger. The results from their research indicate that crop yields will decline significantly both regionally and globally, due to the expected large increase in temperatures globally.

The common finding of these studies is that climate change is unlikely to endanger cereal production for the world as a whole. However, though climatic consequences on crop yields are beneficial for developed countries, the effects are damaging for developing countries.

2.5.2 Evidence from developed countries' agriculture

The early studies on the impact of climate change on agriculture focused on developed countries, particularly the USA. One strand of research used the production function approach to forecast the impact on crop yields through crop simulation models (Adams et al. 1989; Rosenzweig 1989; Adams et al. 1995; Kaiser et al. 1993). Most of these studies estimate substantial harmful effects of climate change on agriculture in the USA. However, a recent study by Lobell et al. (2007) revealed that most Californian yields were only slightly affected by current climatic changes.

Other studies have employed a Ricardian model and used cross-sectional data to estimate the impact of climate change on agriculture (Mendelsohn et al. 1994; Reinsborough 2003; Weber & Hauer 2003; Schlenker et al. 2005; Lippert et al. 2009). Mendelsohn et al. (1994) found that the USA's agriculture would potentially benefit from climate change. This study also forecast a 1% increase in agricultural GDP under a CO_2 doubling scenario. Similar results are found for Canadian agriculture by Weber and Hauer (2003). Reinsborough (2003) also showed that Canadian agriculture would be little affected by climate change in the next three decades. However, Schlenker et al. (2005) estimated negative impacts on agricultural receipts of approximately $5.3 billion annually for the USA. Finally, Lippert et al. (2009) estimated some benefits arising from current climate change for German agriculture using district level data. However, their simulation results provided some indication of losses in the long-term when temperature and rainfall changes will become more severe. The consensus is that climate change is unlikely to affect developed countries' agriculture adversely over the remainder of this century.

2.5.3 Evidence from middle income and lower income countries

Crop agriculture in developing countries is expected to be impacted greatly because of the sector's size, its climate sensitivity and the location of developing countries in the lower latitudes of the world (IPCC 2007; Mendelsohn 2009). Recent studies have investigated the economic impact of climate change on agricultural production in developing countries (Lansigan et al. 2000; Chang 2002; Gbetibouo & Hassan 2005; Kurukulasuriya & Ajwad 2007; Mariara & Karanja 2007; Haim et al. 2008; Sanghi & Mendelsohn 2008; Deressa & Hassan 2009; Moula 2009; Wang et al. 2009). These studies used the Ricardian model, except for the studies by Lansigan et al. (2000), Chang (2002) and Haim et al. (2008) which used the production function approach.

Lansigan et al. (2000) found that climate variability is most likely to affect Philippines rice production. Chang (2002) measured the likely effects of temperature and precipitation on 60 agricultural crops in Taiwan. This study revealed that climate change had important consequences for grain production and that farmers as a whole would suffer mildly from the rise in temperature but an increase in rainfall could be devastating. Using a HadCM3 model, Haim et al. (2008) predicted that Israeli wheat production would be severely affected from 2070 to 2100. However, irrigation and the application of nitrogen might reduce potential production losses.

Gbetibouo and Hassan (2005) employed district level data to assess the economic effects of climate change on a large variety of crops in South Africa. This study reveals that increasing temperature does not affect net revenue of summer crops but is harmful to net revenue of winter crops. Nonetheless, irrigation has emerged as an effective adaptive option to arrest the negative effects of climate change. Employing district level data, Sanghi and Mendelsohn (2008) showed that climate change was likely to cause huge damage in Brazil and India by 2100.

Kurukulasuriya and Ajwad (2007) used farm level cross-sectional data to measure the impact of climate change on the profitability of smallholder farming in Sri Lanka. This study revealed that the arid zone of that country was expected to face the largest negative effects. However, wet areas are likely to benefit. Mariara and Karanja (2007) estimated the long-term impact of climate change on cereal production in Kenya. This study indicated that high summer temperatures lower net revenue while rising winter temperatures result in higher net crop revenue and this increases as rainfall increases. This study also mentions crop diversification, water conservation, irrigation and shading of crops as major adaptive methods. The main drawback of the study is that it did not address the long-term impact of climate change.

In Ethiopia, Deressa and Hassan (2009) determined that climate variables would affect crops significantly. Employing three climate scenario models, this study predicts that there will be a decline in net crop revenue in the years 2050 to 2100. However, adaptive measures will be able to reduce this revenue loss. Another study by Moula (2009) assessed the impact of climate change on smallholder agriculture for Cameroon using nationwide field level data. In this study, crop revenue was found to be more sensitive to rainfall than temperature and that a higher temperature was detrimental to agricultural output. This study also identified some adaptive strategies but it did not address the issue of farmers’ adoption of these strategies.

Mendelsohn et al. (2009) estimated the effects of climate on Mexican agriculture using farm level survey data. They found farm land values were sensitive to climate change. More specifically, warmer temperatures were found to reduce land values. However, rain-fed farms will incur greater losses than irrigated farms.

Wang et al. (2009) estimated the direct effects of rainfall and temperature on crop net revenue both for rain-fed and irrigated farms in China, and found that climate change was benign for irrigated farms but damaging for rain-fed farms. Furthermore, higher temperatures, on average, impact on crop revenue negatively while the average impact of higher rainfall is found to be positive. But the impacts are not unique across the regions of China.

Derbile and Kasei (2012) analysed the susceptibility of millet and guinea corn productivity to heavy rainfall in north-eastern Ghana for the period 1987-2008. Comparing the Standard Precipitation Index (SPI) and yields of millet and guinea corn they showed that heavy rainfall caused lower crop productivity. This finding was also supported by farmers in in-depth interviews and focus group discussions. The weakness of this study is that it did not employ any econometric techniques to establish the cause and effect relationship between crop yield and rainfall.

2.6 Adaptation to climate change by agriculture

2.6.1 Nature of adaptation and its importance

Adaptation to climate change is defined as adjustment in natural or human systems in response to actual or expected climatic conditions or risks (Smit et al. 1999). Adaptation is a policy option for limiting the negative effects of climate change (Kurukulasuriya &

Mendelsohn 2008). These actions maintain, preserve or improve the viability of agricultural production (Smit et al. 1999; IPCC 2001). Adaptive responses include autonomous adaptation (i.e., action taken by individual actors such as single farmers or agricultural organizations) as well as planned adaptation (i.e., climate-specific infrastructure development, regulations and incentives put in place by regional, national and international organisation in order to complement, enhance and/or facilitate responses by farmers and organizations) (Tubiello & Rosenzweig 2008).

Adaptation to climate change is very important if farmers are to offset the expected unfavourable impacts of climate change (Mariara & Karanja 2007; Stern 2007; Hassan & Nhemachena 2008). It can protect the livelihoods of poor farmers and ensure food security (Bryan et al. 2009). Adaptive measures are able to reduce the potential negative impacts of climate change and reinforce the advantages associated with climate change (IPCC 2001; Bradshaw et al. 2004; Reid et al. 2007).

2.6.2 Common adaptation strategies and barriers to adaptation

The most common adaptation strategies in agriculture include changing crop varieties, irrigation, planting trees, crop and livestock diversification, soil conservation, early and late planting, increasing plant spacing, use of clay soil, and adjusting the level and timing of applying fertilizer (Bradshaw et al. 2004; Mariara & Karanja, 2007; Nhemachena & Hassan 2007; Deressa et al. 2008; Kurukulasuriya & Mendelshon 2008; Bryan et al. 2009; Deressa et al. 2009; Molua 2009). Three factors guide farmers' choices of adaptation: household characteristics, institutional factors and social capital. Household characteristics include age, education, gender, household size, farm size, farming experience and wealth (Kurukulasuriya & Mendelshon 2008; Bryan et al. 2009). Institutional factors consist of access to extension services, climate information, access to credit, off farm employment opportunities and land tenure (Hassan & Nhemachena 2008; Deressa et al. 2008; Bryan et al. 2009; Deressa et al. 2009; Gbetibouo 2009). Social capital includes farmer-to-farmer extension and the number of relatives nearby (Deressa et al. 2008; Deressa et al. 2009). These variables all influence the selection of adaptation strategies.

Despite having perceived changes in temperature and rainfall, many farmers cannot make any adjustments to their farming practices. The main barriers to adaptation include lack of information, lack of access to credit and land, and water shortages (Yesuf et al. 2008; Bryan et al. 2009; Deressa et al. 2008; Deressa et al. 2009). Therefore, the adaptation strategies they practised were mostly dependent on their own resources.

2.6.3 Explanation of the determinants of adaptation choices

The literature reports different determinants having different impacts on farmers' choice of adaptation to climate change. Among household socio-economic characteristics, the age of the head of the household appears as an important determinant affecting farmers' adaptation choices. But the direction of the relationship varies in the literature. There exists a positive relationship between age and farmers' decision to adapt (Deressa et al. 2008; Hassan & Nhemachena 2008; Deressa et al. 2009; Gbetibouo 2009) while a negative nexus between the variables was also found in some studies (Anley et al. 2007; Nyangena 2008). The gender of the household head has influenced adaptive decisions at the farm level. It is found that male-led households have more adaptation capacity than female-led households (Asfaw & Admassie 2004; Tenge et al. 2004; Bryan et al. 2009; Deressa et al. 2009). Having a higher labour endowment, households with large family size are more likely to adopt new agricultural ideas and to do agricultural tasks differently (Cropenstedt et al. 2003; Deressa et al. 2009). Various studies have shown a positive relationship between the education level of the head of the household and adaption (Maddison 2006; Hassan & Nhemachena 2008; Deressa et al. 2009). Deressa et al. (2009) also explained that the wealthier the farmer the more likely they are to increase their adoption of agricultural technology. Moreover, higher income farmers are usually higher risk takers. It is, thus, hypothesised that farm and non-farm incomes significantly increase the probability of planting trees, shifting planting dates, using different crop varieties and using irrigation as adaptation choices (Deressa et al. 2008; Deressa et al. 2009; Gbetibouo 2009). Livestock ownership has positive impacts on most of the adaptive decisions since it serves as a store of value (Deressa et al. 2008; Deressa et al. 2009).

Apart from institutional accessibility, extension services for crops and livestock have a positive effect on farmers adapting to climate change. This likelihood to change is increased by access to information through extension services (Maddison 2006; Nhemachena & Hassan 2007; Deressa et al. 2009). Furthermore, information on climate change increases the chances of using diverse crop varieties (Deressa et al. 2009). Farmers' adaptive options are positively impacted by access to credit (Deressa et al. 2009) because greater financial capacity makes farmers better able to adjust their management practices (Hassan & Nhemachena 2008).

The numbers of relatives of a farm household in the locality and farmer-to-farmer extension act as social capital and play an important role in increasing the adaptation (Deressa et al. 2008; Deressa et al. 2009).

2.6.4 Choice models for analysing the determinants of adaptation strategies

Though both agro-economic and Ricardian cross-sectional models incorporate some adaptation issues, these two approaches are unable to assess the determinants of farmers' adaptation choices (Gbetibouo & Hassan 2005; Deressa & Hassan 2009). Logit and probit models are the choice models employed most often for analysing the adoption of agricultural technology. Binary logit and probit models are used when the number of choices that farmers practise limited to two options. When the number of adaptation choices is more than two, an extension of these models, called multinomial logit (MNL) and multinomial probit (MNP) models, are used. Provided that a number of adaptation strategies are investigated, the correct econometric model would be either a MNL or a MNP. Both models assess the impacts of independent variables on a dependent variable (choice of adaptation) with multiple choices in an unordered way. These two models have been used in many climate change adaptation studies (Nhemachena & Hassan 2007; Seo & Mendelsohn 2008; Deressa et al. 2009; Hisali et al. 2011). Nhemachena and Hassan (2007) employed the MNP model to evaluate the determinants of farmers' adaptation strategies in southern Africa. Seo and Mendelsohn (2008) employed the MNL model to capture the crop choices made by South American farmers. Deressa et al. (2009) also used the MNL model to assess the factors that affect farmers' choice of adaptive methods in the Nile Basin of Ethiopia. A recent study by Hisali et al. (2011) employed the MNL model to identify factors influencing farmers' adaptation choices in Uganda. However, the MNL model is widely used because of its simplicity in computational use compared to the MNP model (Tse 1987).

2.7 Impact and adaptation studies for Bangladesh

Bangladesh is frequently cited as one of the countries most vulnerable to climate change. However, studies on the impact of climate change on Bangladesh agriculture are very limited (Mahmood 1997 &1998; Paul 1998; Ali 1999; Rahman 1999; Rashid & Islam 2007). These studies fall into two main categories: simulation studies and descriptive studies.

2.7.1 Simulation or modelling type studies

Mahmood (1997) estimated the effects of temperature variations on Boro rice applying the YIELD model for 12 major rice growing districts. The results suggest the planting date plays an important role in the yields of Boro rice. This study found a non-linear relationship between declining temperatures and the length of the early growth phase and a predominantly linear relationship with other growth stages. It also showed that a rise in temperature provided longer and more stable thermal conditions for the maturity stage. An increase in temperature and in evapotranspiration resulted in declines of yields.

Mahmood (1998) compared the relative performance of the YIELD and the CERES-RICE models for temperature increases and rice productivity. In this study, the productivity estimates of the CERES-RICE model appeared to be more responsive to a small rise in temperature than the YIELD model.

Rahman (1999) applied a rainfall simulation model based on a first-order Markov chain approach to simulate the variation in annual rainfall in the High Barind Tract. Using a crop simulation model this study found no significant difference in the rice yield response function.

Rimi et al. (2009) analysed the trend of climate variables for the 1950–2006 period and evaluated their likely impact on rice production in the Satkhira district, using the DSSAT crop simulation model. Trend analysis of seasonal rainfall revealed a statistically non-significant increasing trend of annual maximum and minimum temperature and annual total rainfall. The crop simulation model showed that the yields of Aus, Aman and Boro rice were adversely affected by the rise in temperature, unpredictable rainfall, flooding, drought and salinity. However, the yield reduction was higher for Aus and Aman than that for Boro. This study also suggested some adaptive strategies such as developing crop cultivars tolerant to these hazards, increasing the use of short-duration crop varieties, shifting planting dates, and using raised bed and less water-consuming crops.

Basak et al. (2010) assessed the impacts on the yields of BR3 and BR14 varieties of Boro rice for 12 districts using the DSSAT model. The model forecast an average yield reduction of over 20% and 50% for the two rice varieties for the years 2050 and 2070, respectively. The rise in daily maximum and minimum temperatures was found to be largely responsible for this yield reduction. This study also reported that climate change might make rice yields more sensitive to planting date.

Yu et al. (2010) used a CGE model to explore the economy-wide impact of climate change. The study estimated an average of 7.4% reduction in long-term rice production every year during the simulation period of 2005–2050. This result showed a reduction in Aman and Aus rice production in all sub-regions. Climate variability and extreme climate events have predominantly negative implications for Boro rice production and will hinder its capacity to compensate for the lost Aman and Aus rice production, further jeopardising the country's food security.

Rahman et al. (2012) used the MRI-AGCM simulation model to simulate mean temperature and rainfall for the 2075–2099 period. They projected varying changes in rainfall across different seasons: 0.64% in monsoon, 1.90% in post-monsoon and 13.46% in winter. Their projection for the change in mean temperature was almost 2.5°C over the same period.

2.7.2 Descriptive or policy type studies

Paul (1998) showed that the drought in 1994–95 negatively affected 15 distinct crops in northwest Bangladesh. The crop most affected was Aman rice, the principal crop in the region. Moreover, rich farmers undertook adjustment measures like crop replacement, irrigation, gap filling and the inter-cropping of wheat and kaon (a local food crop), while poor farmers could not practice any measures because of their inability to buy irrigation equipment or seed. However, this study did not comprehensively estimate the impact of the drought on rice production.

Ali (1999) examined extreme climate events such as cyclone, storm surges, coastal erosion and backwater effect. This study revealed that sea level rises in eastern Bangladesh will result in huge agricultural land loss mainly fuelled by beach erosion. This study also identified some adaptive measures such as the construction of embankments and cyclone shelters, and the introduction of new rice varieties suitable to higher salinity and temperature. But it did not estimate the effects of temperature and rainfall on the coastal area's agriculture production and output.

Ahmed and Chowdhury (2006) examined local people's perceptions about past and present climate change and its consequences on rural livelihoods in two drought-prone districts in the northwest, Nawabganj and Naogaon. Based on the available literature, key informant interviews and participatory rural appraisal sessions, this study identified drought as the major climatic risk. Other risks included cold winters, fog, high temperatures, tornados and floods. Most people perceived that the climate had changed over the decades. More precisely, they mentioned that the average temperature had increased in the summer while the length of the winter had reduced but with an increased number of cold spells. The frequency of drought and the incidence of climate related pests and diseases were reported to have increased in the study areas. The major economic livelihoods identified are small and marginal farmers, wage labourers, petty traders/businessmen and fishers. These groups take different adaptive measures to mute their vulnerability. Their main adaptive practices comprise the excavation of ponds and the retention of rainwater in canals, mango cultivation, and livestock and poultry bird rearing. This study also revealed the very weak capacity of institutions such as the Union Disasters Management Committee and local non-government organisations (NGOs) in the management of disaster risks. Local level institutions also suffer from a lack of coordination amongst them. The major policy suggestions were the cultivation of drought-tolerant crops, the excavation of ponds, rainwater harvesting, the installation of deep tube wells (DTWs), an uninterrupted electricity supply, coordination between government organisations and NGOs, and providing credit on simple terms. However, this study merely provided people's perceptions on their vulnerability. No quantification of vulnerabilities was made using statistical techniques.

FAO (2006) carried out an analysis of the adaptive capacity of the rural livelihood groups in 12 villages of four sub-districts in the Chapai-Nawobgonj and Naogaon districts of the northwest. Focus group discussions were the key method for collecting information from village level stakeholders, mainly farmers. People in the study area perceived that the climate had changed over the years. They estimated that the average temperature had increased in summer and winter had shortened. In contrast, rainfall had become more variable and the frequency of drought had increased. Aman is the crop most affected by drought: production losses sometimes reach up to 70%. In order to mitigate climate vulnerabilities, the households' major adaptive strategies were the installation of DTW irrigation, the excavation of ponds, mango farming, the cultivation of short-duration and drought-tolerant crop varieties and homestead gardening. However, no statistical analysis of the determinants of farmers' adaptation which could help to devise policy was made.

Rashid and Islam (2007) identified drought, flood, soil salinity and cyclone as the major extreme climatic events which affected agricultural operations and production adversely. Changes in behavioural patterns, human practices and international actions are suggested as anticipatory adaptive measures in the study. Huq and Rabbani (2011) analysed policy and institutional initiatives taken by the national government to limit the possible adverse impacts of climate change and climate related events. The National Adaptation Programmes of Actions (NAPA) and the Bangladesh Climate Change Strategy and Action Plan (BCCSAP) were adopted to diminish the vulnerabilities of the most vulnerable groups of the population.

Rawlani and Sovacool (2011) identified agriculture as one of the six sectors vulnerable to climate change. They focused on multiple and integrated adaptation strategies along with technology use to reduce climate vulnerabilities. Salauddin and Ashikuzzaman (2012) analysed the nature and size of population displacement caused by extreme climate events in a village of southwestern coastal Bangladesh. Based on a survey and focus group discussions, they demonstrated increased rural to urban migration in the face of climate change. The use of descriptive statistics such as cross tabulation and percentages confirmed that a significant number of people have already migrated to urban areas due to climate change. They also pointed out that marginal farmers would face huge crop failures in the future due to climate related extreme events.

2.8 Gaps or weaknesses in the existing literature

This review of the existing literature has outlined some gaps or weaknesses. The specific gaps were outlined in the chapter. The general gaps are summarised below:

- Earlier studies on the impact of climate change on agriculture emphasised developed countries' agriculture which indicated they are not affected adversely. The very few studies of developing countries' agriculture have increased recently. The results, however, are not homogeneous because of different agricultural systems, geographical characteristics and technological states. Moreover, most of these early studies have assumed little or no adaptation and focused merely on the likely impact of climate change on agriculture.

- Most of the economic studies on the impact of climate change on agriculture have focused on agriculture as a whole by including all crops in one category and all livestock types in another category. However, crop types and animal species are affected heterogeneously by climate variability and change (Deressa et al. 2005; Isik & Devadoss 2006). Furthermore, the effect of climate change varies between and within AEZs of the same country (Gbetibouo & Hassan 2005). Therefore, there is scope for further area or country specific studies with particular focus on individual crops or livestock (Mariara & Karanja 2007). However, studies on important cereals such as rice or wheat are very limited.

- Most of the past cross-sectional studies used county or district level data. But these studies do not allow for the detailed socio-economic and demographic characteristics of farmers that are likely to affect their choice of adaptation and, thereby, farm productivity. A few recent studies have used farm level data collected through WB, IFPRI and FAO funded projects. Impact and adaptation studies that use detailed farm level data are scant.

- Previous studies using time series data have not focused on rice. Moreover, the results from those studies were not robust because of insufficient statistical and diagnostic tests.

- Previous studies using cross-sectional time series are very limited and have not been done for different rice crops.

- In the case of Bangladesh, there are some simulation studies but no empirical studies using standard econometric techniques.

Chapter 3 Methodology

3.1 Introduction

This chapter outlines in detail the methodology used in answering each of the research questions. It discusses the issues relating to both primary and secondary data collection, their sources and outlines in detail the empirical models used to analyse the data. The analytical parts of this study consist of three stages: (1) macro level (aggregate) analysis employing national level data; (2) semi micro level (district level) analysis involving disaggregated time series data; and (3) micro level analysis using farm level survey data. Accordingly, this chapter is organized as follows. Section 3.2 outlines the methodology used for measuring the impact of climate change on rice production at the macro level. Section 3.3 outlines the methodology used to estimate the impact of climate change on rice yield and its variability at the district level. Section 3.4 outlines the methodology used to analyse farm level impacts and farmers' adaptive strategies as a response to climate change. Section 3.5 depicts an overview of the research design and Section 3.6 concludes this chapter.

3.2 Methodology for analysing climate change at the aggregate level

3.2.1 Time series data and its sources

The climate data on daily maximum and minimum air temperature and total rainfall for the 1948–2009 period were collected from the Bangladesh Meteorological Department (BMD) for all of the country's weather stations. The daily climate data were converted to seasonal averages at the national level according to the growing periods of the three major rice varieties (Aus, Aman and Boro) for the 1972–2009 period. Note, rice data is only available for this time period. The rice yield data at the aggregate level for the three rice varieties were compiled from the *Bangladesh Economic Review* for the 1972–2009 period. The national level dataset is provided in Table 3.1.

Table 3.1 Climate and rice data at the aggregate level

Year	**Aus**				**Aman**				**Boro**			
	Yield	Maxt	Mint	Rainfall	Yield	Maxt	Mint	Rainfall	Yield	Maxt	Mint	Rainfall
1972	315.59	32.35	23.72	1450.22	425.91	31.48	23.82	1471.78	811.72	29.66	15.07	304.22
1973	309.77	31.82	23.87	1788.71	395.66	30.66	24.19	1853.42	835.84	29.53	15.57	641.00
1974	364.69	31.49	23.58	2042.71	474.01	30.80	24.12	2089.79	734.69	29.10	15.02	496.25
1975	363.90	32.05	23.92	1528.69	445.49	30.56	24.02	1804.00	784.06	29.64	15.35	320.42
1976	382.06	31.79	23.76	1957.40	494.92	30.89	23.94	2016.04	805.83	29.72	15.52	374.76
1977	379.10	31.42	23.85	2142.00	481.20	30.78	24.09	1866.00	781.62	29.16	15.41	693.72
1978	397.13	31.66	23.49	1914.17	520.39	30.96	24.20	1865.10	828.38	29.26	14.96	553.47
1979	411.20	32.36	24.24	1434.43	517.84	31.25	24.42	1681.37	728.27	29.86	15.92	212.30
1980	374.35	31.82	24.30	1605.17	494.77	30.85	24.22	1550.37	855.16	29.53	15.90	525.83
1981	427.77	31.15	23.66	2093.77	533.91	31.05	24.06	1719.37	917.43	28.55	15.38	808.70
1982	420.65	31.80	23.87	1899.93	485.35	30.84	23.96	1950.60	979.82	29.56	15.45	351.93
1983	392.72	31.75	23.95	2116.27	507.48	31.12	24.32	2128.20	1002.01	28.81	15.29	703.40
1984	415.38	31.88	23.80	2226.10	528.35	30.85	23.70	2207.97	967.43	29.43	15.25	515.53
1985	383.35	31.96	24.28	1801.07	561.95	31.00	23.73	1743.03	1004.67	29.87	16.00	494.60
1986	402.24	32.44	23.76	1592.80	574.27	31.12	23.95	2014.70	968.85	29.97	15.52	365.03
1987	436.19	32.08	24.16	2133.87	552.71	31.24	24.47	2269.97	982.40	30.00	15.83	385.39
1988	434.35	31.81	24.28	2133.35	556.62	31.21	24.28	2089.00	985.47	29.96	16.17	604.71
1989	430.66	32.49	24.25	1401.68	543.96	31.08	24.04	1801.58	967.67	29.70	15.39	318.23
1990	444.12	31.29	23.83	1972.19	652.97	31.15	24.29	1990.39	994.95	28.94	15.70	673.23
1991	434.16	32.06	24.24	1974.31	642.28	30.84	23.98	2228.38	1009.59	29.52	15.88	570.81
1992	460.21	32.53	24.28	1324.38	658.90	31.44	24.01	1576.03	1045.36	29.30	15.65	324.31
1993	483.91	31.47	23.47	2161.38	670.29	31.04	24.15	2024.66	1025.43	29.22	15.30	692.25
1994	453.91	32.18	24.27	1714.69	652.27	31.38	24.11	1513.72	1061.81	29.71	15.62	526.09
1995	435.52	32.66	24.47	1776.25	615.12	31.21	24.62	2071.06	993.36	30.00	15.73	362.97
1996	439.85	32.41	24.43	1737.28	629.93	31.41	24.07	1918.53	1061.09	30.13	16.04	446.22
1997	475.22	31.98	23.73	1812.84	666.05	31.51	23.97	1916.16	1084.83	28.89	15.20	454.72
1998	484.42	31.93	24.15	2171.00	616.52	31.95	25.13	2138.69	1139.91	29.07	15.66	645.97
1999	459.37	32.47	24.56	1998.75	605.99	31.22	24.33	2243.38	1210.70	30.77	16.36	407.59
2000	519.24	31.96	24.08	1979.38	731.00	31.55	24.34	1872.72	1221.84	29.21	15.55	713.59
2001	585.03	32.45	24.08	1916.55	797.18	31.51	24.58	2048.97	1282.23	30.00	15.41	458.00
2002	588.96	31.97	24.00	2151.38	768.56	31.51	24.27	2086.22	1262.43	29.74	15.83	557.28
2003	602.12	32.23	24.28	1717.71	791.78	31.62	24.40	1857.03	1286.31	29.33	15.72	419.45
2004	616.37	32.35	24.54	1782.84	821.07	31.20	23.89	2378.97	1317.22	29.79	16.22	363.31
2005	592.35	32.55	24.62	1819.28	752.51	31.62	24.48	2068.91	1377.80	30.09	16.32	438.03
2006	682.71	32.73	24.46	1631.97	805.71	31.76	24.54	1733.00	1390.87	30.58	16.28	513.81
2007	675.60	32.30	24.12	1934.69	810.12	31.42	24.51	2384.59	1425.78	29.49	15.61	411.84
2008	663.88	32.35	24.37	1831.50	774.57	31.38	24.09	2061.81	1560.12	29.58	16.11	337.06
2009	719.71	33.05	24.67	1782.44	854.84	32.08	24.46	1849.69	1528.14	30.55	15.94	371.16

Sources: BMD (2010) and *Bangladesh Economic Review*, various issues.
Note: Yield is measured in kg/acre; Maxt = growing season average maximum temperature (°C); Mint = growing season average minimum temperature (°C); Rainfall is seasonal average total rainfall and measured in millimetres.

Table 3.1 shows increasing trends in all variables (yield, maximum temperature, minimum temperature and rainfall) over 38 years. However, the extent of the changes is not the same across the three crops. The highest value for yield is Boro rice followed by Aman and Aus rice. The maximum temperature is highest over the period of Aus rice production and lowest for Boro rice. The minimum temperature is lowest for the period of Boro rice production while Aus and Aman rice are almost unchanged.

3.2.2 Unit roots and stationarity

The application of any regression model requires the time series of the concerned variables to be stationary which means that the mean and variance of each variable do not vary systematically over time. Direct use of non-stationary data in the regression estimation can produce spurious results (Gujrati 2004). It is, therefore, necessary to examine whether the time series of the variables are stationary before performing the regression analysis. A time series variable is said to be non-stationary (or stationary) if it has non-constant (or constant) mean, variance and autocovariance (at various lags) over time. If a non-stationary series has to be differenced d times to become stationary, then it is said to be integrated of order d, i.e. I(d). The Augmented Dickey–Fuller (1979; ADF) test is employed to examine unit roots for stationarity.

For each series under study, the equation for the ADF test is as follows:

$$\Delta X_t = \alpha + \delta t + \beta X_{t-1} + \sum_{i=1}^{n} \gamma_i \Delta X_{t-i} + \varepsilon_t \qquad (3.1)$$

where t is the time or trend variable, ε_t is a pure white noise error term and ΔX_{t-1} = ($X_{t-1} - X_{t-2}$), $\Delta X_{t-2} = (X_{t-2} - X_{t-3})$ and so on. The test for a unit root has the null hypothesis that β=0. If the coefficient is statistically different from 0, the hypothesis that X_t contains a unit root is rejected.

3.2.3 Ordinary least squares (OLS) regression

The relationship between a dependent variable Y and an explanatory variable X can be postulated as a linear model (Chatterjee & Hadi 2006):

$$Y = \beta_0 + \beta_1 X + \mu, \qquad (3.2)$$

where β_0 and β_1 are regression coefficients or parameters while μ is an error term. For each observation of a dataset, this equation becomes:

$$y_i = \beta_0 + \beta_1 x_i + \mu_{i,} \qquad {\scriptstyle i=1,2,\ldots\ldots\ldots,n,} \qquad (3.3)$$

where y_i is the ith value of the dependent variable Y, x_i is the ith value of the explanatory variable X, and u_i is the error in the approximation of y_i. Based on the available data, the parameters β_0 and β_1 are estimated with the use of the least squares method which provides the regression line that minimizes the sum of squares of the vertical distances from each point to the line. The vertical distances are the errors in the dependent variable. These errors are obtained by rewriting equation (3) as:

$$\mu_i = y_i - \beta_o - \beta_1 x_{i,} \qquad {\scriptstyle i=1,2,\ldots\ldots,n}. \qquad (3.4)$$

The sum of squares of these distances are then expressed as

$$\sum_{i=1}^{n} \mu_i^2 = \sum_{i=1}^{n} (y_i - \beta_0 - \beta_1 x_i)^2 \qquad (3.5)$$

The values of $\hat{\beta}_0$ and $\hat{\beta}_1$ that minimize the sum of squares of the error term are given by the solution of

$$\hat{\beta}_1 = \frac{\sum (y_i - \bar{y})(x_i - \bar{x})}{\sum (x_i - \bar{x})^2} \qquad (3.6)$$

$$\hat{\beta}_0 = \bar{y} - \hat{\beta}_1 \bar{x} \tag{3.7}$$

The estimates of $\hat{\beta}_0$ and $\hat{\beta}_1$ are known as the least squares estimates of β_0 and β_1 because they are the solution of the least squares method. The least squares regression line is given by

$$\hat{Y} = \hat{\beta}_0 + \hat{\beta}_1 \text{ X} \tag{3.8}$$

For multiple linear regression with nth explanatory variables ($X_1 \ldots\ldots X_n$) , the fitted/estimated least squares regression is written as follows:

$$\bar{Y} = \hat{\beta}_0 + \hat{\beta}_1 X_1 + \ldots\ldots\ldots\ldots + \hat{\beta}_n X_n \tag{3.9}$$

This is also known as the mean regression which is used to estimate coefficients in Chapters 4 and 6.

3.2.4 Quantile (median) regression (QR) method

3.2.4.1 Basics aspects of quantile regression

Quantile (median) regression (QR) models the relationship between conditional quantiles (percentiles) of the target variable and the covariates (Koenker & Bassett 1978; Timofee & Sterin 2009). QR is particularly useful when the rate of change in the conditional quantile, revealed by the coefficients of the regression, and extreme values are very important (Benhin 2008; Cameron & Trivedi 2009). OLS regression is employed to model the relationship between the conditional mean of the dependent variable and one or more covariates. OLS regression is used to measure conditional percentiles by making a distributional assumption such as normality for the error component in the model. It also assumes that the explanatory variables influence only the location of the conditional distribution of the response and not its scale or any other aspect of its distributional shape (Koenker & Bassett 1978; Cameron & Trivedi 2009; Timofee & Sterin 2009). In contrast, the major advantage of QR over OLS regression is that QR regression is more flexible in modelling data with heterogeneous conditional distributions (Koenker & Bassett 1978). The other advantages noted by Koenker & Bassett (1978), Kabubo-Mariara & Karanja (2007), Benhin (2008), and Cameroon and Trivedi (2009) are:

- It requires no distributional assumption about the error term in the model which makes the method semi-parametric;
- QR is more robust to outliers than mean (OLS) regression; and
- QR allows the study of the effect of explanatory variables on both the location and scale parameters of the model, thereby providing a better understanding of the data.

Because of these advantages, QR presents a complete understanding of the effects of the explanatory variables when a set of percentiles is modelled.

3.2.4.2 Interpreting quantile (median) regression method

For a random variable Y with probability distribution function

$$Y(y) = \ Prob\ (Y \leq y)$$

the τ^{th} quantile of Y can be defined as the inverse function:

$\mathrm{Q}(\tau) = \ \inf\{y : F(y) \geq \tau\}$

where 0< $\tau < 1$. In particular, the median is Q(1/2). For a random sample $\{y_1, \ldots, y_n\}$ of Y, it is well known that the sample median will minimise the sum of absolute deviations:

$\min_{\varepsilon \in R} \sum_{i=1}^{n} |y_i - \varepsilon|$.

Similarly, the general τth sample quantile $\varepsilon(\tau)$, which is the analogue of Q (τ), is formulated as the solution of the optimization problem

$$\min_{\varepsilon \in R} \sum_{i=1}^{n} \rho_{\tau(y_i - \varepsilon)}$$

Where $\rho_{\tau(z)=z(\tau - I(z<0)),0<\tau<1.}$

Here I (.) denotes the indicator function. Just as the sample mean that minimizes the sum of squared residuals

$\hat{\mu} = argmin_{\mu \epsilon R} \sum_{i=1}^{n} (y_i - \mu)^2$,

is extended to the linear mean function E$(Y|X = x) = x'/\beta$ by the solution of

$\hat{\beta} = argmin_{\beta \epsilon R^p} \sum_{i=1}^{n} (y_i - x'_i \beta)^2$

the linear conditional quantile function, $Q(\tau|X = x) = x'\beta(\tau)$ can be estimated by the solution of

$\hat{\beta}(\tau) = argmin_{\beta \epsilon R^p} \sum_{i=1}^{n} \rho_\tau (y_i - x'_i \beta)$

for any quantile $\tau \epsilon (0,1)$. The quantity $\hat{\beta}(\tau)$is known as the τth regression quantile. In the special case when $= 1/2$, the minimization of $\hat{\beta}(\tau)$ becomes the solution of the optimization problem:

$$\hat{\beta} = armin \sum_{i=1}^{n}(y_i - x'_i\beta) \quad (3.10)$$

which is the well-known median (or quantile at the 0.5) regression. This regression has been applied both for assessing changes in major climate variables and the impact of climate variables on rice yield in Chapters 4 and 6.

3.2.5 Descriptive statistics

To discern the changes in climate variables over time, descriptive statistics such as moving average, standard deviation and coefficient of variation are used. Moreover, a linear trend model is generally used to detect the changes in climate. However, this study also employs QR for a better understanding of the changes in climate.

3.2.5.1 Moving average

An average value is computed by using only a specified set of values, for example, an average based on just the last three values (Waller 2008). In case of climate data a 5-year moving average is used.

3.2.5.2 Standard deviation

One of the simplest ways of measuring climate variability is to use the standard deviation estimator in measuring dispersion. The sample standard deviation, $S_{x,}$ is as follows (Waller 2008):

$$S_x = \sqrt{\frac{\sum(x_i - \bar{x})^2}{(n-1)}}$$

where S_x = the estimator of the standard deviation σ_x of a climate variable X

x = sample mean

n = sample size

x_i = ith observation of a climate variable X.

For any dataset, the closer the value of the standard deviation is to zero, the smaller is the dispersion. This implies that the data values are closer to the mean value of the dataset and that the data is more reliable for analytical purposes.

3.2.5.3 Coefficient of variation

The standard deviation as a measure of dispersion is not easy to interpret on its own. Generally, a small value for the standard deviation shows that the dispersion of the data is low and vice-versa. However, the magnitude of these values depends on what is being analysed. A method to overcome the difficulty of interpreting the standard deviation is to take into account the value of the mean of the dataset and employ the coefficient of variation**.** The coefficient of variation, V_x, is a relative measure of variability and defined as follows (Waller 2008):

$$V_x = \frac{S_x}{\bar{x}}$$

The values of standard deviation and coefficient of variation of different climate variables are presented in Chapter 4.

3.2.6 Linear trend model

In measuring growth rate of a variable, a simple linear trend model is usually employed which takes the following form (Gujrati 2004):

$$Y_t = \beta_1 + \beta_2 t + u_t \tag{3.11}$$

where, Y is a climate variable which is regressed on time, t. Such a model is known as a linear trend model and the time variable t is called the trend variable. A positive slope coefficient implies an upward trend in Y while if the value of the slope coefficient is negative, then there is a downward trend in Y. This model is used to assess the changes in climate variables in Chapter 4.

3.3 Methodology for analysing climate change impact at the disaggregated level

This section deals with the methodology for analysing the impact of climate variables on rice yield and its variability across districts.

3.3.1 Panel data and their sources

The focus of this analysis is to assess the impact of climate variables (maximum temperature, minimum temperature and rainfall) on rice yields across selected regions in Bangladesh. Data on the rice yields of the three major varieties of rice in Bangladesh (Aus, Aman, and Boro) were collected from the *Yearbook of Agricultural Statistics of Bangladesh* published by the Bangladesh Bureau of Statistics (BBS). The rice yield data (measured in kilograms per acre [kg/acre]) include the time series average crop yields for rice growing districts. Data on yields for 13 of 19 greater districts are used on the basis of the availability of consistent climate data for those districts. The districts are Dhaka, Mymenshingh, Faridpur, Chittagong, Commilla, Bogra, Sylhet, Rajshahi, Dinajpur, Rangpur, Khulna, Jessore and Barisal. Based on Rashid (1991), these districts are categorized into seven different climate zones (Table 3.2).

Table 3.2 Climate zones in Bangladesh

Name of zone	Code used	District
Southeastern	Zone A	Chittagong
Northeastern	Zone B	Sylhet
Northern part of the north	Zone C	Rangpur
Northwestern region	Zone D	Dinajpur, Bogra
Western	Zone E	Rajshahi
Southwestern	Zone F	Khulna, Jessore, Faridpur
South central	Zone G	Dhaka, Mymensingh, Barisal, Commilla

Source: Based on Rashid (1991)

Data on climate variables, covering the 1948–2009 period were accessed from Bangladesh Meteorological Department (BMD 2010). The data collected included the maximum temperature, minimum temperature and rainfall on a daily basis. For this study, the daily data were first transformed into monthly averages and the monthly data were then converted into average maximum temperature and total rainfall over the month of each growing season for all three rice crops. The growing seasons are illustrated in Table 3.3.

Table 3.3 Growing seasons for three rice varieties in Bangladesh

Rice crop	Season
Aus	April–August
Aman	July–December
Boro	December–May

Source: GOB (2009)

Rice yields are usually reported for the production year which is the same as the financial year. As this does not correspond to the calendar year, for the simplicity of our analysis the years were merged. Thus, for example, rice yield data in 1971–72 is considered as the yield for the year 1972. Accordingly, climate variables are aligned with the yield data. For matching between climate data and rice yield data, the data for this research cover from 1972 to 2009 for the 13 districts (see Appendix I for district level time series data).

3.3.2 Panel unit root test

Any dataset with a time dimension of 20 years or more needs to be tested for its time series properties before estimation (Chen et al. 2004). Non-stationary variables are differenced once and retested. If it is found that the differenced version of data is stationary, then the variables are called integrated of order one usually expressed as I (1). It is I (0) for the stationary times series in level form. The observations on one or more areas in a panel could be non-stationary (Chen et al. 2004). Our dataset covers seven climate zones over 38 years. Therefore, each variable in the dataset needs to be stationary to satisfy ideal conditions and to obtain the best results. Some panel unit root tests on panel data are found in recent literature: Levin, Lin and Chu (LLC) (2002), Breitung (2000), Im et al. (2003), Fisher-type tests using ADF and Philips and Perron (PP) tests in Maddala and Wu (1999), Choi (2001), Hadri (2000) and Harris-Tzavalis (HT) (1999). This study has mainly used Fisher-type tests using ADF because of its superiority over other tests (Baltagi 2005). The HT test was also used as a check. However, only the Fisher-type test is explained here.

Fisher-type test

Maddala and Wu (1999) and Choi (2001) proposed a Fisher-type test which combines the P-values from individual unit root tests. If π_i is defined as the P-value from any individual unit root test for cross-section section i, under the null of unit root, then, for all N cross-sections, the asymptotic result can be written as:

$$-2\sum_{i=1}^{N} ln(\pi_i) \rightarrow {}^{\chi^2} 2N \qquad (3.12)$$

The advantage of this test is that it can be used for different lag lengths in the individual ADF regressions and can be used for any other unit root tests (Baltagi 2005). Moreover, the Fisher-type test using ADF with bootstrap-based values performs the best and consequently is the preferred method for testing the presence of non-stationary in panel data (Maddala & Wu 1999).

The hypotheses under the ADF test are:

H_o: All panels contain unit roots
H_a: At least one panel is stationary

3.3.3 Theoretical model and its specification

Earlier studies on the impact of climate change on agriculture employed either a crop simulation or a cross-sectional model. The crop simulation model using general circulation models (GCM) performs inadequately (Schlenker & Roberts 2008). Further, the widely used Ricardian cross-sectional model is unable to capture the effects of omitted variables on output which generates biased results (Deschenes & Greenstone 2007). In order to overcome this omitted variable problem, the stochastic production function developed by Just and Pope (1978) has been successfully applied in some recent studies to estimate the impact of climate variables on crop yields (Chen et al. 2004; Isik & Devadoss 2006, Kim & Pang 2009).

The Just-Pope production function is usually expressed as:

$$y = f(x|\beta) + h(x|\alpha)\varepsilon,\ E(\varepsilon) = 0, var(\varepsilon) = 1 \qquad (3.13)$$

where y is output, x is the vector of inputs, and ε is a stochastic error term. $f(x|\beta)$ is an average output function that specifies the effects of input on the mean of output; while

$h(x|\alpha)$ is a variance function which states the impact of inputs on the variability of output. Therefore, equation (3.13) takes the following form:

$$E(y) = f(x|\beta) \; and \; var(y) = h^2(x|\alpha) \tag{3.14}$$

These two effects are independent.

The production function in equation (3.13) is also interpreted as an estimation equation with heteroscedastic errors:

$$y_i = f(x_i, \beta) + \mu_i \tag{3.15}$$

$$u_i = g(z_i, \alpha)\varepsilon_i \tag{3.16}$$

Where y refers to the dependent variable, x and z are independent variables, and u is the error term with zero mean and variance: $V(u_i) \equiv \sigma_{u_i}^2 = g(z_i, \alpha)^2$. Accordingly, estimation under the Just-Pope production function is a vital segment of the literature on estimation under heteroscedasticity.

There are two well-known estimation techniques or functional forms to formulate the panel data model: the fixed effect and the random effect models. The assumption behind the relationship between explanatory variables and unobserved effects separates the fixed effect model from the random effect model. The fixed effect model assumes that unobserved effects are non-random and are correlated with the observed explanatory variables (Wooldridge 2002, 2009). However, unobserved effects are random and are not correlated with explanatory variables in the random effect model (Wooldridge 2009). The fixed effect model is consistent, while the random effect estimators are inconsistent, in the presence of correlation. Moreover, the fixed effect model diminishes the problem of endogeneity. In this case, the unobserved district or climate zone specific effects are assumed to be fixed over time and vary across climate zones. Therefore, the fixed effect model is selected for this study.

The expressed model (equation 3.15) has conventionally been estimated using either feasible generalized least squares (FGLS) or maximum likelihood (ML) estimation methods following the theoretical framework of Just and Pope (1978). This study has principally used the FGLS method.

3.3.4 The feasible generalized least squares method

The FGLS estimation method includes three consecutive steps (Saha et al. 1997):

Step 1: Non-linear or ordinary least squares are used to estimate equation (3.15).

Step 2: The log of squared residuals, $\hat{\mu}_i^2$, from step 1 is used in the following stage:

$$\ln(\hat{\mu}_i^2) = \ln(g(z_i, \alpha)^2) + \epsilon_i \quad (3.17)$$

where $\epsilon_i = \ln \varepsilon_i^2$. The equation (3.17) can be re-expressed, without any loss of generalisation, as:

$$\ln(\hat{u}_i^2) = \alpha_0^* + \ln(g(z_i, \alpha)^2) + \epsilon_i^* \quad (3.18)$$

Where $\epsilon_i^* = \epsilon_i - E[\epsilon_i]$, and $\alpha_0^* = E[\epsilon_i] = E[\ln(\varepsilon_i^2)]$; and a result, $E[\epsilon_i^*] = 0$. The consistent estimates of α, denoted by $\hat{\alpha}$, are obtained as OLS estimation of (3.18).

Step 3: This step comprises a weighted least squares regression of equation (3.15) as follows:

$$y_i^* = f^*(x_i, \beta) + \mu_i^* \quad (3.19)$$

Where $y_i^* = y_i . g(z_i, \hat{\alpha})^{-1}, f^*(x_i, \beta) = f(x_i, \beta). g(z_i, \hat{\alpha})^{-1}$ and $\mu_i^* = \mu_i . g(z_i, \hat{\alpha})^{-1}$. The estimated parameter from the third stage is denoted as $\widehat{\beta}$.

Amemiya (1985) and Jobson and Fuller (1980) demonstrated that the estimate $\hat{\alpha}$ in the second step was consistent. This ensures that the FGLS estimate $\hat{\beta}$, is consistent.

3.4 Methodology for analysing climate change impact at the micro (farm) level

The survey part of this study was aimed at collecting primary data to analyse the farm level impact of climate change and adaptation. The design of the survey is as follows.

3.4.1 The broad study area

The study area for this research is a severe drought-prone area of Bangladesh known as the HBT (BMDA 2000; Brammer 1999; BMDA 2006; Islam et al. 2011). It is the largest Pleistocene terrace in the country and made up of Pleistocene alluvium. The HBT covers an area of 7,770 km^2 (Karim et al. 1998; BMDA 2000, 2006). This area lies roughly between latitudes 24^o20'N and 25^o35'N and longitudes 88^o20'E and 89^o30'E (Asadudzaman & Rushton 1998; BMDA 2000, 2006). The HBT is at a higher elevation with two terrace levels: one at 40 m while the other (medium) is between 20 m and 23 m. Almost 47% of the HBT is classified as highland, 41% as medium and the rest is lowland. Agriculture is undertaken on more than 80% of its hill slopes (BMDA 2000, 2006). Rainwater is the sole source of groundwater recharge in the area as it is too high for flooding. The HBT is an arid region of the country because of massive deforestation, extreme dry weather and very low rainfall. The HBT consists of three districts: Rajshahi, Nawabganj and Naogaon. This study is focused on the Rajshahi district since it has a weather station and climate related data are available for this district. Moreover, previous studies focused on the two other drought-prone districts while no study has yet been conducted on the Rajshahi district. This district covers 2,407 km^2 (BBS 2005) and lies between $24^o6'N$ and $25^o13'N$ latitude and $88^o2'E$ and $89^o21'E$ longitude (Siddiqui 1976) (Figure 3.1). The district is bounded by the Naogaon district on the north, West Bengal of India, the Kushtia district and the River Padma on the south, the Natore district on the east and the Nawabganj district on the west (BMDA 2006; Siddiqui 1976).

The weather of the Rajshahi district is characterised by the lowest and most variable rainfall and the highest maximum temperatures in Bangladesh (Ahmed & Chowdhury 2006; FAO 2006). Agriculture is the major livelihood activity in the district. Other activities include small business operators and workers, service industries and the transport sector. The total cultivable land is 157 728 ha (BBS 2005). The many poor peasants include 31% who are landless. There distribution of farmers are 47% small, 19% medium and 3% large (BBS 2005). The major crops of the district include rice, wheat, jute, sugarcane, turmeric, oil seed, onion, garlic, potato and betel leaf.

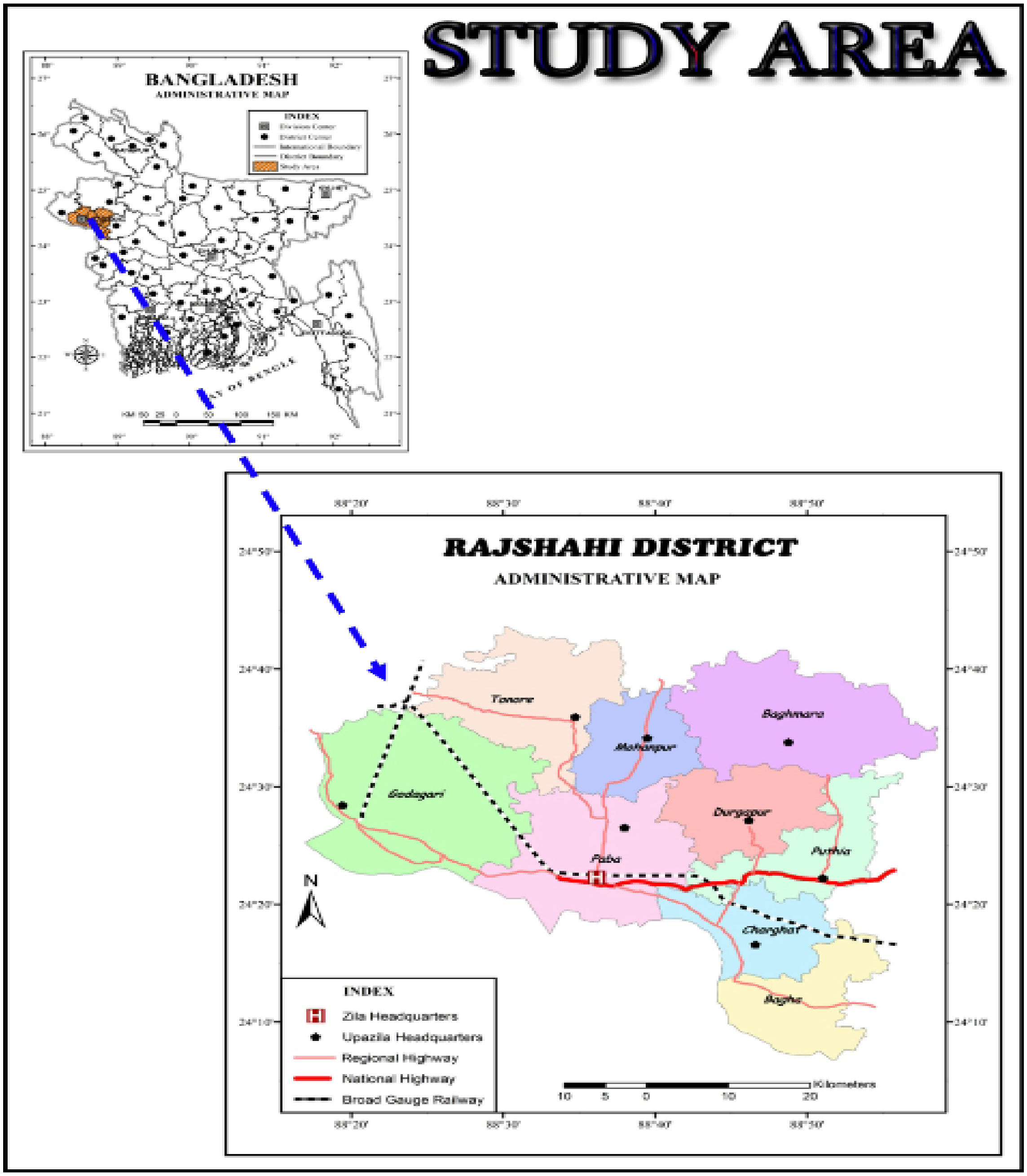


Figure 3.1 Map of the Rajshahi district

Source: adapted from http://www.banglapedia.org/httpdocs/HT/R_0079.HTM

3.4.2 Description of specific study area

Based on the available literature, newspapers reports and consultations with agriculture extension officers at division and district levels, two Upazilas (sub-districts; namely

Tanore and Godagari) were chosen for the field survey. Godagari covers an area of 472 km^2 (Figure 3.2) with a population of 217 811 while Tanore has an area of 295 km^2(Figure 3.3) with a population of 138 015 (BBS 2008).

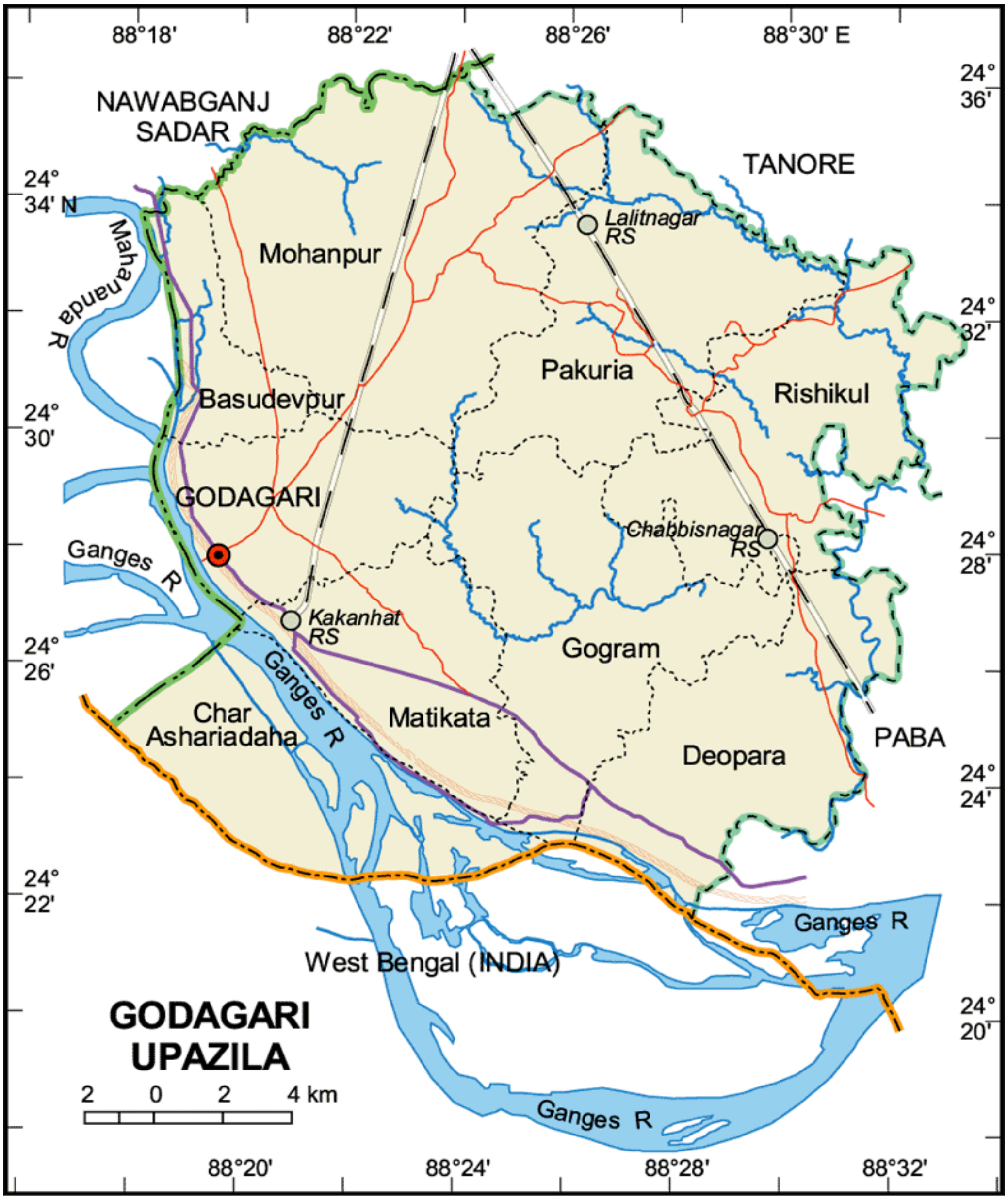


Figure 3.2 Map of the Godagari Upazila

Source: http://www.banglapedia.org/httpdocs/HT/G_0144.HTM.

Agriculture is the main economic activity in the Godagari Upazila and rice is the main staple food grown and consumed. The Padma (the Ganges) and Mahananda rivers are the two main rivers of this sub-district.

Figure 3.3 Map of the Tanore Upazila

Source: http://www.banglapedia.org/httpdocs/HT/T_0048.HTM.

Agriculture is also the main occupation in Tanore Upazila and rice cultivation is the major livelihood activity. The main water bodies of this sub-district are the Shiba River and Beelkumari beel.

After consultation with sub-assistant agriculture officers at the field level and based on newspapers reports, 15 villages were selected for the field survey: Kolipur, Ghuntighor, Bijoynagar, Najirpur, Digram, Khagrabad, Maria, Shibrampur, Shadipur, Jhinarpara, Moshupara, Jothgokul, Jhumarpara, Telopara and Dhamdum. The reasons for their selection included:

- the villages have comparatively large numbers of farming households;
- rice cultivation, mainly rain-fed Aman, is the major livelihood activity;
- different types of farmers (large, medium, small, marginal and landless) live in these villages;
- many farmers are practicing different types of adaptation strategies; and
- there exists easy road access to the villages from the sub-district headquarters.

3.4.3 Study population and sampling strategy

The population of this study is all farm households residing in the selected villages. Thus there are very many farm households. The standard statistical formula for selecting a sample size results in a huge number which is impractical for an individual researcher because of time and funding constraints (Gilbert 2008; Blaikie 2010). Since all the farmers in the villages face similar socio-economic, environmental and climate conditions in their farming activities, they make up a mostly homogeneous group which validates the use of a small sample size which can be representative of the whole population (Gilbert 2008; Blaikie 2010). Therefore, sample size is determined based on other criteria rather than a statistical formula. A sample size of 350 is considered the optimal size for a structured interview in quantitative research (Perry 1998). In addition, 5% of the population has been regarded as a sufficiently large sample size for survey research (Bartlett et al. 2001). This study aimed to survey a sample of 550 randomly chosen rice farming households, which is 15% of the farm population in each village. This was expected to reflect the farming features of all farmers in the villages. The distribution of the sampling strategy is given in Table 3.4.

Table 3.4 Population and sample size for the survey

Village	Farm Households	Sample Size (15% of the population)
Kolipur	127	19
Ghuntighor	240	36
Bijoynagar	213	32
Najirpur	173	26
Digram	453	68
Khagrabad	127	19
Maria	347	52
Shibrampur	247	37
Shadipur	533	80
Jhinarpara	120	18
Moshupara	133	20
Jothgokul	67	10
Jhumarpara	227	34
Telopara	247	37
Dhamdum	80	12
Total sample size	3334	550

Source: Sub-Assistant Agricultural Officers in the study area.

A complete and numbered list of all rice farming households in the respective villages was collected from the Sub-Assistant Agricultural Officers (SAAOs) in the study areas. The numbered list provided names and addresses of farmers with their farm sizes. Afterwards, a simple random sampling using a computer-generated random number table was applied to the list to select 550 farm households. In this way the randomness in the sampling procedure was ensured.

3.4.4 Questionnaire survey

3.4.4.1 The design of the questionnaire

The main objective of the questionnaire was to determine farmers' perception of the impact of climate change on rice production and to evaluate how farmers were responding to climate change. Accordingly, a draft questionnaire was developed. The questions were directly related to the research questions of this study. The questionnaire had eight sections: households' socio-demographic characteristics, farm characteristics, land and soil characteristics, institutional accessibility, farmers' perception of climate change, impact of climate change on rice production, farmers' adaptations strategies in the face of climate change, and costs and returns in the previous production year (see Appendix II for the complete survey questionnaire). The details of these sections are discussed below:

The first section of the questionnaire (Section A) gathered farm households' socio-demographic information. It included household head's gender, age, education, main occupation, secondary occupation, household size, annual farm income, non-farm income and household assets.

The second section (Section B) was on farm characteristics: farm size, including own land, rented-in land, rented-out land, leased-in land, leased-out land and homestead land. It also included households' tenure status, livestock ownership and the farming experience of the household head.

The third section (Section C) focused on land elevation and soil quality. Land elevation was classified into four types: high, medium high, medium low and low. Soil quality was classified into four types: clay, clay-loamy, loamy and sandy.

The fourth section (Section D) contained farm households' institutional accessibility. The questions related to households' accessibility to extension services on rice production, farmer-to-farmer extension services, advance weather forecasts, agricultural credit, agricultural subsidies, irrigation facilities, electricity, crop selling places, distance to market, farmers' perception of the availability of major agricultural inputs (such as irrigation, seed, fertilizer, herbicides, pesticides and labour), and membership of a group or organization.

The fifth section (Section E) was to elicit farmers' perceptions about climate change over the past 10–20 years. Farmers provided their opinions on changes to the major climate variables of interest to this study as well as drought, availability of groundwater, availability of surface water, heatwave and cold wave. For each climate attribute, there were four mutually exclusive options: increased, decreased, remained the same, and don't know.

The sixth section (Section F) queried farmers' perceptions of rice production losses due to climate change. The first question was whether farmers perceived any loss in rice production. Second, the perception of production loss was measured using a likert scale which consisted of five options: very severe, severe, moderate, slight and no loss. The third question was about the percentage loss of Aman rice production.

The seventh section (Section G) focused on farmers' adaptation to the changing climate. Farmers were asked whether they had undertaken any adaptation strategies in order to limit adverse climate change impacts on rice production. Farmers were provided with a set of options from which they could choose. This section also included questions regarding adapt to the adaptation (other adjustment mechanisms to the adaptation strategies) as well as barriers to adaptation.

The final section (Section H) examined the costs and returns of rice production for the 2010-11 production year. Cost items consist of per bigha costs of irrigation (1 bigha = 33 decimals of land), plough, labour, fertilizer, seed, herbicides and pesticides. Returns included production of rice in maund/bigha and price/maund (1 maund = 40 kg). It also included an estimate of the total cultivated land in order to calculate the total return and total costs.

3.4.4.2 Validity and reliability of the questionnaire

Validity and reliability are two very important issues in surveying. They are concerned with the psychological characteristics of measurement and its precision as measurements are hardly perfect, particularly in the case of questionnaire responses, which can be hard to measure accurately and hence often result in measurement errors (Williams 2003; Muijs 2004; Singh 2007).

Validity attempts to evaluate whether a measure of a concept actually measures that concept (Singh 2007). In other words, validity asks the question: are we measuring what we want to measure (Muijs 2004)? Reliability implies the consistency of measures, that is, the capability of a measurement instrument to measure the same thing each time it is used in differing circumstances (Singh 2007).

Validity of the questions in this questionnaire were theoretically defined and based on the literature on the impact of climate change and adaptation at the farm level. The variables or questions were drawn from the literature on the topic. Therefore, the questions are content valid.

Reliability of the questionnaire can be achieved by internal consistency (Williams 2003). The internal consistency of the questionnaire was achieved by asking respondents questions in more than one way during a face-to-face interview and testing for consistency in responses.

3.4.4.3 Pre-piloting the questionnaire

It is important to test a questionnaire in order to identify any ambiguities in the questions and to identify the range of probable responses for each question. The test is not a formal process rather more of an information gathering technique (Williams 2003). Accordingly, the questionnaire was trialled with academics and discipline experts at Rajshahi University, Bangladesh. The questionnaire was also tested with the Upazilla Agriculture Extension Officer, Tanore and two SAAOs in the study area. The questionnaire was amended after each session. This procedure made the questionnaire unequivocal, suitable and acceptable to the final respondents.

3.4.4.4 Piloting the questionnaire

Based on the pre-piloting test and informal interviews with Agricultural Extension Officers and SAAOs in the study area, the draft questionnaire was modified to accommodate new questions and to remove irrelevant ones. It is essential to test the questionnaire with a similar population to the proposed survey group in order to check how respondents respond to the questions. It also provides suggestions for alternatives (Williams 2003; Muijs 2004; Greasley 2008). After the preliminary testing, the amended questionnaire underwent a formal pilot programme with ten individual farmers and with four groups of 6–8 farmers. This procedure made the questionnaire ready for conducting the survey (see Appendix II for final questionnaire).

3.4.4.5 Conducting the survey

The surveying took place from October to December 2010. Four trained field investigators under the close supervision of the researcher of this study conducted the field surveying. All four field investigators were graduates of the Economics Department of the University of Rajshahi, which is located in the study area. Moreover, the investigators were given extensive training both theoretical and in the field before the survey was conducted. The researcher closely monitored the implementation of the survey and participated in the fieldwork. The final questionnaire was administered either at the home of a farmer or on the farm in a personal interview. The interview enabled the investigators to explain the questions in detail and in different ways to the farmers. Since most of the farmers are illiterate and telephones are almost non-existent, mail and telephone survey methods were not applicable for the study area. Therefore, the personal interview was the most pertinent method for this study in order to generate the most reliable information.

3.4.4.6 Data coding, entry and cleaning

After collecting the completed questionnaire, it was coded for ease of data entry. Data from the completed questionnaires were entered into the Statistical Package for Social Sciences (SPSS; version 15) by the researcher. The SPSS is a useful software package for questionnaire surveys because of its flexibility, ease to use and its convertibility into other packages' files (Williams 2003). In this study, the SPSS data file was later converted to a Stata file for regression analyses (see Chapters 6 and 7).

Once the data entry was completed, the data were then cleaned by producing frequency figures for each question and examining the outliers. Consequently, a large number of completed questionnaires were rechecked to avoid inconsistencies. At this stage, the data file was ready for final analysis.

3.4.5 Data analysing methods

Although the survey included two inter-related parts (impact and adaptation), the data analysing techniques use different procedures which have some similarities. Therefore, they are explained separately.

3.4.5.1 Data analysing methods for impact analysis

Table 3.5 summarises the major statistical tools used along with their purposes and the software used.

Table 3.5 Statistical techniques, their use and the statistical package used

Statistical tools	Purpose of use	Software used
Frequencies and Percentages	For analysing categorical variables, e.g., socio-demographic profile of respondents	SPSS 15
Descriptive statistics such as mean, standard deviation, maximum, minimum	For analysing the numeric or scale variables	SPSS 15
Graphs such as pie chart and bar diagram	For depicting categorical variables, e.g., percentage of production loss in group is depicted in graph	Excel 2007
Pearson chi-square test	To compare the relationship between two categorical variables, e.g., bi-variate analysis of association of net revenue and its determinants. Bi-variate association between production loss and its determinants are illustrated by the test for this study.	SPSS 15
Systematic and directional measures	To provide some sense of the strength of the bi-variate relationship under Pearson chi-square test	SPSS 15
Independent sample T-test	To compare the mean of a continuous variable between two groups of different variables, e.g., mean of production loss due to climate change is compared between integrated and non-integrated farms.	SPSS 15
Mean Procedure	To compare the mean of net revenue and production loss among more than two categories of a variable.	SPSS 15
ANOVA	To verify the significance of the results under mean procedure.	SPSS 15
Bi-plot	To present a visible relationship between two categorical variables with more than two groups, e.g., levels of profit and farm types are depicted by a bi-plot.	SPSS 15
Multivariate regression (both mean and median regression)	To analyse the determinants of net revenue and production loss under changing climate.	STATA 10
Breusch-Pagan test	To check the problem of heteroscedasticity under mean regression.	STATA 10
Variance Inflation Factor (VIF)	To check the presence of multicollinearity under mean regression.	STATA 10

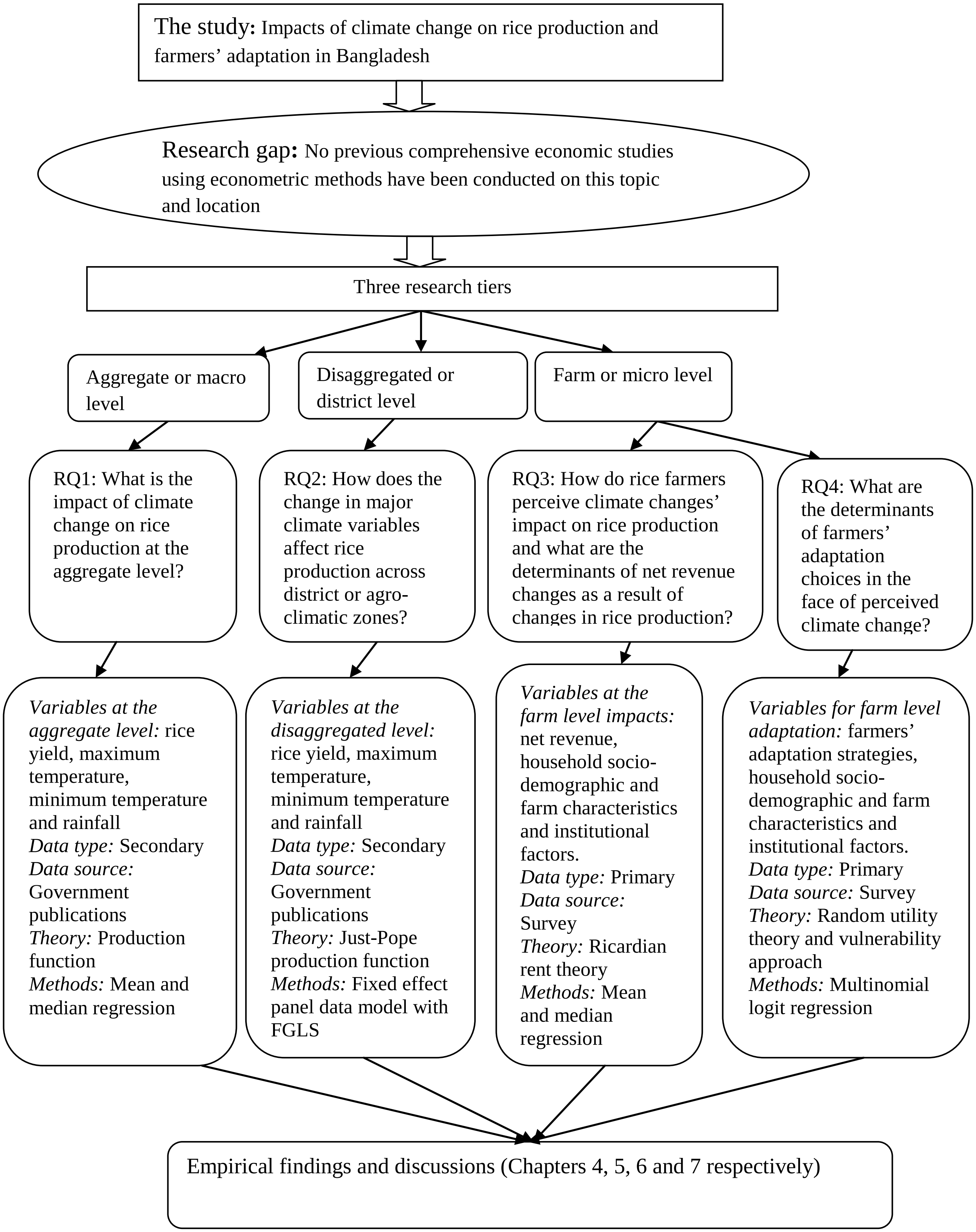
3.4.5.2 Data analysing methods for adaptation analysis

The second part of the survey method was concerned with farmers' perceptions about climate change and their adaptation strategies, adapt to adaptations and barriers to adaptation. For these data, both descriptive statistics and the regression model were used (Table 3.6.)

Table 3.6 Statistical techniques for analysing rice farmers' adaptation to climate change

Statistical tools	Purpose of use	Software used
Line chart	To observe the trend in climate variables	Excel 2007
Bar chart, pie chart, column chart	To represent the farmers' adaptation choices, barriers to adaptation	Excel 2007
Multinomial logit model (MNL)	To analyse the determinants of farmers' adaptation choices	STATA 10
Hausman test	To test the assumption of IIA for the MNL model	STATA 10

3.5 Research design: an overview



The coordination matrix in Table 3.7 relates the research questions to their research methodology. It sets out a matrix of research questions, data required, data sources and the major methods of analysis.

Table 3.7 The coordination matrix

Research questions	**Data required**	**Data sources**	**Major methods of analysis**
What is the impact of climate change on rice production at the aggregate level?	Aggregate time series data on rice yields for Aus, Aman and Boro, time series data on yearly maximum temperature, minimum temperature and total rainfall at a national level.	Secondary data from Bangladesh Economic Review and Bangladesh Meteorological Department	Mean and median regression
How does the change in major climate variables affect rice production across district or agro-climatic zones?	District level time series data on rice yields for Aus, Aman and Boro, time series data on yearly maximum temperature, minimum temperature and total rainfall across districts.	Secondary data from Yearbook of Agricultural Statistics of Bangladesh and Bangladesh Meteorological Department	A balanced panel model using the framework of a Just-Pope production function
How do rice farmers perceive climate changes' impact on rice production and what are the determinants of net revenue changes as a result of changes in rice production?	Perception about production loss, total production costs, production revenue, household socio-demographic, farm and institutional characteristics such as gender, age, occupation and education of household head, farm income, non-farm income, household size, household asset, farm size, farm type, tenure status, farming experience, integration of farms, access to weather information, official extension service, farm-to-farmer extension, access to credit, subsidy, irrigation, electricity, crop selling place, membership status in an organization, years of involvement in the organization, distance of local and urban market from home.	Primary data from 550 farm households	Chi-square test, Independent sample T-test, mean and median regression

What are the determinants of farmers' adaptation choices in the face of perceived climate change?	Perceptions about climate change such as change in temperature, rainfall, droughts, availability of ground and surface water, cold wave and heat wave. Farmers' socio-demographic characteristics: gender, age, and education of household head; farm income; household assets; household size; farm characteristics: farm size, farming experience, tenure status, livestock ownership; institutional accessibilities: farmers access to weather information, credit, subsidies, official extension services, farmer-to-farmer extension, electricity at home and distance to local and urban market.	Primary data from 550 farm households	Multinomial logit regression

3.6 Conclusion

The key objective of this chapter was to outline the methodological framework to be used in this study. Accordingly, the method by which all three levels for analysing the impact of climate change and adaptations on rice farming in Bangladesh have been explained in detail. For the first stage (i.e., the impact of climate change at national level) the key methods are mean and median regressions. For the second stage (i.e., the impact at district level) a Cobb-Douglas type fixed panel model with FGLS as the estimation method has been applied using the theoretical framework of a Just-Pope production function. Finally, descriptive statistics such as chi-square test, independent sample t-test, mean procedure, ANOVA, mean, median and multinomial logit regressions are applied at the third or farm level.

Chapter 4 An Overview of Climate Change in Bangladesh and Rice Yield Responses: An Analysis of Aggregate Level Data

4.1 Introduction

This chapter is focused on the first research question. Has the Bangladesh climate changed over the last 60 years? Do climate projections indicate future climate changes? Have rice yields in Bangladesh increased over the past 40 years? What is the relationship between climate variables and rice yields since the country's independence in 1971? This chapter endeavours to answer these questions by:

- analysing the changes in major climate variables over the past 60 years (e.g., maximum temperature, minimum temperature and rainfall); and
- assessing the impact of these climate variables on rice yields of different varieties using time series data.

To answer these questions, this chapter commences with a definition of climate change and variability. Then an analysis of climate change for Bangladesh and its variability is undertaken. Rice yield responses to the changes in climate are then examined. Finally, some concluding comments are presented.

4.2 Defining climate change and variability

Climate change is a prime example of a negative environmental externality (Tol 2009). According to the IPCC (2007), climate change refers to any changes in major climatic variables over a long time. These changes occur because of either natural variability or human activities. However, according to the Framework Convention on Climate Change, a change of climate is attributed directly or indirectly to human activities that alter the composition of the global atmosphere (IPCC 2007).

Climate change can also be defined as an overall shift in climate conditions such as mean maximum or minimum temperature and average total rainfall in a given region over a long period. Climate variability refers to temporal variation about the mean. Nonetheless, the difference between these two concepts is not absolute, especially as a change in climate per se may induce, *ipso facto,* a change in variability around a changing mean (Rosenzweig & Hillel 2008). It is noteworthy that the severity and frequency of extreme climate events such as flood, drought and cyclone are on the rise due to climate change (IPCC 2007; Rosenzweig & Hillel 2008).

4.3 Present climate of Bangladesh

Temperature, rainfall, wind speed and solar radiation mainly characterise the climate system of Bangladesh and determine the four seasons (Islam & Neelim 2010). Bangladesh has a tropical monsoon climate with four distinct seasons (Brammer 1999; Brammer 2002):

a) Pre-monsoon (March–May): This is the hot or summer season characterised with high temperatures and evaporation rates, and occasional line squalls (nor'-westers) by thunderstorm rainfall, strong wind and occasional hail; tropical cyclones (typhoons) are also liable to affect coastal areas.

b) Monsoon (June–September): This season is the period of high intensity rainfall, humidity and cloudiness.

c) Post-monsoon (October–November): The characteristics of this season include a hot and humid period with decreasing rainfall, but sunny and with heavy dew at night.

d) Dry or winter season (December–February): This season is depicted as the coolest, driest and sunniest period of the year.

Mean annual temperature is almost 25°C everywhere in the country but ranges between 18°C in winter and 30°C in the pre-monsoon season (Brammer 1999). Mean annual rainfall is lowest in the west (1250–1500 mm) and highest in the north, east and south (>2500 mm); and it exceeds 5000 mm in the extreme northeast of Sylhet. However, rainfall is very variable, resulting in severe droughts and floods.

Rashid (1991) divided Bangladesh into seven climatic sub-zones (Figure 4.1). These sub-zones are described briefly:

Southeastern sub-zone: This zone consists of greater Chittagong district and Chittagong Hill Tracts and a coastal strip extending from southwest Sundarban to the south of Comilla. Heavy rainfall and small range of mean temperature are the major climatic characteristics of this region.

Northeastern zone: This zone comprises the greater Sylhet district. The salient climatic features of this region include mild summer temperatures, heavy rainfall and a cloudy cold winter.

Northern part of the north: This zone includes the greater Rangpur district and the northern part of the greater Dinajpur district. In terms of climate, this is an area of extremes: heavy rainfall, hot summer temperatures and cold winters are three major climatic characteristics.

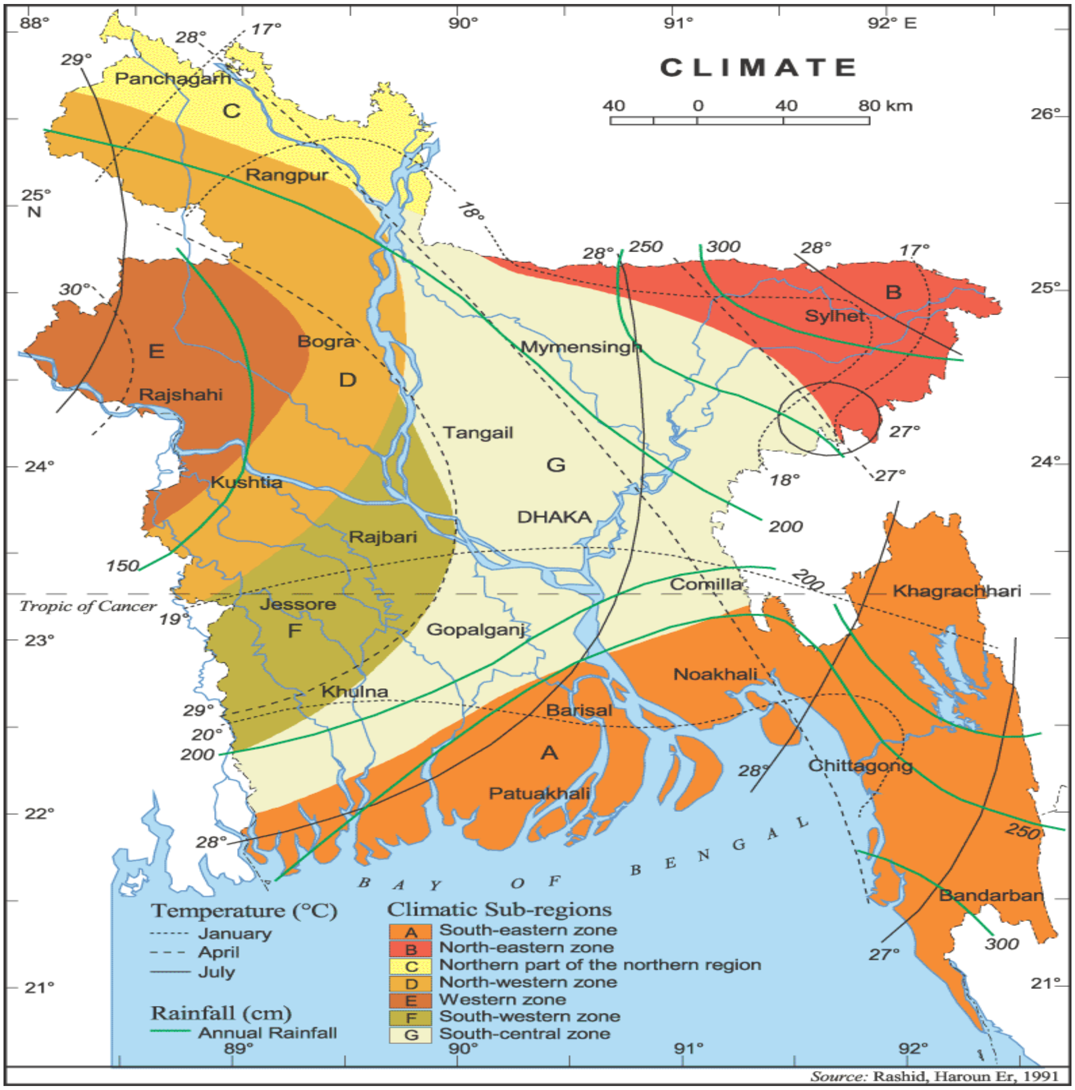


Figure 4.1 Climate zones in Bangladesh
Source: Rashid (1991), (http://www.banglapedia.org/httpdocs/HT/C_0288.HTM)

Northwestern zone: This area contains the Dinajpur, Bogra, Pabna and Kushtia districts. The main climatic conditions are hot summer temperatures and a moderate rainfall.

Western zone: This is the driest and hottest sub-zone which includes the greater Rajshahi districts and parts of adjacent districts. Very hot summer temperatures and relatively low rainfall are the climatic features of this zone. This is the area of interest for the farm level analysis.

Southwestern zone: This zone comprises the Khulna, Jessore and Faridpur districts with fewer extremes. Climatic characteristics are hot summer temperatures and fairly heavy rainfall.

South central zone: This is an area of mild summers and fairly heavy rainfall. This zone consists of the Dhaka, Tangail, Mymensingh and Barisal districts.

4.4 Methods for discovering variability in climate

Three statistical methods are employed to examine the variability of climate. First, descriptive statistics such as mean, standard deviation and coefficient of variation (CV) are used. Second, a simple trend model is used to examine the time trend of variability. Third, a more robust technique of analysing the strength of association, QR, is used to observe changes in climate variables over time. Variability of a variable over a long period of time is traditionally explained by a linear trend model fitted by an ordinary least squares (OLS) method (Hazell 1982; 1985; Kwasi 1998; Rimi et al. 2009). But this model based on simple linear regression only measures the rate of change in the mean of the distribution of observations, whereas climate variability can include not only changes in the mean state but also changes in the spread of the data distribution over time (Koenker & Bassett 1978; Timofee & Sterin 2009; Trivedi & Cameron 2009). When analysing the trend of climate series, the QR method can generate information on trends along the whole range of quantile values from 0 to 1 (e.g., at quantiles 0.1, 0.25, 0.5, 0.75 and 0.9, corresponding to 10%, 25%, 50%, 75% and 90% of the observations respectively) of the distribution of the dependent variable which is more informative than traditional regression techniques such as OLS. This study has therefore principally employed the QR method along with descriptive statistics and the linear trend model. Using this approach and applying it to Bangladesh time series data for the 1948–2009 period, due to greater availability of data, the changing behaviour of climate and its variability over time is briefly examined in the following section.

4.5 Empirical results of climate change and variability

4.5.1 Evidence from the simple statistical methods

Various simple statistical methods are used to assess climate variability. Table 4.1 sets out the variability in the three commonly used climate variables (average annual maximum temperature, average annual minimum temperature and average annual total rainfall) using those simple tools. These three variables are constructed from daily data from 32 weather stations throughout Bangladesh. Three time periods are considered to observe the variability over time.

Table 4.1 Climate variability in Bangladesh over the 1948–2009 period

Major climate variable	**Statistical tool**	**1948–1967**	**1968–1987**	**1988–2009**
Average annual maximum temperature (°C)	Mean	30.34	30.24	30.56
	Standard Deviation	0.23	0.25	0.31
	Coefficient of Variation (%)	0.77	0.83	1.03
Average annual minimum temperature (°C)	Mean	20.79	21.03	21.37
	Standard Deviation	0.23	0.23	0.25
	Coefficient of Variation (%)	1.10	1.11	1.19
Average annual total rainfall (mm)	Mean	2225.70	2367.34	2475.66
	Standard Deviation	260.65	262.26	262.27
	Coefficient of Variation (%)	11.71	11.08	10.59

Source: Author's own calculation based on data collected from BMD (2010)

Table 4.1 indicates significant climate variability. First, the mean for both the average annual maximum temperature and the average annual minimum temperature has increased steadily over the three periods. Absolute variability, measured by standard deviation, also increased over the same period but the relative variability, measured by

CV, is higher for the average minimum temperature than the average maximum temperature. Mean for the average annual total rainfall has also risen over the three periods. Though absolute variability in rainfall has increased, the relative variability decreased. All these provide evidence of a changing climate in Bangladesh over the last 60 years. A better representation of these changes is illustrated in Table 4.2 which shows the absolute and relative variability of climate variables over time. There seems to be time trend in both absolute and relative measures of variability.

There are considerable time trends in the mean values of all climate variables. Mean values for maximum and minimum temperature and rainfall increase gradually over the period. However, the growth in minimum temperature is higher than that of maximum temperature. Absolute variability also rises throughout the time horizon. Though CV for maximum temperature increases, CV for minimum temperature and rainfall increases initially and then declines with frequent fluctuations indicating variability in climate.

These aspects of variability become clearer if these observations are plotted against time. Figures 4.2–4.10 plot the mean, standard deviation (absolute variability) and coefficient of variation (relative variability) of the respective climate variables.

Table 4.2 Mean values, standard deviation and coefficient of variation

Year	Average maximum temperature			Average minimum temperature			Average rainfall		
	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
1952	30.22	0.13	0.45	20.69	0.14	0.67	2306.73	176.63	7.66
1953	30.29	0.15	0.51	20.76	0.23	1.12	2295.61	170.90	7.44
1954	30.39	0.13	0.44	20.84	0.19	0.89	2254.60	134.76	5.98
1955	30.41	0.11	0.37	20.86	0.16	0.74	2263.14	128.30	5.67
1956	30.36	0.17	0.56	20.84	0.17	0.82	2364.28	146.09	6.18
1957	30.42	0.18	0.59	20.78	0.24	1.14	2210.36	349.80	15.83
1958	30.51	0.29	0.94	20.81	0.30	1.42	2111.42	371.49	17.59
1959	30.37	0.40	1.32	20.77	0.29	1.40	2209.79	477.42	21.60
1960	30.42	0.42	1.38	20.79	0.29	1.39	2188.69	480.24	21.94
1961	30.43	0.42	1.37	20.82	0.28	1.36	2087.69	425.85	20.40
1962	30.40	0.41	1.35	20.81	0.30	1.44	2148.61	362.94	16.89
1963	30.30	0.30	0.99	20.68	0.16	0.78	2227.69	322.52	14.48
1964	30.39	0.18	0.60	20.76	0.26	1.25	2159.43	185.48	8.59
1965	30.32	0.12	0.39	20.75	0.26	1.24	2204.44	193.12	8.76
1966	30.38	0.09	0.29	20.82	0.31	1.51	2207.09	191.08	8.66
1967	30.33	0.12	0.39	20.88	0.24	1.17	2237.10	146.01	6.53
1968	30.25	0.17	0.55	20.91	0.21	1.01	2241.70	146.71	6.54
1969	30.26	0.17	0.57	20.86	0.17	0.82	2237.05	139.40	6.23
1970	30.23	0.18	0.61	20.94	0.20	0.98	2244.50	145.81	6.50
1971	30.13	0.15	0.50	20.86	0.18	0.86	2292.62	121.43	5.30
1972	30.21	0.25	0.83	20.86	0.18	0.87	2228.90	258.05	11.58
1973	30.22	0.24	0.80	20.93	0.22	1.07	2274.04	285.09	12.54
1974	30.15	0.25	0.82	20.92	0.23	1.09	2309.72	315.52	13.66
1975	30.16	0.25	0.82	20.88	0.19	0.92	2263.12	323.81	14.31
1976	30.24	0.23	0.78	20.94	0.18	0.87	2274.34	327.86	14.42
1977	30.13	0.15	0.51	21.00	0.13	0.60	2431.08	187.24	7.70
1978	30.14	0.15	0.50	20.93	0.10	0.49	2415.91	183.87	7.61
1979	30.27	0.21	0.71	21.07	0.25	1.20	2277.44	266.06	11.68
1980	30.27	0.21	0.71	21.15	0.28	1.31	2267.79	273.75	12.07
1981	30.16	0.28	0.91	21.15	0.28	1.33	2295.24	295.22	12.86
1982	30.21	0.27	0.88	21.14	0.29	1.35	2243.81	257.63	11.48
1983	30.18	0.28	0.93	21.19	0.23	1.10	2326.41	369.57	15.89
1984	30.10	0.17	0.56	21.04	0.23	1.09	2492.38	307.82	12.35
1985	30.16	0.26	0.88	21.00	0.17	0.79	2524.67	257.63	10.20
1986	30.31	0.25	0.82	21.01	0.17	0.79	2495.00	265.56	10.64
1987	30.41	0.30	1.00	21.10	0.26	1.24	2565.56	247.92	9.66
1988	30.53	0.22	0.71	21.20	0.33	1.58	2537.99	216.62	8.54
1989	30.60	0.09	0.30	21.25	0.26	1.21	2417.25	252.62	10.45
1990	30.51	0.24	0.79	21.28	0.26	1.20	2502.44	248.70	9.94
1991	30.43	0.27	0.89	21.32	0.22	1.03	2586.33	267.03	10.32
1992	30.38	0.22	0.73	21.25	0.21	1.01	2435.33	399.07	16.39
1993	30.28	0.18	0.60	21.14	0.14	0.67	2439.97	402.94	16.51
1994	30.29	0.21	0.69	21.17	0.12	0.56	2423.97	420.06	17.33
1995	30.39	0.21	0.71	21.21	0.18	0.85	2378.06	399.35	16.79
1996	30.52	0.25	0.83	21.23	0.20	0.94	2291.17	325.19	14.19
1997	30.47	0.29	0.94	21.18	0.26	1.24	2385.28	241.00	10.10
1998	30.53	0.22	0.72	21.32	0.32	1.52	2398.83	265.02	11.05
1999	30.62	0.31	1.02	21.43	0.35	1.63	2521.06	187.70	7.45
2000	30.57	0.34	1.10	21.38	0.36	1.66	2551.51	182.32	7.15
2001	30.55	0.32	1.05	21.36	0.36	1.68	2580.19	154.80	6.00
2002	30.62	0.27	0.87	21.46	0.23	1.06	2632.57	101.35	3.85
2003	30.61	0.27	0.89	21.39	0.18	0.86	2533.02	148.23	5.85
2004	30.49	0.16	0.52	21.33	0.07	0.33	2549.38	167.73	6.58
2005	30.59	0.18	0.60	21.44	0.19	0.87	2539.01	166.47	6.56
2006	30.67	0.32	1.04	21.54	0.21	0.97	2476.74	227.81	9.20
2007	30.65	0.33	1.08	21.53	0.21	0.98	2512.97	269.42	10.72
2008	30.66	0.32	1.05	21.55	0.20	0.93	2535.84	249.56	9.84
2009	30.84	0.40	1.29	21.60	0.19	0.87	2435.78	251.16	10.31

Sources: Based on data collected from BMD (2010) ; Notes: Original data series were from 1948 to 2009. Five-yearly moving average is taken to compute mean value series. As a result time period has reduced to 1952–2009. Standard deviations (SD) are based on the corresponding five-yearly figures. CV = [(SD) /Mean] ×100.

In Figure 4.2, the variability in mean annual temperature over the period can be located visually. Mean annual temperature, on average, appears to decrease up to 1985, then tends to increase sharply up to 2009 with some variations over the period. However, the overall trend is upward.

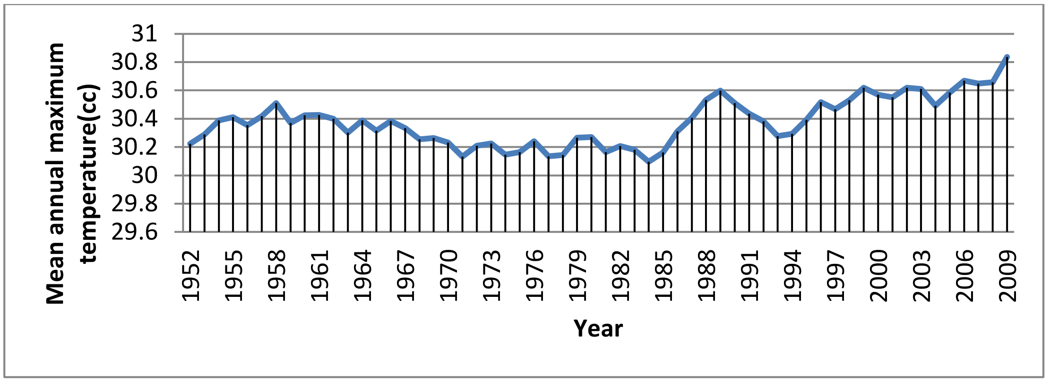


Figure 4.2 Moving average of mean annual maximum temperature

The absolute variability in mean maximum temperature for the 1952–2009 period is shown in Figure 4.3. It shows a rapid increase to 1961 then it decreases quickly to 1967. From 1967 to 2009 it exhibits a steady increase with some fluctuations over the period. All these indicate the variability in the mean maximum temperature.

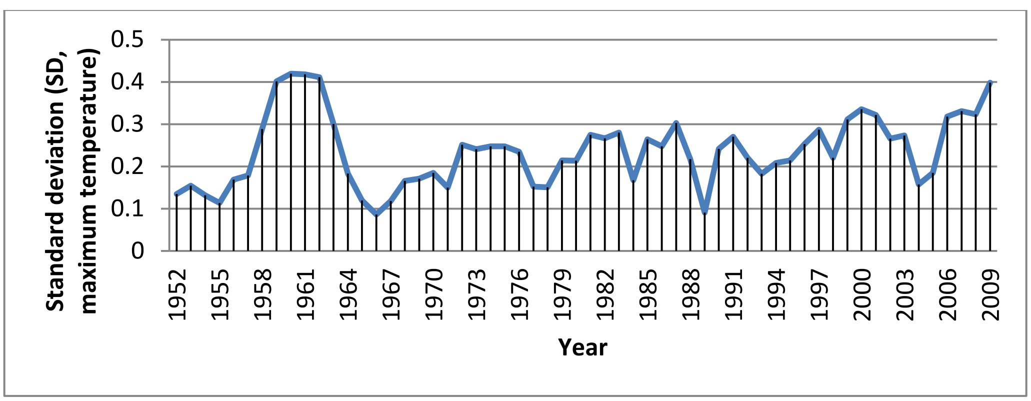


Figure 4.3 Standard deviation of mean maximum temperature

The relative variability of the mean maximum temperature against time is plotted in Figure 4.4. One can locate overall similar characteristics in its behaviour to those for absolute variability of maximum temperature. However, there is a difference. This relative variability has increased to a higher average value.

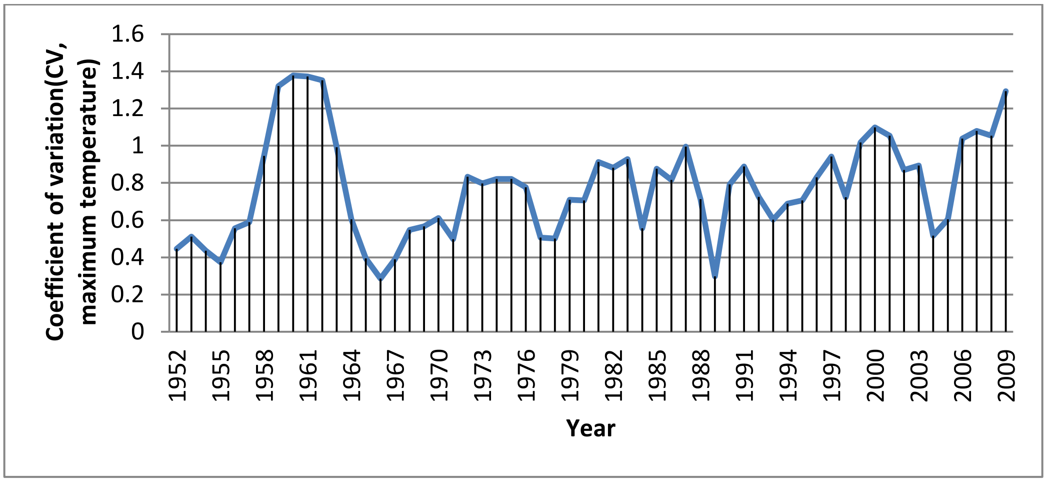


Figure 4.4 Coefficient of variation in mean maximum temperature

In Figure 4.5, one can easily observe a sharp increase in the mean minimum temperature. The speed of increase is higher for the 1985–2009 period compared to the 1952–1984 period. This gives an indication of a steady increase in the mean minimum temperature over the period. Overall time trend, therefore, can be established. Moreover, if this figure is compared with maximum temperature it becomes clear that the rate of increase in the minimum temperature is higher than that of the maximum temperature.

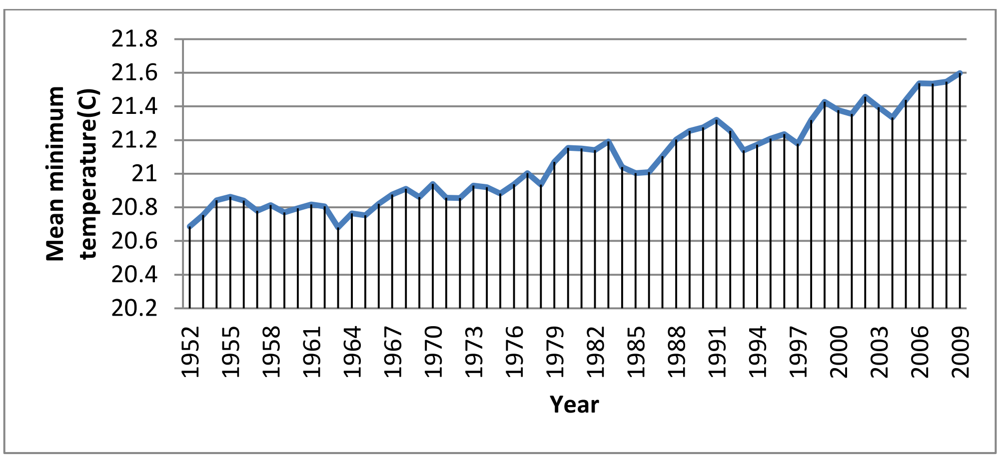


Figure 4.5 Moving average of mean annual minimum temperature

The behaviour of absolute variability in the minimum temperature over the period is depicted in Figure 4.6. The overall time trend is not significant. However, there are spurts and dips in absolute variability which provide a vivid image of variability in the minimum temperature.

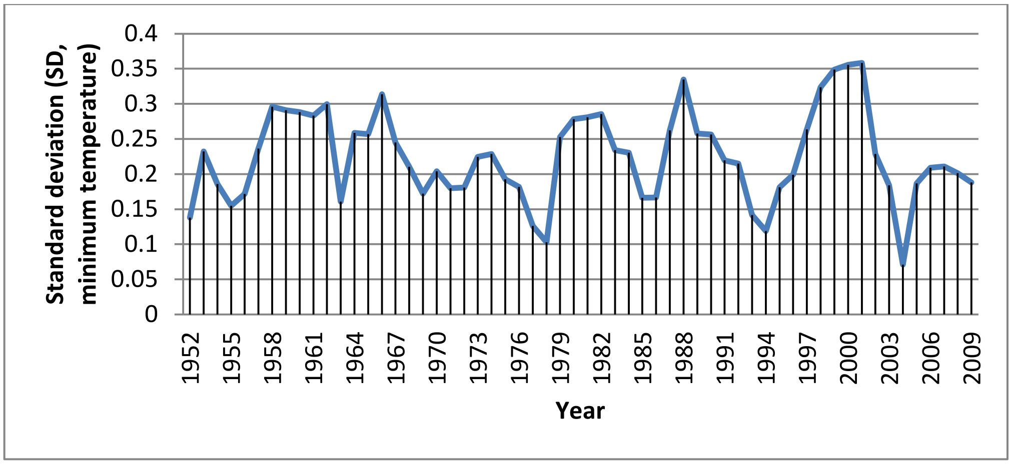


Figure 4.6 Standard deviation of mean minimum temperature

The relative variability in the mean minimum temperature is portrayed in Figure 4.7. It follows a similar pattern to that for absolute variability. However, the relative variability has a higher average value compared to that for absolute variability.

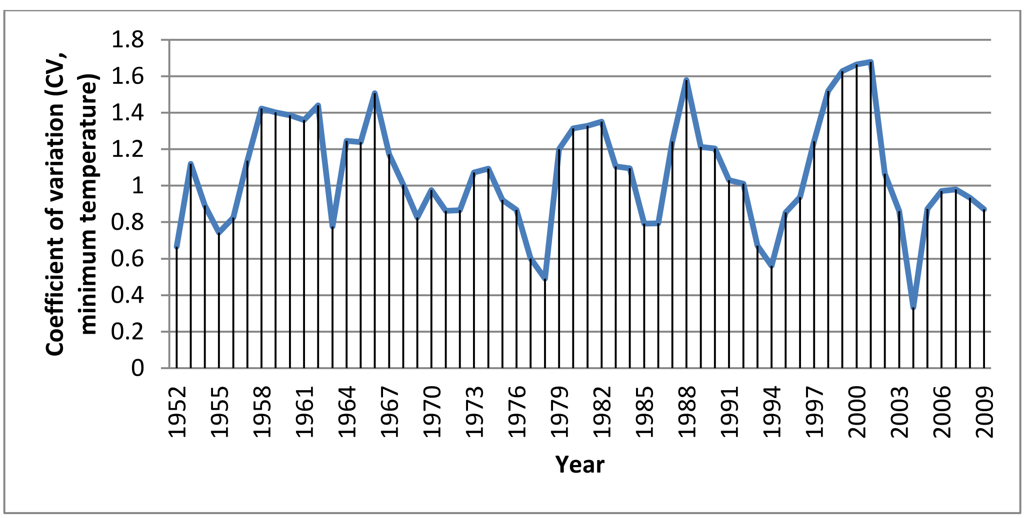


Figure 4.7 Coefficient of variation in minimum temperature

The mean annual rainfall against time is shown in Figure 4.8. This shows a steady increase in the mean annual rainfall over the 1952–2009 period. There is a small but apparent upward trend in the variable for the period.

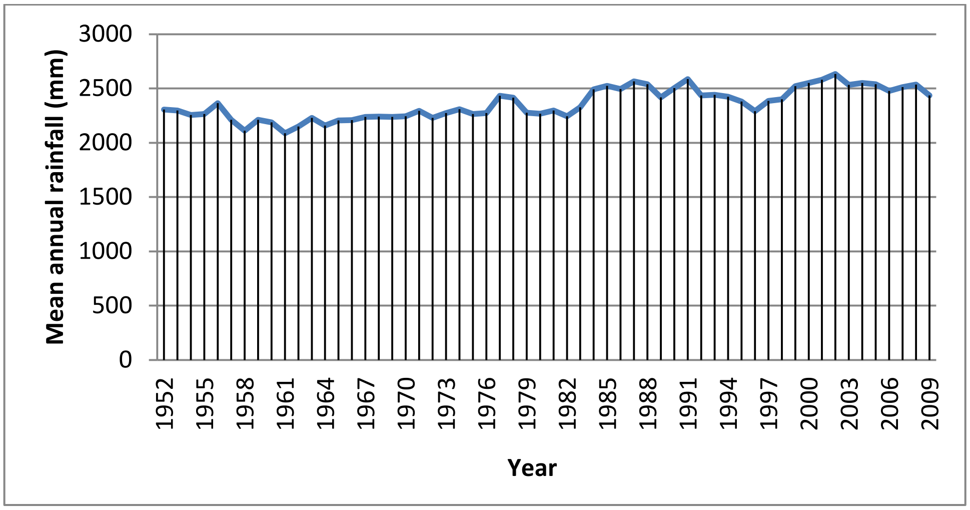


Figure 4.8 Moving average of mean annual rainfall

Absolute variability in the mean annual rainfall against time is depicted in Figure 4.9. From 1955 to 1959 there was a sudden and rapid increase in rainfall variability but it started to decrease rapidly in 1960 and continued to decline to 1964. Since then, the overall absolute variability in rainfall increased until 1994. From 1994 to 2009 the average variability of rainfall has declined with a few ups and downs.

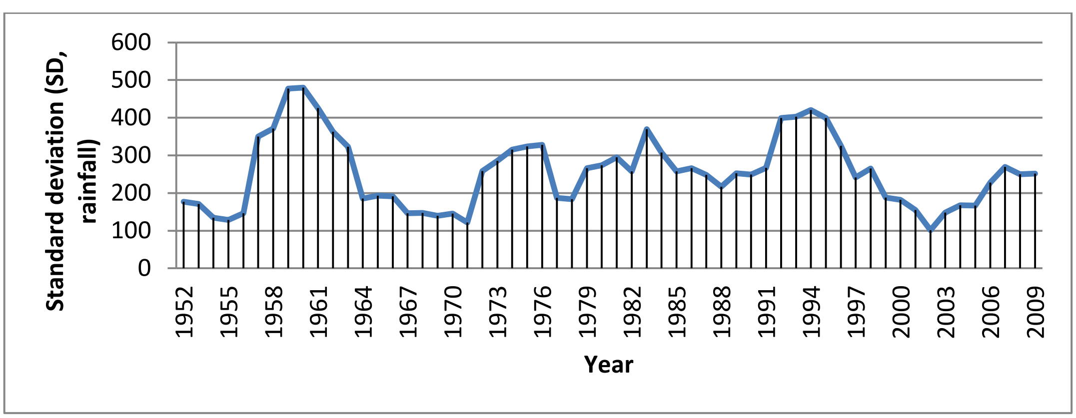


Figure 4.9 Standard deviation of mean annual rainfall

The relative rainfall variability over the period is depicted in Figure 4.10. The pattern of change in the relative variability is similar to that for absolute variability. No overall trend is seen but a phase specific trend can be located easily.

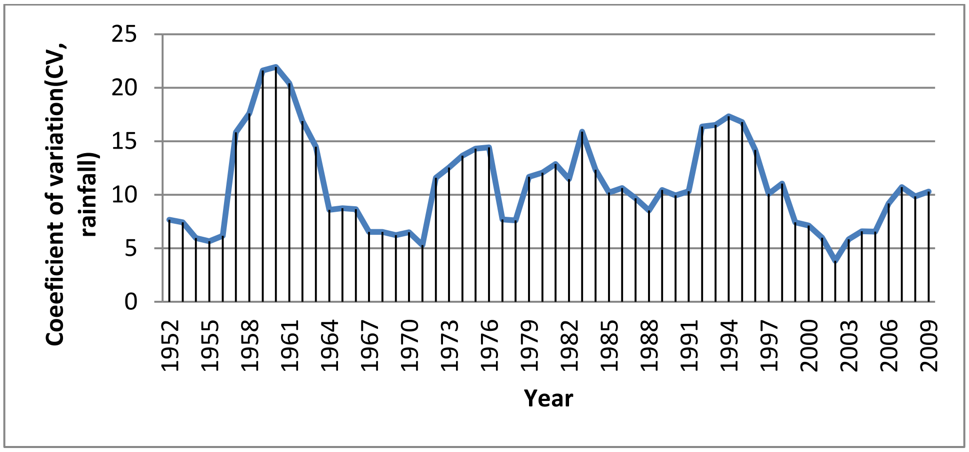


Figure 4.10 Coefficient of variation of annual rainfall

In terms of the above analyses of absolute and relative variability in climate, there is strong evidence to suggest that there is increased variability in major climate variables over time. A thoughtful observation of the figures reveals different phases of fluctuations in climate which supports the thesis of the existence of overall climate change.

4.5.2 Evidence from trend model

In order to build the quantitative justification for the change of climate variability, linear regression (linear trend model) for three major aggregate climate variables with time (T) as the explanatory variables are estimated over the whole period. Results are illustrated in Table 4.3 where equation 1(a) represents five-yearly moving average (mean), equation 1(b) indicates the standard deviation and equation 1(c) stands for coefficient of variation for maximum temperature and so on for the other climate variables of minimum temperature and annual rainfall, respectively.

Table 4.3 Trends in the variability of three major climate variables, 1952–2009

Aggregate climate variables	Dependent variables	Intercept	Coefficient	R^2	t-value	P-value	F-value	Prob. >F
Maximum temperature (Equation 1)	Mean (a)	19.59996	0.00544*	0.2950	4.84	0.000	23.43	0.000
	Standard deviation (b)	-2.35420	0.00131**	0.0701	2.05	0.045	4.22	0.044
	Coefficient of variation (c)	-7.43433	0.00415***	0.0659	1.99	0.052	3.95	0.051
Minimum temperature (Equation 2)	Mean (a)	-7.15653	0.01425*	0.9028	22.81	0.000	520.31	0.000
	Standard deviation (b)	0.204865	0.0000****	0.0000	0.02	0.984	0.000	0.984
	Coefficient of variation (c)	2.39664	-0.00067****	0.0014	-0.28	0.780	0.08	0.780
Annual rainfall (total) (Equation 3)	Mean (a)	-2020333	1050.86*	0.9216	25.67	0.000	658.69	0.000
	Standard deviation (b)	-1467770	77.6537*	0.2611	4.45	0.000	19.79	0.000
	Coefficient of variation (c)	171.9669	-.080805**	0.1290	-2.88	0.006	8.29	0.005

Notes: Superscript *, ** and *** denote significance levels at 1%, 5% and 10% respectively, and **** denotes not significant.

Equations 1(a) and 1(b) clearly exhibit a strong time trend in mean and standard deviation of maximum temperature respectively. Both equations are statistically significant with considerable explanatory power. A strong time trend is also found in equation 2(a) in terms of both statistical significance and explanatory power. This equation has three times higher explanatory power than equation 1(a). Equation 2(b) implies no trend in absolute variability. The estimates for this equation are also poor both in terms of R^2 and t-value. Equations 3(a) and 3(b) are analogous to equation (1) with the statistically significant coefficient and significantly higher R^2. As a whole, there is a tendency for the mean and standard deviation of climate variables to increase. Therefore, the absolute climate variability appears to have risen to a higher level over the last 60 years which provides clear evidence of a changing climate in Bangladesh.

The trend model based on an OLS provides only a partial view of the relationship between variables. A more complete picture using QR method provides information about the relationship between the response and predictor variables at different points in the conditional distribution of the response variable.

4.5.3 Evidence from quantile regression analysis

Quantile regression (QR) expands the estimation technique used above (simple linear regression, SLR) to any part or selected quantile of the dependent variable (e.g., climate variable). This can provide a comprehensive analysis of the pattern of climate change (Timofeev & Sterin 2010; Gruza & Ran'kova 2004). Table 4.4 compares the results of both the SLR and QR models. Following Timofeev and Sterin (2010), QR parameters for 0.01^{th}, 0.05^{th}, 0.10^{th}, 0.25^{th}, 0.50^{th}, 0.75^{th}, 0.90^{th}, 0.95^{th} and 0.99^{th} quantiles are estimated. To compare the results, the bootstrap method with 500 replications was used for the QR. The results are shown in Table 4.4 where the QR coefficients are seen to vary considerably from the OLS coefficients, even those for median regression. However, QR coefficients are not the same across the selected quantiles; statistically significant differences in trends are observed when quantile values vary from 0.01 to 0.99.

Table 4.4 Comparing results between OLS and QR estimates at different quantiles

Variable	**OLS**	**QR_01**	**QR_05**	**QR_10**	**QR_25**	**QR_50**	**QR_75**	**QR_90**	**QR_95**	**QR_99**
Trend for maximum temperature	.0066196 (0.001) R^2 =0.16	- .0012437 (0.877) R^2 =0.01	.0070858 (0.120) R^2 =0.09	.0067934 (0.050) R^2 =0.06	.004913 (0.098) R^2 =0.05	.0039352 (0.122) R^2 =0.06	.007483 (0.016) R^2 =0.08	.0107523 (0.009) R^2 =0.15	.0112047 (0.016) R^2 =0.22	.0078104 (0.057) R^2 =0.26
Trend for minimum temperature	.0144222 (0.000) R^2 =0.59	.0120676 (0.000) R^2 =0.31	.0095986 (0.027) R^2 =0.30	.0160999 (0.000) R^2 =0.32	.0149156 (0.000) R^2=0.38	.0143015 (0.000) R^2=0.39	.0154033 (0.000) R^2=0.33	.0165238 (0.000) R^2=0.37	.0125252 (0.000) R^2 =0.38	.011157 (0.000) R^2=0.39
Trend for total rainfall	1022.77 (0.000) R^2 =0.82	856.2787 (0.000) R^2 =0.64	866.2059 (0.000) R^2 =0.60	863.4118 (0.000) R^2 =0.60	1014.22 (0.000) R^2 =0.62	1070.941 (0.000) R^2 =0.63	1283.929 (0.000) R^2 =0.54	1373.2 (0.000) R^2 =0.48	1383.12 (0.000) R^2 =0.45	1575.875 (0.000) R^2 =0.41

Trends for maximum temperature are not statistically significant at the lower quantiles (e.g., at 0.01 and 0.05). However, they are significant at the higher quantiles (e.g., at 0.90, 0.95 and 0.99). The explanatory power of the trend model for maximum temperature rises from lower to higher quantiles. However, the trends in minimum temperature are statistically significant throughout the chosen quantiles, whilst the explanatory power of trend is higher in the higher quantiles than those of the lower quantiles. Lastly, trend coefficients of QR for rainfall are clearly different from the OLS coefficients and they are also statistically significant with lower explanatory power in the higher quantiles. Therefore, the QR method provides a more detailed picture of the changing climate at the different points of time. These results are consistent with the studies of Timofeev and Sterin (2010) and Chamaille-Jammes and Murindagomo (2007).

From the above analyses using three different statistical techniques: descriptive statistics, linear trend model and QR, it can be established that there has been a change of climate over the last six decades in Bangladesh. The next sub-section will focus on the future projections of climate change drawn from the literature.

4.6 Future climate change projections

Two types of climate change projection studies are available: projections based on observed data and projections based on climate models.

The annual mean changes in temperatures of 1.0°C, 1.4°C and 2.4°C by 2030, 2050 and 2100 respectively are estimated in Table 4.5. However, the increase in winter (December-February) temperature is higher than the monsoon temperature throughout the projected years. Meanwhile, annual rainfall increases of nearly 4%, 6%, and 10% for the same years respectively are observed. The rainfall change in the winter season is negative while it is positive in the monsoon season for all the years under consideration.

Table 4.5 Future climate scenarios for Bangladesh

Year	Temperature change (°C) mean (standard deviation)			Rainfall change (%) mean (standard deviation)		
	Annual	DJF	JJA	Annual	DJF	JJA
2030	1.0(0.11)	1.0(0.18)	0.8(0.16)	+3.8(2.30)	-1.2(12.56)	+4.7(3.17)
2050	1.4(0.16)	1.6(0.26)	1.1(0.23)	+5.6(3.33)	-1.7(18.15)	+6.8(4.58)
2100	2.4(0.28)	2.7(0.46)	1.9(0.40)	+9.7(5.80)	-3.0(31.60)	+11.8(7.97)

Source: Adopted from Agarwala et al. (2003)
DJF = December, January and February; JJA = June, July and August

Using the General Circulation Model (GCM) for Bangladesh, Ahmed and Alam (1999) reported that there would be an increase of 1.3°C and 2.6°C rise in the temperatures by 2030 and 2075 respectively. They also found a seasonal variation in the temperature of +1.4°C in the winter and +0.7°C in the monsoon by 2030 while the variations are projected to be 2.1°C and 1.7°C for these seasons respectively by 2075. Rainfall will be reduced to an insignificant rate in 2030 while there will not be any noticeable rainfall in the winter by 2075. Yu et al. (2010) projected a median temperature rise of 1.1°C, 1.6°C and 2.6°C and a median annual rainfall increase of 1%, 4% and 7.4% by 2030, 2050 and 2080 respectively. This study shows that rainfall is subject to huge inter-annual and intra-annual variations. All these scenarios might have severe effects on rice production in Bangladesh. However, the focus of this study is to assess the past effects of climate on rice yields which require an analysis of variability of rice yields.

4.7 Detecting variability in rice yields

A study by Alauddin and Tisdell (1991) confirmed that variability in rice yields had increased over the 1947–1985 period in Bangladesh. This was associated with some natural and political factors, such as droughts, flood and the War of Liberation in 1971. The present study examines the yield variability in Bangladesh using simple statistical tools for the 1972–2009 period. These results are shown for two period in that 38 years and are reported in Table 4.6.

Table 4.6 Variability in rice yields for the 1972–2009 period

Varieties of rice	Statistical tools	1972–1991	1992–2009
Aus	Mean	395.97	552.13
	Standard Deviation	37.94	94.77
	Coefficient of Variation (%)	9.58	17.16
Aman	Mean	519.50	723.47
	Standard Deviation	63.53	83.24
	Coefficient of Variation (%)	12.23	11.51
Boro	Mean	897.29	1237.51
	Standard Deviation	99.75	174.20
	Coefficient of Variation (%)	11.12	14.08

It is clear from Table 4.6 that absolute variability for all rice varieties, expressed by standard deviation, has increased in the second time period as compared to the first period. Relative variability has also increased in the second period for all varieties except Aman. If a comparison is made among rice yields, it can be observed that the relative variability was highest for Aman in the first period while the Aus yield exhibits maximum variability in the second period. Overall, this simple analysis has proven that the variability in rice yields has increased over the years. This might be attributed to introduction of high yielding varieties (HYVs), extreme climate events such as floods, droughts and cyclones, extreme temperature and so on. The following section concentrates on how much variability in rice yields can be explained by climate variables.

4.8 Rice yield responses to climate variables

4.8.1 A brief overview of literature

There have been some studies on the impact of climate change at the aggregate level in Bangladesh (Ali 1996; Ali 1999; WB 2000; Mirza 2002; Mirza et al. 2003; Hutton &

Haque 2004; Pouliotte et al. 2009). Most of these studies have focused on the livelihoods of people in the southwestern coastal areas of the country which are vulnerable to cyclones, sea level rise, floods and storm surges. Most importantly, previous studies investigated agriculture as a whole, but there is no study on the economic impact of climate change on rice production using any aggregate level data. Some simulation studies have been performed to estimate the impact of climate variability on rice productivity in Bangladesh using either the CERES-Rice or DASSAT models (Karim et al. 1996; Mahmood 1998; Mahmood et al. 2003; Basak et al. 2009; Basak et al. 2010). Nonetheless, there is a need for an empirical study to assess the relationship between climatic variables and rice yields using regression models (Almaraz et al. 2008). A few international studies have been carried out (Lobell et al. 2007; Almaraz et al. 2008). However, these studies, using time series data, did not check the stationarity properties of the data which is a requirement for the time series data analysis of more than 20 years (Gujrati 2004; McCarl et al. 2008). Thus, the high R^2 values found in these studies may be considered to be spurious results. Moreover, the studies did not address the problem of auto-correlation, heteroscedasticity and multicollinearity explicitly. In order to achieve unbiased estimates, these problems need to be taken into consideration (Gujrati 2004). The present study will address this gap in the literature. To our knowledge, there is no study on the economic impact of climate variables on rice yields in Bangladesh. Therefore, the objective of this analysis is to verify the relationship between climate variables and rice yields.

4.8.2 Production of different rice varieties in Bangladesh

Three major rice crops (Aus, Aman and Boro) grow in three different seasons. Aus is normally planted in March–April and harvested in June–July. Aman is generally sown in July–August and harvested in November–December. Finally, Boro is planted in December–January and harvested in May–June. To some extent, this rice crop calendar varies from place to place depending on soil texture and elevation of land. These growing seasons practically harmonise with three climatic seasons, namely, the hot summer (March–May), the monsoon (July–October) and the winter (December–February). Table 4.7 illustrates the fundamental climatic characteristics of the three growing seasons.

Table 4.7 Basic features of climate during three rice growing seasons in Bangladesh

Rice growing season	maxt (°C)	mint (°C)	rainfall (mm)
Aus (April–August)	33.10–31.22	25.55–24.40	2218–1317
Aman (July–December)	31.02–29.52	23.19–21.77	1903–1020
Boro (December–May)	30.76–28.55	16.35–14.96	809–212

Source: BMD (2010)

Notes: $maxt$ = mean maximum temperature, $mint$ = mean minimum temperature

Climate always plays a vital role in rice production. According to BRRI (1991), Aus rice needs supplementary irrigation during the initial stage of its growing season while Aman is an almost completely rain-fed rice that grows in the monsoonal months, although it requires supplementary irrigation during planting and sometimes in the flowering stage depending on the availability of rainfall. Boro rice is completely irrigated because it grows in the dry winter and the hot summer (Mahmood 1997). More than 90% of Boro rice production is presently irrigated compared with only 5% of Aman and 8% of Aus rice (Ahmed 2001).

4.8.3 Data, its sources and properties

To analyse the impact of climate variables on rice yield at aggregate level, climate data were obtained from BMD (2010) and rice yield data from various issues of the *Bangladesh Economic Review* for the 1972–2009 period. The summary statistics of all data are presented in Table 4.8.

Table 4.8 Descriptive statistics of data for the 1972–2009 period

Statistics	**Variables**											
	Yield (kg/acre)			Maximum temperature (°C)			Minimum temperature (°C)			Total rainfall (mm)		
	Aus	Aman	Boro	Aus	Aman	Boro	Aus	Aman	Boro	Aus	Aman	Boro
Mean	470	616	1058	32.1	30.3	29.6	24.9	22.3	15.7	54726	45587	14659
Median	436	610	1003	32.2	30.3	29.6	24.9	22.3	15.6	56180	45914	14239
Maximum	720	855	1560	33.1	31.0	30.8	25.6	23.1	16.4	66908	60465	24261
Minimum	310	396	728	31.2	29.5	28.6	24.4	21.8	14.7	32864	24783	6369
Std. Dev.	105	126	220	0.43	0.35	0.49	0.31	0.30	0.37	8511	8528	4493
Skewness	0.86	0.28	0.57	-0.14	-0.17	0.20	-0.02	0.34	0.13	-0.58	-0.00	0.30
Kurtosis	2.78	1.97	2.52	2.58	2.62	3.03	2.06	3.03	2.24	2.61	2.52	2.36
Jarque-Bera	4.75	2.19	2.42	0.40	0.41	0.26	1.40	0.75	1.00	2.34	0.37	1.26
Probability	0.09	0.33	0.29	0.82	0.81	0.88	0.50	0.69	0.60	0.31	0.83	0.54
Observations (N)	38	38	38	38	38	38	38	38	38	38	38	38

The mean value of yield for Boro rice is the highest, more than two times higher than that of Aus rice. Mean maximum and minimum temperature is highest for Aus rice while it is lowest for Boro rice. The total rainfall in the Aus and Aman period is three and four times higher respectively than the total rainfall in the Boro period. The Jarque-Bera statistic is significantly different from zero and the P-value of the test is reasonably high for almost all of the variables except the Aus rice yield. Therefore, the normality assumption for Aus rice yield is rejected. Therefore, the individual time series data might be non-stationary which results in spurious regression. This warrants further investigation of the data series to be stationary before the regression is estimated. Accordingly, an Augmented Dickey-

Fuller (ADF) test was carried out to check the stationarity of the data series (i.e., presence of unit roots for each variable) and the results are reported in Table 4.9.

Table 4.9 Augmented Dickey Fuller test for checking stationarity of the data series

Variable	Integration of order for Aus	Integration of order for Aman	Integration of order for Boro
yield	I (1)	I (1)	I (1)
maxt	I (0)	I (1)	I (0)
mint	I (0)	I (0)	I (0)
train	I (0)	I (0)	I (0)

It can be seen that yield for all three rice crops are integrated of order one, I(1), implying non-stationarity of the series. However, the climate variables are all integrated of order zero for the Aus and Boro rice varieties indicating that these data series are stationary in their level form. However, the maximum temperature is of I(1) indicating unit root in the level data for Aman rice. The variables with I(1) need to be first differenced before an estimation can be made (Gujrati 2004; McCarl et al. 2008). Since all or most of the variables are not integrated at the same order under each model, a co-integration test was not performed; instead, regression analysis using either an OLS with the differenced variables or a QR (quantile at 0.5) can be performed. For the same reason, causality analysis was not performed. Instead, it is assumed that yield changes are caused by climate variations and not vice versa as followed in Lobell and Field (2007).

4.8.4 Empirical model selection

The objective of this analysis is to explore the relationship between rice yields and climate variables in order to estimate the potential impact of climate change using regression models and time series data at an aggregate level. This can be done either by using OLS or QR depending on the distribution of the dependent variable. OLS is applied when the dependent variable is normally distributed while QR is employed if the variable is not normally distributed. Median regression is more robust to outliers than mean regression. Furthermore, QR provides a better understanding of the data by assessing the effects of explanatory variables on the location as well as the scale parameters of the model. More importantly, median regression does not require classical assumptions about the distribution of the regression error terms (Cameron & Trivedi 2009). Consequently, quantile or median regression is suitable for heterocedastic data which can correct the model for the problem of heteroscedasticity (Koenker & Bassett 1978; Benhin 2008; Cameron & Trivedi 2009).

Following Ozkan and Akcaoz (2002), Lobell et al. (2007) and Almaraz et al. (2008), three climate variables (maximum temperature, minimum temperature and rainfall) are used as independent variables. Previous studies used different units of time such as months, phenological period, and growing season for climate variables. However, this study has used growing season average for the temperature variable and growing season total for the rainfall variable. This is because growing season average climate is able to capture the net effect of the whole range of the development process by which yields are affected by climate (Lobell & Field 2007). Moreover, growing season average temperature is a key determinant of average yield (Cabal et al. 2010). Growing season monthly average maximum and minimum temperature and growing season total rainfall were used in some studies (Granger 1980; Chang, 2002; Lobell & Field 2007; Lobell et al. 2008). In this study, the rice yield data for all three crops are regressed on the climate variables in order to estimate their effects on the rice yield. The distribution of each rice crop yield was checked against time by drawing histograms before selecting the regression type: OLS or QR. Inspection of the histograms revealed that the distributions for Aman and Aus rice yields did not follow a normal distribution but Boro rice appeared to have a normal distribution. Therefore, mean regression (OLS) was selected for Boro rice estimation while median regression (QR) was selected for Aman and Aus rice. These methods will best estimate the central tendency of the data. Therefore, on the basis of the distribution of the yields (dependent variables) for three rice crops, the following regression models are employed:

Aus Model:

$$Y_{Aus_t} = \alpha + \beta_1 maxt_t + \beta_2 mint_t + \beta_3 train_t + \varepsilon_t \qquad (4.1)$$

Where, Y_{Aus} = yield for Aus rice (in kg/acre)

$maxt =$ average maximum temperature (°C) from April to August

$mint =$ average minimum temperature (°C) from April to August

$train =$ total rainfall (mm) from April to August

ε_t = error term

t = time (i.e. year)

Median regression (at 0.5 quantile) is employed for the estimation of the Aus model. The objective is, thus, to estimate the median of the dependent variable, conditional on the values of independent variables. Median regression minimises the sum of absolute residuals.

Aman Model:

$$Y_{Aman_t} = \alpha + \beta_1 maxt_t + \beta_2 mint_t + \beta_3 train_t + \varepsilon_t \quad (4.2)$$

$where, Y_{Aman}$= yield of Aman rice (in kg/acre)

$maxt$ = average maximum temperature (°C) from July to December

$mint$ = average minimum temperature (°C) from July to December

$train$ = total rainfall (mm) from July to December

ε_t = error term

t = time (i.e. year)

The regression method employed for Aman rice model is also median regression.

Boro Model:

$$Y_{Boro_t} = \alpha + \beta_1 maxt_t + \beta_2 mint_t + \beta_3 train_t + \varepsilon_t \quad (4.3)$$

Where, Y_{Boro}= yield of Boro rice (in kg/acre)

$maxt$ = average maximum temperature (°C) from December to May

$mint$ = average minimum temperature (°C) from December to May

$train$ = total rainfall (mm) from December to May

ε_t = error term

t = time (i.e. year)

The method of estimation for the Boro model is OLS where the objective is to estimate the mean of the dependent variable which minimizes the sum of the squares of the residuals. All variables under each model are log transformed before estimation.

4.8.5 Empirical results and discussion

Results from Aus model

The impact of climate variables on Aus rice yield is shown in Table 4.10 where it is observed that overall yield is statistically significant implying that the climate variables are able to explain some variation in Aus rice production.

Table 4.10 Results from the Aus model

Independent variables	Coefficient	t-value	P-value
Cons	-47.47***	-4.19	0.000
$\boldsymbol{maxt}$	12.39***	3.50	0.001
$\boldsymbol{mint}$	-2.03	-0.50	0.617
$\boldsymbol{train}$	0.90***	4.43	0.000

Model Pseudo R^2 = 0.37
Adjusted R^2 = 0.32
Sparsity = 0.452
Quasi-LR statistic = 16.81
Prob (Quasi-LR stat) = 0.000

Note: *** represents the level of significance at 1%.

The R^2 value indicates that 37% of the variation in Aus rice yield is explained by climate variability. The t-values for average maximum temperature and total rainfall associated with their P-values reveal that these two climate variables are highly significant. Both *maxt* and *train* are statistically significant at 1% level implying a highly significant contribution of these variables on the Aus rice yield. Though *mint* does not appear to be statistically significant, it is negatively associated with the Aus rice yield.

Results from Aman model

The contribution of climate variables on rain-fed Aman rice is presented in Table 4.11. The results are very interesting. The probability of the Quasi-LR statistic ensures the utility of the overall model.

Table 4.11 Results from the Aman model

Independent variables	Coefficient	t-value	P-value
Cons	-34.59***	-2.84	0.007
maxt	5.59*	1.93	0.061
mint	-6.97**	-2.09	0.044
train	0.83***	4.15	0.000

Model Pseudo R^2 = 0.54
Adjusted R^2 = 0.50
Sparsity = 0.327
Quasi-LR statistic = 43.08
Prob (Quasi-LR stat) = 0.000

Note: ***, ** and * represent the levels of significance at 1%, 5% and 10% respectively.

All three climate variables are statistically significant for Aman rice production. However, the effects of maximum temperature and rainfall are positive while minimum temperature has an adverse impact on Aman rice yield. Moreover, 29% of variability in Aman rice yield is explained by the climate variables which signify the crucial role of climate for Aman rice cultivation.

Results from Boro model

Boro rice is grown with irrigation during the dry season. The contribution of the relevant climate variables obtained from the linear regression analysis is illustrated in Table 4.12.

Table 4.12 Results from the Boro model

Independent variables	Coefficient	t-value	P-value	VIF
Cons	1.71	1.04	0.305	
maxt	-1.57**	-2.49	0.018	1.71
mint	1.24***	3.12	0.004	1.71
train	0.02	0.99	0.330	1.42

Model, R^2 = 0.29
Adjusted R^2 = 0.23
Durbin-Watson = 1.98
F-statistic = 4.59
P value of F-statistic = 0.008
Breusch-Pagan chi-square (1) = 1.05
Prob> chi2 = 0.30

Note: *** and ** represent the levels of significance at 1% and 5% respectively.

The model has an F-value of 4.59 with a p value of 0.008. This implies that the overall model is statistically significant at the 1% level. The R^2 value means that 29% of the variation in Boro rice yield is explained by the climate variables. Moreover, the Durbin-Watson statistic reveals that the model does not suffer from the problem of serial correlation. This value is an improvement over the study by Ozkan and Akcaoz (2002) with their Durbin-Watson statistic of 1.09 indicating the problem of positive serial correlation. The values of VIF imply that there is no multi-collinearity among the independent variables while the P-value of the Breusch-Pagan chi-square ensures that the model is not suffering from the problem of heteroscedasticity. The t-value of average maximum temperature is 2.49 and that for average minimum temperature is 3.12 which indicate both *maxt and mint* are statistically significant. However, the relationship between yield and *maxt* is negative while *mint* has a positive effect on yield. This suggests that both climate variables affect Boro rice yield considerably. Total rainfall during Boro rice period is insignificant because this rice crop grows under completely irrigated conditions. This finding of insignificant effect of total rainfall on Boro rice production is consistent with Rimi et al. (2009) for Bangladesh where a simulation model was applied. However, the results of the present study are more robust than these past studies both in terms of methods and diagnostic tests.

4.9 Concluding comments

The first goal of this chapter was to examine the changes in climate variables at the aggregate level. An examination of the annual maximum and minimum temperatures and rainfall using different statistical techniques has provided evidence of the changing climate over the last six decades in Bangladesh. For all three climate variables, the effects of the trends are statistically significant; however, the increase in minimum temperature is higher than that for maximum temperature. These results are consistent with those of Islam and Neelim (2010). However, the results from current studies are more robust in terms of statistical techniques, particularly the use of the QR method which has provided a complete and better picture of the changes in climate variables over the years.

The second goal was to estimate the relationship between rice yields and climate variables using the aggregate level time series data for the 1972–2009 period. In doing so, both OLS and QR models were used. The overall findings reveal that three climate variables have substantial impacts on the rice yield of three different crops. For the Aus model, average seasonal maximum temperature and total seasonal rainfall are statistically significant. Moreover, the average minimum temperature is found to affect Aus rice very adversely though this effect is not significant. The overall Aus model is also found to be significant. In the case of Aman rice model, all three climate variables have become statistically significant. However, the direction of effects is not the same. Maximum temperature and rainfall have positive impacts on yield while minimum temperature affects yield negatively. Finally, both maximum and minimum temperatures have substantial effects on yield in the Boro rice model. However, the maximum temperature is found to be negatively related to Boro rice yield. One interesting finding is that rainfall is significant for Aus and Aman rice which supports the fact that they grow in rain-fed conditions: Aus partially and Aman entirely. In terms of F and R^2 values, the three models are of statistical significance and the results for overall goodness for fit are consistent with Lobell (2010). Therefore, two climate variables, namely maximum and minimum temperatures are found to adversely affect Boro and Aman rice yields respectively. Considering this severe sensitivity of rice yield to climate factors, variety-specific adaptation strategies need to be adopted to reduce the adverse impacts of climate change.

Finally, it is noteworthy that aggregate level data is unable to produce any regional variations of climate variables and its impact on crop yield (Chen et al. 2004; Lobell et al. 2007). Analysing data at the disaggregated level is, therefore, crucial to capturing regional variation and to obtain a more comprehensive and deeper understanding of the issue.

Chapter 5 Climate Change Impacts on Rice Yield and Variability: An Analysis of Disaggregate Level Data

5.1 Introduction

In the previous chapter the empirical nexus between three climate variables and rice yield has been estimated using aggregate level time series data. However, average aggregate data at the national level does not take into account potentially large differences between different crop producing regions or districts (Chen et al. 2004; Lobell et al. 2007). In reality, different areas are impacted heterogeneously by climate change (Mendelsohn & Williams 2004; Gbetibou & Hassan 2005). Even then, the impact of climate change varies within and between agro-ecological regions of the same country (Gbetibou & Hassan 2005; Haim et al. 2008). This, therefore, warrants research using more disaggregated climate and rice yield data for a clearer understanding of the economic impact of climate change on rice production. Therefore, this chapter aims to estimate the economic impact of climate change on rice yields using cross-sectional time series data as well as disaggregated climate and rice yield data at the district level. These local level estimates have the potential to reflect more accurately the relationship between the variables of interest (Chen et al. 2004; Guiteras 2009). This estimation will address research question two. In so doing, specific additional research questions are formulated to direct our analysis further:

- Is there any variation in climate variables across the regions or districts?

- How do the changes in temperature and rainfall influence the mean and variability of yield of three different rice varieties (Aus, Aman and Boro) across all seven climate zones?
- What will be the impact of future climate change scenarios on rice yields?

The organisation of this chapter is as follows. Section 5.2 provides a brief overview of the literature. Section 5.3 presents the methodology used for estimation purposes. Empirical findings are reported and discussed in section 5.4 and Section 5.5 concludes the chapter.

5.2 A brief overview of the literature

One of the major determinants of fluctuations in crop yield is year-to-year changes in climatic variables (Hazell 1984; Anderson & Hazell 1987). There have been several studies measuring the effects of climate variables on crop productivity using either simulation models such as CERES-maize, CERES-rice or EPIC (Phillips et al. 1996; Rosenzweig et al. 2002; Tan & Shibasaki 2003) or regression models (Mendelsohn et al. 1994; Chang 2002; Haim et al. 2008).

Mostly, two major methodologies were employed in these studies to assess the impact of climate on agriculture: the production function approach (also known as crop modelling or agronomic models) (Mearns et al. 1997) and the Ricardian approach (Mendelsohn et al. 1994).

The first approach, based on controlled experiments, simulates data on climate factors and crop yields in a laboratory-type setting. With careful control and randomised application of environmental conditions, this approach has its capability to forecast the potential climatic impacts on agricultural yields. However, this approach does not take into consideration farmers' attitudes toward adaptation and thus results in an overestimation of negative impacts and an underestimation of positive effects (Adam et al.1990; Mendelsohn et al. 1994; Adams et al. 1999; Haim et al. 2008).

In contrast, the Ricardian approach estimates the relationship between land values and agro-climatic factors by making use of cross-sectional data (Mendelsohn et al. 1994; Kumar & Parikh 1998). The main strength of this approach is that it captures farmers' adaptations that affect land values (net revenue or farm income). Consequently, the model has been successfully applied in many countries including the USA (Mendelsohn et al. 1994; Mendelsohn & Dinar 2003); England and Wales (Maddison 2000); Kenya (Kabubo-Mariara & Karanja 2007); Taiwan (Chang 2002); South Africa (Gbetibouo & Hassan 2005); Cameroon (Moula 2009); China (Wang et al. 2009); and India and Brazil (Sanghi & Mendelsohn 2008). However, the model, in its original form, cannot be applied to most developing countries because of the absence of efficient land markets. The major weakness of a Ricardian model lies in its inability to incorporate omitted variables such as unobservable skills of farmers and quality of soil which are also known as time independent and location specific factors (Barnwal & Kotani 2010). However, although variability in yield is found to be affected by climate variables in some studies (Chen et al. 2004; Chen & Chang 2005; Kim & Pang 2009), a Ricardian model is unable to assess the effect of climate change on yield variability (Mearns et al. 1997). This has already led some economists to use a panel data approach to account for the problem of omitted variables by including district or regional dummies in the model (Chen et al. 2004; Schlenker & Roberts 2006; Deschenes & Greenstone 2007; Guiteras 2007; McCarl et al. 2008; Kim & Pang 2009; Barnwal & Kotani 2010; Cabas et al. 2010). Moreover, panel data provides more information and degrees of freedom, and can control individual heterogeneity. Furthermore, there are several other advantages in using a panel data approach such as increasing sample size considerably and it being better suited to study the dynamics of change by employing repeated cross-section observations (Gujarati 2004; Baltagi 2008).

Previous studies carried out internationally are based on the theoretical framework of Just and Pope's (1978) stochastic production function approach. However, there have been, to the best of the researcher's knowledge, no studies applying the panel data approach in Bangladesh. There are a few regional and national level studies on the impact of climate change or of droughts on rural livelihoods and crop agriculture using descriptive statistics (Paul 1998; Ali 1999; Rashid & Islam 2007) and simulation models (Karim et al. 1996; Mahmood 1998; Mahmood et al. 2004; Rimi et al. 2009; Basak et al. 2010). Therefore, there is a need to assess the effects of climate variables on mean rice yield and its variability in Bangladesh using a panel data approach. The analysis in this chapter is based on the stochastic production function approach introduced by Just and Pope (1978 and 1979).

This chapter will contribute to the literature in some important ways. First, there are few empirical studies about the impact of climate change on mean crop yield and its variability (Chen et al. 2004; Isik & Devadoss 2006; Kim & Pang 2009). Second, earlier studies using panel data have used average temperature and rainfall as the two climate variables (Chen et al. 2004; Isik & Devadoss 2006; Kim & Pang 2009). Average temperature was constructed as an average of maximum temperature and minimum temperature. However, the inclusion of maximum and minimum temperature is only able to capture the differential impacts of day and night temperature (Peng et al. 2004; Boomiraj et al. 2010; Welch et al. 2010). Therefore, this study is the first that has employed both maximum and minimum temperature as temperature-related climate variables as well as rainfall in a panel data approach. Third, past studies using panel data evaluated the impact of climate change on a particular crop or a group of crops as a whole (Chen et al. 2004; Schlenker & Roberts 2006; Deschenes & Greenstone 2007; Guiteras 2007; McCarl et al. 2008; Kim & Pang 2009; Barnwal & Kotani 2010; Cabas et al. 2010). However, different varieties of a crop are impacted differently by climate change (Deressa et al. 2005; Isik & Devadoss 2006; Kabubo-Mariara & Karanja 2007) which warrants crop-variety specific research. In this study, the impacts of climate variables are assessed for all three major rice crops in Bangladesh.

5.3 The methodology for estimation purposes

5.3.1 Data, its sources and basic properties

This section has used pooled cross-sectional time series data for the three major rice crops (Aus, Aman and Boro) for 13 out of 19 greater districts in Bangladesh. The selection of the districts was based on the availability of consistent data both on climate and rice yield. Details about the sources of data and their timeframe were outlined in Chapter Three. District level data on climate and rice yield for the 1972–2009 period are grouped into seven climatic sub-zones of Bangladesh as outlined by Rashid (1991) and discussed in Chapter Four (the time period for analysis matches available climate and rice production data). The summary statistics of data are described in Table 5.1. These data reveal that there is a correlation between higher mean values and higher standard deviation values. Both maximum and minimum temperature is higher during Aus rice period and lowest during Boro rice period. But absolute variability in temperature is higher for Boro rice. The variability in rainfall varies considerably among the three rice varieties which in large part correspond to their growing seasons.

Table 5.1 Summary statistics on yields and climate variables

Rice Variety	Variables	Unit	Obs	Mean	Standard Deviation	Maximum	Minimum
Aus	*yield*	(kg/acre)	494	627.09	725.17	9714.6	48.35
	maxt	(°C)	494	32.43	0.99	35.4	29.32
	mint	(°C)	494	24.83	0.70	26.3	18.4
	train	(mm)	494	1597.61	627.58	4296	303
Aman	*yield*	(kg/acre)	494	621.73	180.66	1115.6	82.56
	maxt	(°C)	494	30.42	0.57	32.4	28.98
	mint	(°C)	494	22.10	0.61	23.9	19.9
	train	(mm)	494	1315.61	472.89	3647	347
Boro	*yield*	(kg/acre)	494	1073.68	308.88	4687.3	103.9
	maxt	(°C)	494	29.50	1.02	32.5	24.4
	mint	(°C)	494	17.69	1.06	20.2	12.1
	train	(mm)	494	478.27	280.09	70	1684

5.3.2 Descriptive statistics for district level climate variability

Descriptive statistics such as mean, standard deviation and CV are used to examine the district level variability for climate variables. Since the first objective of this chapter is primarily to examine the inter-district or inter-region variations in climate, the relative variability expressed by the CV is a more appropriate measure than the standard error (Alauddin & Tisdell 1991).

5.3.3 Panel unit roots and stationarity

It is essential to investigate the presence of unit roots for each potential variable before we estimate the model either using the FGLS or MLE method. One important assumption of the Just and Pope model is that the variables under estimation are stationary (Chen et al. 2004). Therefore, variables having the properties of I(1) must be differenced before panel estimation occurs (McCarl et al. 2008). Otherwise, using a non-stationary dataset directly might yield spurious results (Chen & Chang 2005; Granger & Newbold 1974). However, the time series properties of one variable comprising many regions in a panel data setting are hard to characterise (Chen et al. 2004). This study uses the Fisher-type test as proposed in Maddala and Wu (1999). The Fisher test obtains more precise results and achieves higher power compared to other tests such as LLC (Barnwal & Kotani 2010). An explanation of this method is in Chapter Three.

5.3.4 Empirical model specification and estimation method

In order to determine the effects of climate variables on the level of yield and its variability, the stochastic production function approach pioneered by Just and Pope (1978 & 1979) is applied here. The fundamental concept underpinning this approach is that the production function can be decomposed into two segments: the first segment is linked to the mean output level while the second segment is associated with the variability of that output (Cabas et al. 2010; Kim & Pang 2009). The general form of the Just and Pope production function is (Just & Pope 1978):

$$y = f(X) + h(X)\epsilon, \quad (5.1)$$

where y is yield, X is a set of explanatory variables. The parameter estimation of $f(X)$ provides the average impact of the explanatory variables on yield while $h(X)$ offers their effect on the variability of yield (Chen & Chang 2005). Based on Saha et al. (1997) and Chen et al. (2004) the following form of production function is estimated:

$$y = f(x) + u = f(X, \beta) + h\,(X, \alpha)\epsilon, \quad (5.2)$$

where, y is rice yield (Aus, Aman and Boro), X is a set of independent variables (e.g., temperature, rainfall, location and time period) and ϵ is the exogenous production shock with $E(\epsilon) = 0$ and $\mathrm{Var}(\epsilon) = \delta^2_{\epsilon}$. With this formulation, explanatory variables affect both mean and variability of rice yield because $E(y) = f(x)$ and $Var(y) = Var(u) = h(.)$. The parameter estimation of $f(.)$ gives the average effects of the independent variables on yield, while $h(.)$ reveals the impacts of the covariates on the variability of yield. It is noteworthy that a positive sign on any parameter of $h(.)$ implies a rise in that variable, i.e., an increase of the variability of yield. A negative sign on the same function indicates a decrease of the variability indicating that weather variables are risk declining inputs.

Three functional forms of production functions (Cobb-Douglas, quadratic and translog) are used for the estimation of the Just and Pope Production function (Teveteras 1999; Chen et al. 2004; Isik & Devadoss 2006; Kim & Pang 2009). Because of the multiplicative interaction between the mean and variance, a translog functional form violates the Just and Pope postulates (Koundouri & Nauges 2005; Teveteras 1999; Tveteras 2000). Therefore, Cobb-Douglas and linear quadratic forms are selected for the mean yield function estimation. These two forms are consistent with the Just and Pope postulates (Tveteras 2000; Kim & Pang 2009).

Mean function

The mean function is specified as:

Cobb-Douglas form

$$y = \alpha_0 + \alpha_t T + \prod_j x_j^{\alpha_j} \quad (5.3)$$

Linear- Quadratic Form

$$y = \alpha_0 + \alpha_t T + \sum_j \alpha_{1j} x_j + \sum_j \alpha_{2j} x_j^2 + \sum_j \sum_{k(k\neq j)} \alpha_{jk} x_j x_k \tag{5.4}$$

where $x_j and\ x_k$ are explanatory variables that include weather variables, T represents time trend and $\alpha's$ imply coefficients to be estimated. The justification of including the time trend is that it can capture technological progress over the period under consideration.

Variance function

Only the linear functional (CD) form is considered for the variability function because the variance function has a non-linear form and the inclusion of quadratic terms for explanatory variables makes the analysis more difficult. Following Just and Pope (1978, 1979), Kumbhakar and Tveteras (2003) and Koundouri and Nauges (2005), the variability function $h(.)$ is modelled as a Cobb-Douglas form:

$$h(x) = \beta_0 T \prod_j x_j^{\beta_j} \tag{5.5}$$

or

$$h(x) = \beta_0\, T\, x_1^{\beta_1}.\ x_2^{\beta_2}.\ x_3^{\beta_3} \ldots\ldots\ x_n^{\beta_n} \tag{5.6}$$

Logarithmic transformation of this function (Equation 5.6) produces the linear function as follows:

$$ln\ h(x) = \ln(\beta_0\, T^{\beta_t}\, x_1^{\beta_1}.\ x_2^{\beta_2}.\ x_3^{\beta_3} \ldots\ldots\ x_n^{\beta_n})$$

$$ln\ h(x) = \ln \beta_0 + ln\mathrm{T}^{\beta_t} + lnx_1^{\beta_1} + ln\, x_2^{\beta_2} + lnx_3^{\beta_3} + \cdots .. + lnx_n^{\beta_n}$$

$$ln\ h(x) = \ln \beta_0 + \beta_t lnT + \beta_1 lnx_1 + \beta_2 lnx_2 + \beta_3 lnx_3 + \cdots + \beta_n lnx_n \tag{5.7}$$

where $\beta's$ are parameters to be estimated.

Fixed effects and random effects models are usually used for a panel model (Baltagi 2005; Wooldridge 2009). This study has used the fixed effects model purposely for two reasons. First, it allows region or district specific characteristics to be included which are one of the motivations of using a panel model. To take into account the regional differences in the mean yield function, regional dummies are included in the model. Second, the fixed effects model is appropriate in situations where there is a possibility of correlation between regressors and time-invariant distinctiveness (Wooldridge 2009). In contrast, the random effects model necessitates the assumption of no correlation between unobserved time-invariant characteristics and the explanatory variables. Therefore, the fixed effects model is selected for this study and this selection is consistent with past studies (McCarl et al. 2008; Kim & Pang 2009; Barnwal & Kotani 2010; Cabas et al. 2010).

Both MLE and a three-step FGLS were prescribed in Just and Pope (1978, 1979) for estimating both functional forms. However, FGLS estimation has been employed in most empirical studies, although MLE is more efficient and unbiased than FGLS for small samples (Saha et al. 1997). Given the large sample here, FGLS was used in this study as described in Judge et al. (1988) to estimate a form of fixed effects panel model for the above equations. Moreover, both FGLS and MLE were used in the preliminary analyses but FGLS was found to produce better results. This is another reason for the choice of FGLS as an estimation method. Furthermore, panel model estimation involving both cross-section and time series data may encounter the problems of heteroscedasticity and auto-correlation (Gujrati 2004; Cameroon & Trivedi 2009). These two problems are better addressed in FGLS since it assumes that panels are homoscedastic and there is no auto-correlation (Kapoor et al. 2007).

5.4 Results

5.4.1 Descriptive statistics for climate variability at district level

In this section, climate variability is examined for each district and for each climatic zone. Table 5.2 sets out the inter-district climate variability. It is evident from the table that values of descriptive statistics for different climate variables vary considerably across and/or between the districts or regions. The districts of Rajshahi, Jessore and Khulna have experienced highest mean maximum temperature whereas the relative variability is the highest for Rangpur and Sylhet.

Table 5.2 Inter-district climate variability for the 1972–2009 period

Greater district	Yearly mean maximum temperature			Yearly mean minimum temperature			Yearly average total rainfall		
	Mean	Std	CV	Mean	Std	CV	Mean	Std	CV
Dinajpur	30.09	0.39	1.29	19.93	0.40	2.02	1958	449	22.96
Rangpur	29.60	0.61	2.05	20.00	0.70	3.49	2262	478	21.14
Rajshahi	31.11	0.38	1.21	20.54	0.44	2.15	1505	316	21.02
Bogra	30.67	0.40	1.31	20.86	0.35	1.70	1810	381	21.04
Mymensingh	29.92	0.37	1.24	20.74	0.46	2.22	2228	612	27.47
Sylhet	29.83	0.61	2.06	20.38	0.54	2.67	4071	612	15.04
Dhaka	30.65	0.54	1.77	21.64	0.44	2.04	2130	405	19.02
Comilla	30.20	0.43	1.42	20.93	0.33	1.57	2080	378	18.18
Jessore	31.55	0.50	1.58	20.85	0.30	1.44	1665	332	19.97
Faridpur	30.49	0.45	1.46	21.18	0.63	2.96	1872	347	18.53
Khulna	31.16	0.44	1.41	21.73	0.46	2.13	1842	358	19.46
Barisal	30.53	0.43	1.40	21.20	0.36	1.70	2116	363	17.17
Chittagong	30.35	0.54	1.79	21.68	0.44	2.01	2898	492	16.97

Source: Author’s own calculation based on data collected from BMD (2010).

In terms of mean minimum temperature, the districts of Faridpur, Khulna, Chittagong, Dhaka and Barisal have the maximum values while the Dinajpur district has the lowest value. From the view point of relative variability, the Rangpur district experiences the highest variability. Other districts having high coefficients of variation include Rajshahi, Mymensingh, Sylhet, Dhaka, Faridpur, Khulna and Chittagong. Lowest variability in minimum temperature is found in the Jessore district. For rainfall data, the Sylhet district experiences highest yearly average total rainfall which is just above 4000 mm while the average total rainfall is lowest in Rajshahi. In terms of rainfall variability, the districts of Mymensingh, Rajshahi, Rangpur, Dinajpur and Bogra experience larger variations. This rubric picture becomes more comprehensive if these are analysed in the context of climatic zones as illustrated in Table 5.3.

Table 5.3 Inter-climate zones variability in climate variables for the 1972-2009 period

Climatic zone	**Yearly mean maximum temperature (°C)**			**Annual mean minimum temperature (°C)**			**Yearly average total rainfall (mm)**		
	Mean	Std	CV	Mean	Std	CV	Mean	Std	CV
Southeastern	30.35	0.54	1.79	21.68	0.44	2.01	2898	492	16.97
Northeastern	29.83	0.61	2.06	20.38	0.54	2.67	4071	612	15.04
Northern part of the north	29.60	0.61	2.05	20.00	0.70	3.49	2262	478	21.14
Northwestern	30.38	0.32	1.06	20.40	0.36	1.76	1884	359	19.03
Western	31.11	0.38	1.21	20.54	0.44	2.15	1505	316	21.02
Southwestern	31.07	0.42	1.35	21.25	0.37	1.75	1793	285	15.90
South central	30.32	0.36	1.19	21.13	0.32	1.51	2138	359	16.77

Source: Author’s own calculation based on data collected from BMD (2010).

The data reveals that variability in climate variables changes across climate zones. Annual mean maximum temperature is highest for the western zone while it is lowest for the northern part of the north zone. The zones having the highest relative variability in maximum temperature include the northeastern and the northern part of the north. In terms of minimum temperature, the southeastern, northeastern, northern part of the north and western zones experience the highest variability. From the viewpoint of rainfall, the western zone receives the lowest annual mean total rainfall. Variability in rainfall is also higher for the western and the northern part of the north zones.

Overall, there have been significant variations in climate variables across the districts and climate zones. However, the changes are more profound when seen in the context of climate zones. One important dimension of this finding is that the western zone (i.e., Rajshahi district) has the highest maximum temperature and the lowest annual rainfall which has made the zone the most severely drought-prone area of Bangladesh. These findings are consistent with Islam and Neelim (2010). This is a strong basis for separate research focusing on the western zone (i.e., the greater Rajshahi district), which is the focal point of Chapters 6 and 7.

5.4.2 The panel unit root test

The Fisher-type test is used to examine the stationarity properties of the variables under a panel model. There are two versions of the Fisher-type test: ADF and PP. This study finds identical results from these two versions and produces the results using ADF test. Moreover, another test, Harris-Tzavalis (HT), is also used to ensure the robustness of the results. The results are reported in Table 5.4.

Table 5.4 Panel unit root tests

Rice variety	Variables	ADF test statistic (P-value)		Harris-Tzavalis test statistic	
		Without trend	With trend	Without trend	With trend
Aus	*yield*	87.00 (0.000)	115.76(0.000)	0.67(0.000)	0.64(0.000)
	maxt	287.53(0.000)	395.38(0.000)	0.27(0.000)	-0.04(0.000)
	mint	237.48 (0.000)	255.32(0.000)	0.28(0.000)	0.16(0.000)
	train	530.41(0.000)	481.65(0.000)	-0.11(0.000)	-0.15(0.000)
Aman	*yield*	51.46(0.002)	161.90(0.000)	0.78 (0.000)	0.26(0.000)
	maxt	217.89(0.000)	401.00(0.000)	0.46 (0.000)	0.12 (0.000)
	mint	184.20(0.000)	185.39(0.000)	0.41 (0.000)	0.30 (0.000)
	train	477.22(0.000)	414.80(0.000)	-0.02 (0.000)	-0.06 (0.000)
Boro	*yield*	119.53(0.000)	186.35(0.000)	0.32(0.000)	0.01(0.000)
	maxt	301.56(0.000)	316.74 (0.000)	0.14 (0.000)	0.01 (0.000)
	mint	199.68 (0.000)	269.67(0.000)	0.38 (0.000)	0.17 (0.000)
	train	499.39 (0.000)	459.50(0.000)	-0.11 (0.000)	-0.15(0.000)

Notes: Hypothesis under ADF Test: H_o: All panels contain unit roots; H_a: At least one panel is stationary.
Hypothesis under HT test: H_o: Panels contain unit roots; H_a: Panels are stationary.

The estimated test statistics implies that rice yields and climate variables exhibit similar results under both with and without time trend. This suggests that the null hypothesis of unit roots (i.e., non-stationary) is rejected at the 1% level of significance for all variables in the table. This implies that all variables under the model are stationary. These results are consistent with McCarl et al. (2008), and Kim and Pang (2009). Therefore, the three-stage FGLS can be applied to analyse the data without differencing.

5.4.3 The empirical model

Estimates of the linear Cobb-Douglas and linear quadratic functions for mean yield and linear function for yield variability are made using the FGLS estimation method. Regional dummies are included to the mean yield function but not to the variability function assuming different regions have different mean yields with almost identical variances across zones. Six regional dummies for seven climate zones are included to avoid dummy variable trap (Gujrati 2004). The estimated results for the three rice varieties are now presented.

Result for Aus rice

The regressors for the Aus rice model are jointly statistically significant because the overall Wald statistic of 984.36 under the linear functional form has a P-value of 0.000 and that of the quadratic form is 788.01 has also a P-value of 0.000.

The detailed results are illustrated in Table 5.5. The sign and statistical significance of the estimated coefficients for the regressors in the mean yield function are found to be different between the linear and quadratic functional forms. Rainfall has a negative effect on mean Aus yield in the linear model but a positive effect in the quadratic model. It is statistically significant in the linear model, but not in the quadratic model. Both maximum and minimum temperatures are positively related to mean yield in the linear model while they have a negative effect in the quadratic model. However, both temperatures are statistically insignificant in either model. No quadratic and interaction terms for climate variables in the quadratic model are statistically significant. All regional dummies in the linear model are individually statistically significant apart from the southwestern region. The statistically significant regions are the southeastern, northeastern, northern part of the north and northwestern. Therefore, most of the regional dummies are statistically significant in both models. The trend is positively related to the mean yield and statistically significant in both models.

Table 5.5 Estimation results for Aus rice

Variables	Linear Model (Cobb-Douglas)		Quadratic Model	
	Coefficients	P-value	Coefficients	P-value
Mean yield				
Trend	0.019***	0.000	0.195***	0.000
T_{max}	1.150	0.404	-392.280*	0.099
T_{min}	0.167	0.875	-37.331	0.881
R	-0.246**	0.030	1.478	0.936
T_{max}^2			46.631	0.175
T_{min}^2			-8.303	0.424
R^2			-0.021	0.944
$T_{max} * T_{min}$			21.010	0.670
$T_{max} * R$			-2.603	0.593
$T_{min} * R$			2.342	0.670
Southeastern	0.564***	0.000	0.527***	0.000
Northeastern	0.447***	0.000	0.347*	0.081
Northern part of the north	0.355***	0.000	0.357***	0.000
Northwestern	0.339***	0.000	0.334***	0.000
Western	0.234**	0.040	0.106	0.387
Southwestern	0.033	0.666	-0.010	0.894
South central (omitted to avoid dummy variable trap)				
Constant	35.815***	0.000	703.142	0.266
Yield variability				
Trend	0.007***	0.000	0.006***	0.000
T_{max}	0.720***	0.000	0.691***	0.000
T_{min}	-0.658***	0.000	-0.649***	0.000
R	-0.008	0.446	-0.007	0.496
Constant	-9.849***	0.000	-9.796***	0.000
Model Summary				
Log likelihood	739.56		686.17	
Wald chi-square	984.36		788.01	
Prob> chi-square	0.00		0.00	
AIC	-1469.12		-1362.34	
BIC	-1448.10		-1341.32	

Note: ***, ** and * represent levels of significance at 1%, 5% and 10% respectively.

For the yield variability function, the estimated coefficients show that increases in minimum temperature diminishes the variability of Aus rice yield. That is, minimum temperature is risk reducing whereas maximum temperature and total seasonal rainfall are risk increasing. However, only maximum temperature is individually statistically significant in the yield variability function. The trend variable is also statistically significant. This implies that crop yields increase over time due to technological progress such as improved irrigation coverage, expansion of HYVs and increased use of fertilizer.

These results are also in line with the findings of Anderson and Hazell (1987), Isik and Devadoss (2006), and Kim and Pang (2009).

Results for Aman rice

The impact of climate change on Aman rice yield is reported in Table 5.6. The Wald statistics have a P-value of 0.000 both for the linear and quadratic models. This implies that the regressors under both models are statistically significant. The values of the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) were used to select the better functional form. The linear model is marginally better because it has a higher negative value.

The sign and level of significance for the impacts of climate variables for Aman rice differ between the linear and quadratic models. Maximum temperature has a positive impact on mean yields in the linear model and a negative effect in the quadratic model. Minimum temperature has a negative effect on rice yield in the linear model while a positive impact in the quadratic model. Finally, rainfall has a positive impact on rice yield though the effect is not statistically significant in either functional form. In the quadratic model, the quadratic term for minimum temperature is statistically significant with a negative effect on rice yield. The other two quadratic terms have positive impact but with no statistical significance. None of the three interaction terms are statistically significant but the interaction between maximum and minimum temperature has a positive effect on rice yield while the other two interaction terms have a negative impact.

Table 5.6 Estimation results for Aman rice

Variables	Linear Model (Cobb-Douglas)		Quadratic Model	
	Coefficients	P-value	Coefficients	P-value
Mean yield				
Trend	0.016***	0.000	0.015***	0.000
$\boldsymbol{T_{max}}$	4.054***	0.000	-134.129***	0.011
$\boldsymbol{T_{min}}$	-1.586***	0.000	113.628**	0.057
$\boldsymbol{R}$	0.018	0.624	6.614	0.229
$\boldsymbol{T_{max}^2}$			20.334	0.110
$\boldsymbol{T_{min}^2}$			-19.145**	0.028
$\boldsymbol{R^2}$			0.019	0.759
$\boldsymbol{T_{max} * T_{min}}$			2.696	0.868
$\boldsymbol{T_{max} * R}$			-1.246	0.433
$\boldsymbol{T_{min} * R}$			-0.841	0.443
Southeastern	0.374***	0.000	0.381***	0.000
Northeastern	0.021	0.616	0.001	0.984
Northern part of the north	0.220***	0.000	0.212***	0.000
Northwestern	0.099***	0.001	0.099***	0.001
Western	0.046	0.226	0.046	0.224
Southwestern	-0.091***	0.001	-0.091***	0.001
South central (omitted to avoid dummy variable trap)				
Constant	-34.014***	0.000	(omitted)	(omitted)
Yield variability				
Trend	0.005***	0.000	0.005***	0.000
$\boldsymbol{T_{max}}$	1.151***	0.000	1.147***	0.000
$\boldsymbol{T_{min}}$	-0.581***	0.000	-0.580***	0.000
$\boldsymbol{R}$	0.039***	0.000	0.039***	0.000
Constant	-8.623***	0.000	-8.615***	0.000
Model summary				
Log likelihood	922.41		909.30	
Wald chi-square	1495.62		1417.29	
Prob> chi-square	0.00		0.00	
AIC	-1834.82		-1808.60	
BIC	-1813.81		-1787.59	

Note: ***, ** and * represent levels of significance at 1%, 5% and 10% respectively.

All of the regional dummies are statistically significant in both models aside from the northeastern and western zones. Moreover, most of the significant regions have positive impact on yield except the southwestern which has a negative effect.

For the yield variability function, the effects of maximum temperature and rainfall on rice yield variability are positive and statistically significant. The impact of minimum temperature on rice yield is negative with statistical significance. This implies that minimum temperature is risk decreasing while maximum temperature and rainfall are risk increasing. Finally, the trend variable has a positive impact on both rice yield and variability in both models.

Results for Boro rice

Unlike Aman, Boro is an entirely irrigated rice crop. The impact of climate change on the mean and variability of Boro rice yield are illustrated in Table 5.7. The P-values of the Wald statistic confirm that both functional forms have overall statistical significance. However, the values of AIC and BIC make the linear model more significant.

The effects of climate variables on the mean and variability of rice yields differ between the linear and the quadratic models. The effect of minimum temperature on mean rice yield in the linear model is positive and statistically significant. The other statistically significant climate variable is the interaction term for minimum temperature and rainfall in the quadratic model. The remaining coefficients on the climate variables are not statistically significant in either model. Nevertheless, maximum temperature and rainfall have negative impacts on mean rice yield in both models. Of the regional dummies, the southeastern, northeastern and northwestern are statistically significant. However, the southeastern and northeastern have positive effects whilst the northwestern has a negative impact on mean rice yield.

For the yield variability function, the effects of minimum temperature and seasonal total rainfall on rice yield variability are statistically significant. However, the effect of minimum temperature is positive while that of rainfall is negative. This indicates that the minimum temperature is risk increasing while rainfall is risk decreasing in production.

Table 5.7 Estimation results for Boro rice

Variables	Linear Model (Cobb-Douglas)		Quadratic Model	
	Coefficients	P-value	Coefficients	P-value
Mean yield				
Trend	0.013***	0.000	0.013***	0.000
T_{max}	-0.036	0.949	-71.304	0.139
T_{min}	1.416***	0.000	6.631	0.828
R	-0.018	0.584	-1.613	0.597
T_{max}^2			12.330	0.130
T_{min}^2			0.209	0.918
R^2			-0.045	0.298
$T_{max} * T_{min}$			-3.734	0.662
$T_{max} * R$			-0.276	0.782
$T_{min} * R$			1.067*	0.070
Southeastern	-0.114**	0.040	-0.139***	0.018
Northeastern	-0.326***	0.000	-0.280***	0.000
Northern part of the north	0.009	0.886	-0.015	0.828
Northwestern	0.133***	0.005	0.125***	0.011
Western	0.063	0.303	0.051	0.421
Southwestern	-0.007	0.846	-0.011	0.786
South central (omitted to avoid dummy variable trap)				
Constant	3.109*	0.094	121.082	0.175
Yield variability				
Trend	0.004***	0.000	0.003***	0.000
T_{max}	-0.007	0.869	-0.006	0.904
T_{min}	0.315***	0.000	0.315	0.000***
R	-0.038***	0.000	-0.037	0.000***
Constant	3.220***	0.000	3.216	0.000***
Model summary				
Log likelihood	1100.58		-1063.44	
Wald chi-square	532.95		460.23	
Prob> chi-square	0.00		0.00	
AIC	-2193.16		-2118.87	
BIC	-2176.35		-2102.06	

Note: ***, ** and * represent levels of significance at 1%, 5% and 10% respectively.

Though the effects of maximum temperature on yield variability are not statistically significant, they have a negative effect. This implies that the maximum temperature is risk decreasing.

5.4.4 Climate elasticities of rice yields

Since the quadratic models have both quadratic and interaction terms, it is not possible to compare the signs and extent of the estimated coefficients in that model to those of the linear model. The estimation of elasticities is used to assess and compare the effects of climate variables both in the linear Cobb-Douglas and quadratic functional models (Isik & Devadoss 2006). The elasticities are calculated at the mean values of the explanatory variables (Isik & Devadoss 2006). The coefficients for climate variables such as maximum temperature, minimum temperature and rainfall can be translated into elasticities by multiplying the average climate variable and dividing by average yield (Chen et al. 2004). These elasticities are reported in Table 5.8. The estimated elasticities are different between the linear and quadratic models for mean yield while the values for elasticities are slightly different in the yield variability function.

Table 5.8 Elasticities of climate variables

Yield function	Climate variables	Rice variety	Linear Cobb-Douglas Model	Quadratic Model
Mean Yield	Maximum temperature	Aus	0.0598	-20.2934
		Aman	0.1984	-6.5645
		Boro	-0.0010	-1.9598
	Minimum temperature	Aus	0.0066	-1.4788
		Aman	-0.0564	4.0406
		Boro	0.0233	0.1093
	Rainfall	Aus	-0.6265	3.7657
		Aman	0.0372	13.9959
		Boro	-0.0080	-0.7187
Yield Variability	Maximum temperature	Aus	0.0372	0.0358
		Aman	0.0563	0.0562
		Boro	-0.0002	-0.0002
	Minimum temperature	Aus	-0.0260	-0.0257
		Aman	-0.0206	-0.0206
		Boro	0.0052	0.0052
	Rainfall	Aus	-0.0189	-0.0188
		Aman	0.0829	0.0833
		Boro	-0.0168	-0.7187

The elasticities of the maximum temperature vary from -0.0010 to 0.1984 in the mean yield function for the three varieties of rice and -0.0002 to 0.0563 in the variance functions. Since these values are less than unity, the response of mean yields and variability of all three rice varieties to the changes in the maximum temperature are, therefore, inelastic. An increase in maximum temperature level usually decreases the mean and variance of Boro rice yield while it increases the mean and variability of Aus and Aman rice. Moreover, the estimated elasticities' range is from -1.9598 to -20.2934 in the quadratic model implying mean yield changes to maximum temperature are elastic. This leads to the conclusion that the maximum temperature is yield decreasing for all rice varieties in the quadratic model. Furthermore, the estimated elasticities of maximum temperature are higher for Aman and Aus than that of Boro in both the mean yield and yield variability functions.

The estimated elasticities of the minimum temperature range from -1.4788 to 4.0406 in the mean yield functions while the range is between -0.0260 and 0.0052 in the yield variability functions. The estimated elasticities of minimum temperature for mean yields in the linear function is less than unity and thus inelastic for Aus, Aman and Boro. The elasticity for mean yield for Boro rice in the quadratic model is also inelastic. However, the estimated elasticities for the mean yields of Aus and Aman are greater than 1 in the quadratic model and thus elastic. The response of yield variability of all three rice yields to changes in minimum temperature is inelastic. An increase in minimum temperature reduces the variability of Aus and Aman rice yields, while it increases the variability of Boro rice yield.

The estimated elasticities of rainfall vary from -0.6265 to 13.9959 in the mean yield functions and -0.7187 to 0.0833 in the yield variability functions. Thus, the response of mean yields of Aus, Aman and Boro to changes in rainfall is mixed. More precisely, the mean yields for Aus and Aman to changes in rainfall are inelastic in the linear model, but elastic in the quadratic model. However, the mean yield for Boro is inelastic in both linear and quadratic models. The estimated elasticities are less than 1 in the yield variability function which makes the variance of the three rice yields to changes in rainfall inelastic. The signs of the elasticities imply that rainfall is risk increasing for Aman rice whilst it is risk decreasing for Aus and Boro yields.

5.4.5 Effects of future climate change

The elasticity estimates are now used in order to estimate the impacts of future climate change scenarios on rice yield and its variability. In so doing, a few climate change scenarios are modelled, based on scenarios from the Ministry of Environment and Forest (MOEF 2005). This is applied to the growing periods of the three rice varieties and is shown in Tables 5.9 to 5.11. The changes in rice yields for each climate scenario are measured using the percentage changes in maximum temperature, minimum temperature and rainfall together with the elasticity estimates from Table 5.8. The percentage changes in mean Aus yield and variance for the years 2030, 2050 and 2100 are presented in Table 5.9.

Table 5.9 Change in mean Aus yield and yield variability (percentage)

Year	Changes in climate conditions			Changes in Aus rice yield			
	Maximum temperature	Minimum temperature	Rainfall	Mean		Variability	
				LC	LQ	LC	LQ
2030	0.3	1.18	4.1	-0.074	-24.82	-0.094	-0.093
2050	0.2	1.24	2.3	-0.020	-19.35	-0.109	-0.109
2100	-1.6	-0.74	6.7	-0.577	+106.05	-0.114	-0.107

Note: LC = linear Cobb-Douglas and LQ = linear quadratic

These results imply that the mean yields for Aus rice would fall, to some extent, in response to the projected climate changes for the years 2030 and 2050. However, the percentage decrease in mean yield under the quadratic model is far greater than that of the linear model. Furthermore, mean yield for 2100 decreases in the linear model whereas it increases in the quadratic model. The variability of Aus rice yield would decline by almost the same percentage in both functional forms over the three periods. Most importantly, the decrease in variability increases over time.

Table 5.10 Change in mean Aman yield and yield variability (percentage)

Year	Changes in climate conditions			Changes in Aman rice yield			
	Maximum temperature	Minimum temperature	Rainfall	Mean		Variability	
				LC	LQ	LC	LQ
2030	1.3	1.78	3.8	+0.404	+8.54	+0.099	+0.098
2050	0.89	1.65	3.0	+0.168	+14.16	+0.030	+0.030
2100	1.54	1.98	12	+0.533	+15.74	+1.76	+1.76

Note: LC = linear Cobb-Douglas and LQ = linear quadratic

The percentage changes in mean Aman yield and variance for 2030, 2050 and 2100 are presented in Table 5.10. These data indicate that all three scenarios of climate change would result in an increase in mean rice yield in both the linear and quadratic models. However, mean yield increase in the quadratic model is well above the value for the linear model. On the other hand, future climate changes would increase Aman yield variability over the years and the variations are profound when comparing 2030 and 2100. However, the percentage variability changes are very similar in both models.

Table 5.11 Change in mean Boro yield and yield variability (percentage)

Year	Changes in climate conditions			Changes in Boro rice yield			
	Maximum temperature	Minimum temperature	Rainfall	Mean		Variability	
				LC	LQ	LC	LQ
2030	0.02	0.65	-8.7	+0.100	+1.58	+0.04	+1.33
2050	0.07	0.59	-4.7	+0.085	+0.60	+0.03	+0.72
2100	-0.009	1.80	-10	+0.254	+2.68	+0.08	+1.56

Note: LC = linear Cobb-Douglas and LQ = linear quadratic

The change in Boro rice yield would increase for all the three time periods and in both models as shown in Table 5.11. For example, the percentage increases in mean yield are 0.10% and 1.58% for the linear and quadratic models respectively for 2030 while the values are 0.25% and 2.68% for 2100, respectively. The variance of Boro yield would increase over the three periods. It is noteworthy that mean yield and variability for rice yields however expand at decreasing rates. However, future climate change would have adverse impacts on rice yield variability which might result in production fluctuations and spiral price changes for rice (Kim & Pang 2009).

5.5 Concluding comments

Climate change will impact upon the mean and variability of rice crop yields (Chen et al. 2004; Isikand & Devadoss 2006; Kim & Pang 2009). The first objective of this chapter was to assess climate variability at the district and climate zone levels. Descriptive statistics reveal that there are significant variations in climate variables across the districts and climate zones during the 1972–2009 period. However, the changes are more profound when district level data are aggregated to climate zone. One important dimension of the findings is that the western zone (i.e., the Rajshahi district) has the highest maximum temperature and the lowest annual rainfall which makes the zone the most severe drought-prone area of Bangladesh. These findings are also consistent with other studies (FAO 2006).

The second, and main, research objective of this chapter was to evaluate the effects of climate changes on the yield and variability of three main rice varieties using disaggregated data. The Just-Pope production function was used as the theoretical framework and a balanced panel data model was utilised to achieve this objective. The results reveal that the impacts of climate variables vary among the three rice varieties. Maximum temperature is positively related to Aus and Aman mean rice yield in the linear model while the relationship is negative in the quadratic model. The elasticity values under the variance function imply that maximum temperature is risk increasing for Aus and Aman rice while risk decreasing for Boro rice production. However, the impacts of minimum temperature on yield variability are different. An increase in minimum temperature is likely to decrease the yield variability for Aus and Aman rice production while the yield variability for Boro rice is increased. Therefore, minimum temperature is risk increasing for Boro rice and risk decreasing for Aus and Aman varieties. Finally, the impacts of rainfall on yield variability are positive for Aman rice and negative for Aus and Boro rice. This confirms that rainfall is risk increasing for Aman rice while risk decreasing for Aus and Aman rice.

These results provide further evidence of the potential productivity losses which will occur with changes in climate. Moreover, most of the regional dummy variables are statistically significant with differential impacts on rice yield. This proves that different climate zones are impacted differently by climate change. Therefore, the severity of climate change effects on rice yields varies among the climate zones. This cautions against national or state level adaptation policies which may be ineffective and consequently suggests region specific or climate zone specific adaptation policies. This then warrants the need for more location-focused research on climate change and agricultural production to devise local or micro level adaptation policies for reducing yield variability, ensuring food security and alleviating rural poverty in the presence of climate change.

Three time scenarios (2030, 2050 and 2100) were developed to model potential climate changes on rice yield and its variability. The changes in rice yield for each of these scenarios were measured using the percentage changes in maximum temperature, minimum temperature and rainfall in an aggregate form. The results reveal that future climate change is expected to increase the variability of rice yield for Aman and Boro varieties. However, the variability will be higher for rain-fed Aman rice compared to the irrigated Boro rice crops.

Finally, a major caveat is that although the panel data model is an improvement over time series and cross-sectional data; the model does not always provide a cure-all for the econometrician's problems (Gujrati 2004). For example, how individual farmers are affected by climate change is not discernable from the panel data model results. It has been found elsewhere that the impact of climate change is more profound at the farm level (Downing 1992; Benson & Clay 1998). Data from a survey of farmers thus can indicate the impact of climate change and climate related extreme events more explicitly. This is the focus of the next two chapters. The focus of Chapter 6 is on the micro level analysis of the impact of climate change at the farm level while Chapter 7 is devoted to analysing the determinants of farmers' adaptive strategies at the farm level.

Chapter 6 Climate Change Impacts on Rice Production: An Analysis of Farm Level Data

6.1 Introduction

The preceding chapter focused on the impact of climate change on rice yield variability using disaggregated district level data. That relationship better represents the underlying connection between climate change and rice production compared to Chapter 4 where aggregate level data were used. However, district level data are not able to explain how individual farmers are affected by climate change (Downing 1992; Benson & Clay 1998; Lobell et al. 2007). Moreover, farms of different sizes are impacted differently by climate change and climate related extreme events. The differential impacts can be better captured by examining farm level micro data. The impact of climate change on crop production varies depending on farm characteristics, farm households' socio-demographic characteristics and institutional factors. This chapter investigates the variation of rice production and production loss due to climate change at the farm (micro) level.

The main aim of this chapter is to answer research question three. Specific research questions to assist in that task are: (i) Do the adverse effects of climate change differ among different types of farmers?; (ii) Do the non-integrated (rice only) farms face more adverse impacts in terms of profit (or net revenue) than integrated (rice and livestock) farms?; (iii) Is the adverse impact of climate change different for irrigated and non-irrigated farms?; (iv) What are the socio-economic determinants of a farm's net revenue under changing climate conditions? and (v) What are farmers' perceptions about production losses due to climate change and what factors induce this loss? Answers to these research questions are crucial to formulating area-specific policies to address climate vulnerability. This chapter is organised as follows. Section 6.2 provides a brief overview of the literature. The theoretical framework is explained in Section 6.3. Section 6.4 presents the methodology used. Research results and discussion are in Section 6.5 while Section 6.6 concludes the chapter.

6.2 A brief overview of the literature

There have been several studies on climate vulnerability and adaptation using farm level data. Early studies on the impact of climate change using a cross-sectional approach have focused on agriculture in developed countries especially the USA (Mendelssohn et al. 1994, Adams et al. 1995). However, crop agriculture in developing countries is expected to face substantial damage because of its climate sensitivity and the location of these countries in the lower latitudes (IPCC 2007; Mendelsohn 2009). Only in recent times have studies investigated the economic impacts of climate change on agricultural production in developing countries (Gbetibouo & Hassan 2005; Kurukulasuriya & Ajwad 2007; Kabubo-Mariara & Karanja 2007; Sanghi & Mendelsohn 2008; Deressa & Hassan 2009; Moula 2009; Wang et al. 2009). These studies, except for Kurukulasuriya and Ajwad (2007) for Sri Lanka, used county or district level data which did not include socio-economic and demographic characteristics of farms. These factors are also highly likely to affect farm productivity.

Detailed household level analyses are able to provide richer results and more effective policy making (Dinar et al. 2008; Wang et al. 2009; Kurukulasuriya and Ajwad 2007). In these studies however, their focus was on the impact of climate change on agriculture as a whole, not a particular crop. Different crops are impacted differently by climate variability and change (Deressa et al. 2005; Isik & Devadoss 2006). Therefore, there is scope for studies with a particular focus on individual crops (Kabubo-Mariara & Karanja 2007). Furthermore, the impact of climate change varies between and within AEZs of the same region or country (Mendelsohn & Tiwari 2000; Gbetibouo & Hassan 2005) which warrants location specific research.

Due to crop agriculture's significant contribution to GDP and its vulnerability to climate change, there is an urgent need for research on the impact of climate change in Bangladesh. Only one relevant study (Paul 1998) was found which investigated the response of farmers of northwestern Bangladesh to the 1994–95 drought. This study showed that drought negatively affected 15 distinct crops of the region. The most affected crop, as identified through a farmers' survey, was Aman rice. However, quantification of these effects was absent from this study: a precise quantification of effects is very important to policy makers for devising suitable adaptation strategies. In addition, the main methodology employed by Paul (1998) to examine the relationship between household characteristics and household level adjustment mechanisms to drought was descriptive statistics, namely, a chi-square test. However, the chi-square test is unable to show the direction and strength of relationship between variables, which is important for policy making. The Paul (1998) study thus is methodologically weak.

Therefore, the general objective of this chapter is to assess the impact of climate change on rice production using survey data from farm households in a severely drought-prone area of Bangladesh. This is an improvement over previous studies in three important aspects. First, the focus is on an individual crop, rice, the staple food of Bangladeshis. Second, a detailed dataset on farm households is used which is more informative than county or district level farm data. Third, it uses richer statistical tools such as a chi-square test along with directional measures; independent sample t-test, mean procedure with ANOVA, biplot under correspondence analysis and, more importantly, both mean and median regression analyses. This enhanced analysis will contribute to the scarce empirical literature for developing countries in general and for Bangladesh in particular.

6.3 Theoretical framework

It is assumed that farmers aim to maximize net revenue (or profit) from farm production subject to exogenous factors and conditions (Mendelsohn et al. 1994; Wang et al. 2009). Net crop revenue is defined as total revenue less the total cost of production divided by the amount of land cultivated. Total costs include both fixed and variable costs such as fertilizer, seed, irrigation, labour, pesticides and machinery costs. Net revenue is a measure of returns per unit of land for each farm household. The use of net revenue is justified on the basis that it is consistent with crop yield that indicates crop productivity or farm profitability. Furthermore, this approach is in line with the studies that followed Mendelsohn et al. (1994) as an analytical framework (Moula 2009; Wang et al. 2009). According to the literature, various non-climatic factors affect farmers' net revenue or farm productivity. These factors include: gender, age, level of education, farm income, non-farm income, household size, household assets, farm size, tenure status, livestock ownership, access to extension services, access to weather information, access to credit, access to subsidies, access to irrigation water, and access to electricity (Kurukulasuriya & Ajwad 2007; Kabubo-Mariara & Karanja 2007; Moula 2009; Wang et al. 2009).

In an economy where crop agriculture is the major livelihood activity, the direct impact of climate change and extreme climate events are manifested in the form of a decline in crop production through a reduction in cultivated area and/or crop yield (Paul 1998; IPCC 2007; Challinor & Wheeler 2008; Hisali et al. 2011). This, ultimately, reduces a farm's net revenue. A significant percentage of production loss is directly caused by climate change and extreme events such as droughts, floods and cyclones. IPCC (2007) predicted a 30% crop yield loss in South Asia by 2050 due to climate change. According to the proponents of the structural–political economy approach of vulnerability theory, production losses of farming communities due to climate related extreme events will vary depending on their socio-demographic and farm characteristics and institutional factors (Watt 1983; Dreze & Sen 1990; Emel & Peet 1989).

6.4 Methodology

6.4.1 Selection of study location

The survey part of this study, purposively, took place in two sub-districts namely Tanore and Godagari of Rajshahi district, a severely drought-prone area of Bangladesh (see Chapter Three for a description). On the basis of two informal focus group discussions with farmers in these sub-districts and consultations with SAAOs who reside at the field level and AEOs at sub-district level, a total of 15 villages were selected for surveying. The primary crop produced in the district is Aman rice.

6.4.2 Sampling procedure

A simple random sampling technique was used to select sample households in each village and the sample size for each village was proportional to the population of each village. This sampling procedure resulted in a self-weighting sample (Demeke et al. 2011). The sample size for this study was 550 farm households. The heads of the sample households were interviewed using a structured questionnaire with mainly closed-ended questions. The method used was a face-to-face interview. The main parts of the survey questionnaire included socio-demographic characteristics, farm characteristics, institutional accessibility, farmers' perception about climate change and consequent production loss, farmers' adaptation strategies to adverse effects, barriers to adaptation, and costs and returns from rice production (see Appendix II).

6.4.3 Data analysis

Previous cross-sectional studies have used the Ricardian model as illustrated in Mendelsohn et al. 1994 (Gbetibouo & Hassan 2005; Kurukulasuriya & Ajwad 2007; Kabubo-Mariara & Karanja 2007; Sanghi & Mendelsohn 2008; Deressa & Hassan 2009; Moula 2009; Wang et al. 2009). However, the Ricardian model requires data from farm households across a country or region, which is often impractical to achieve due to time and funding constraints. Moreover, the model requires a perfectly competitive land market which is non-existent in most developing countries, including Bangladesh. Following Kamanga et al. (2009), this study, therefore, has used a chi-square test, an individual sample t-test and multiple regressions (both mean and median). The regression analysis tools are used to examine the contribution of the socio-demographic, institutional and farm characteristics to farm profit (defined as net revenue) under changing climatic conditions. Use of these statistical techniques is a methodological improvement over the study by Paul (1998). This study also extends the chi-square test employed by Paul (1998) with the use of symmetric and directional measures to show the strength of the bivariate relationship between the variables.

6.5 Results

6.5.1 General characteristics

Socio-economic characteristics of sample households

Males head 97% of the households in the sample population. The average age of the head of the household is 47 years with a mean of five schooling years with 72% overall having attended school. These characteristics are similar to the population that Paul (1998) sampled. The average number household size is six with an average of two income earning members. This indicates that two-thirds of household members are dependents. In terms of economic activities, agriculture, mainly crop cultivation, is the major livelihood activity for 92% of households. Over 80% of their total income comes from agriculture. These figures are similar to the national figures for farming communities in Bangladesh (BBS 2008; GOB 2010). The other important livelihood activities include running small businesses, providing services and day labour.

Farm size and ownership

Farmers are categorised as small (up to 2.49 acres), medium (2.5–7.49 acres) and large (more than 7.50 acres) (GOB 2009). Small farmers also include marginal and landless (tenants) farmers. In the sample, 81% were small, 15% were medium sized and only 4%

were large. The national figures for these types of farmers are 80%, 17% and 3% respectively (BBS 2008). Therefore, the sample is representative of both Bangladesh and the Rajshahi district. Mean farming experience of 23 years was observed. The average land holding is 3.37 acres. Based on the households' tenure status, 64% of households are categorised as owner farmers while the remaining 36% are tenant farmers. Nearly 90% of the sample households own livestock and/or poultry (e.g., cattle, buffalo, goat, sheep and duck).

Topography and soil

All land is located above the normal flood level. Fifty-five percent of the sample is categorised as high land. The other types of land elevation comprise low land (23%), medium low land (13%) and medium high land (9%). In terms of soil quality, almost two-thirds of the soils are clay with clay-loamy, loamy and sandy soil accounting for 16%, 10% and 8% respectively.

Institutional accessibility

Institutional accessibility indicates farmers' access to extension services, weather information, credit, subsidies, irrigation water, electricity etc. These factors play a vital role in crop production. Only 34% of households have access to extension services. In the provision of extension services, the contribution of SAAOs is significant. The role of NGOs is negligible in the district. It is noteworthy that nearly all farmers practice farmer-to-farmer extension. Accurate weather forecasting and its accessibility to farmers play a very important role, particularly in determining planting and harvesting times of crops. However, only 46% of households have access to regular weather information, with television as the major source. Only 31% of households have access to credit. Subsidies, particularly for small and landless farmers, are crucial for ongoing agricultural production. However, only 10% of households receive government subsidies in the form of agricultural inputs (e.g., fertilizer, diesel and seed) and money. Most of the farm households (nearly 95%) have access to irrigation water from the Barind Multipurpose Development Authority (BMDA). Two-thirds of households have electricity in their home. However, almost all households reported that the regular availability of electricity for irrigation purposes was problematic. This situation is consistent with the rest of the country which also experiences regular and lengthy blackouts.

Farmers' perception of input supplies

Farmers' perceptions of the availability of supply of inputs are presented in Table 6.1.

Table 6.1 Farmers' perception of the availability of major agricultural inputs

Farmers' opinion	**Major agricultural inputs**				
	Fertilizer	Seed	Irrigation water	Herbicides/pesticides	Labour
Very good (%)	18.0	17.3	0.4	18.5	8.9
Good (%)	54.9	50.2	0.36	54.0	26.4
Moderate (%)	26.5	30.7	11.1	27.3	49.6
Not good (%)	0.5	1.8	84.9	0.2	15.1

The probable reasons for the poor availability of irrigation water are the decreasing groundwater table, electricity shortages and insufficient number of DTWs. The availability of seed is good or very good for two thirds of households. More than two-thirds of households are satisfied with the supply of chemical fertilizer. The supply of herbicides and pesticides is very similar to that for fertilizer. The availability of labour is moderate to just 50% of households. However, labour shortages are experienced during the planting and harvesting periods. Focus group discussions with farmers confirmed these findings.

6.5.2 Determinants of net revenue: chi-square test

It is important for policy makers to understand how farmers' profit or net revenue from rice production varies. In order to observe the relationship between net revenue and various socio-demographic and institutional determinants a chi-square test was employed. The results are presented in Table 6.2.

Table 6.2 Bi-variate analysis of association of net revenue and its determinants

Variables	**Pearson chi-square test**		**Symmetric measures (phi)**		**Directional measures (uncertainty coefficient)**	
	Value	P-value	Value	P-value	Value	P-value
Gender	10.213	.177	.138	.177	.012*	.072
Age	45.279**	.021	.290**	.021	.026**	.011
Education	45.303**	.021	.290**	.021	.028***	.005
Occupation	23.46	.710	.208	.710	.015	.932
Farm income	71.309***	.003	.363***	.003	.040***	.000
Non-farm income	50.174**	.046	.305**	.046	.032*	.069
Household size	18.639	.608	.186	.608	.011	.545
Household assets	64.023**	.016	.344**	.016	.035***	.005
Farm size	45.184	.340	.289	.340	.024	.234
Farmer type	37.996***	.001	.265***	.001	.031***	.000
Tenure status	57.083***	.000	.325***	.000	.042***	.000
Farming experience	52.142***	.004	.311***	.004	.031***	.001
Livestock ownership	15.08	.035	.167**	.035	.012**	.048
Access to extension	25.475***	.001	.217***	.001	.018***	.001
Farmer-to-farmer extension	4.929	.669	.096	.669	.006	.478
Access to weather information	75.942***	.000	.375***	.000	.056***	.000
Access to subsidies	6.920	.437	.113	.437	.006	.446
Access to irrigation water	11.791	.108	.148	.108	.013**	.041
Irrigated land (%)	37.770	.103	.264	.103	.023*	.060
Access to electricity	47.697***	.000	.300***	.000	.038***	.000
Crop selling place	85.05***	.000	.397***	.000	.146***	.000
Membership status	69.42***	.000	.359***	.000	.051***	.000
Years' of involvement	14.83	.038	.304**	.038	.035**	.030
Distance to local market	58.61***	.001	.329***	.001	.043**	.000
Distance to urban market	196.83***	.000	.604***	.000	.172***	.000

Note: *, **, *** indicate significance at 10%, 5 % and 1% respectively.

Whilst the chi-square test is useful to determine whether there exists a relationship between two categorical variables, it cannot show the strength of the relationship. Phi (under symmetric measures) and the uncertainty coefficient (under directional measures) are able to give some sense of the strength of the relationship. Based on a Pearson chi-square test, 15 variables were found to be statistically significant determinants of farmers' net revenue: respondent's age, education, households' yearly farm income, non-farm income, household asset, types of farmers, tenure status, farming experience, livestock ownership, access to weather information, access to electricity, crop selling place, membership status, distance of local market from home and distance of urban market from home. However, this relationship is only suggestive, not conclusive. The significance values of phi for the same variables indicate a statistically significant relationship. However, the values of phi range between 0.096 and 0.604 indicating the relationship is from fairly weak to strong. Phi values above 0.3 imply a strong while those of under 0.3 indicates a weak relationship between two variables (Muijs 2004). In terms of directional measures, p values of uncertainty coefficient indicate most of the variables are statistically significant.

6.5.3 Comparing the means of net revenue: independent sample t-test

The relationship between net revenue and its different nominal factors can be examined individually using the chi-square test. This is obviously inadequate for this study. For example, one of the research questions in this chapter is to check the difference between the means of net revenue of integrated and non-integrated farms. This can be done using the independent sample t-test. The results from the t-test are reported in Table 6.3.

Table 6.3 Comparing the means of profit between groups

Variables	Independent sample t-test for the equality of means when equal variance is assumed		Means (in Taka /decimal of land)	
	Value	P-value	First	Second
Gender (male vs female)	-1.43	0.152	110	145
Age	2.11**	0.035	124	106
Education (literate & illiterate)	2.49**	0.013	118	96
Occupation (agriculture vs non-agriculture)	0.997	0.319	113	98
Farm income	5.42***	0.000	141	96
Non-farm income	-1.16	0.245	103	114
Household size	-.761	0.477	107	114
Household assets	-0.70	0.944	111	112
Farm size (higher vs lower)	1.96**	0.050	123	106
Farmer type (large vs small)	2.58**	0.010	133	107
Tenure status (yes vs no)	3.46***	0.001	122	96
Farming experience	1.28	0.198	117	107
Integration of farms	1.83*	0.068	114	91
Access to extension	-2.00**	0.045	100	118
Farmer-to-farmer	-0.656	0.512	111	115
Access to weather information	-6.83***	0.000	82	136
Access to credit	-5.21***	0.000	80	126
Access to subsidies	-1.78*	0.075	99	114
Access to irrigation water	-.564	0.573	111	122
Irrigated land (%)	1.28	0.202	116	106
Access to electricity	4.89***	0.000	123	78
Crop selling place	6.29***	0.000	125	67
Membership status	-6.00***	0.000	76	127
Years' of involvement	-0.527	0.599	71	77
Distance to local market	3.71***	0.000	128	98
Distance to urban market	3.24***	0.001	127	100

***Significant at 1% probability level, ** Significant at 5% probability level,* Significant at 10% probability level.
Note: continuous variables were converted into two categories with the use of their mean values. First category is above the mean value while the second one is below the mean.

By looking at the means of net revenue between two groups of variables, it can be stated that there are considerable differences. However, the mean differences for all variables are not statistically significant. Variables that have produced statistically significant different means are age, education, farm income, farm size, farmer type, tenure status, integration of farms, access to extension, weather information, credit, subsidy, electricity, crop selling place, membership status, distance of local market and distance of urban market from home. One of the specific research questions of this chapter was: whether there is any difference in net revenue of rice farming between types of farmers. To make this comparison viable, the farmers are placed into two groups (consistent with the t-test): large and medium vs. small and landless. The result suggests that the mean of profit is higher for large and medium farmers than that for small and landless farmers, and the mean difference is statistically significant at the 0.05 level. Another important research question was whether the profit of integrated farms is higher than the profit for non-integrated farms or specialised farms. Results from the t-tests indicate that the mean difference between integrated and non-integrated farms is statistically significant, although only at the 10% level. A recent study by Seo (2010) has also found that the net revenue of a mixed farm is less vulnerable than that of a more specialised farm.

6.5.4 Mean procedure for variables with multiple categories

In the independent sample t-test, the categorical variable must have only two groups. The mean procedure is used to compare the mean of net revenue of different farmer types and levels of irrigation. Table 6.4 sets out a comparison of mean profit among landless, small, medium and large farmers.

Table 6.4 Mean profit for different groups

Type of farmer	Mean	No.	Std Deviation	Median	Skewness	Kurtosis
Landless	92.7016	189	124.60871	98.4848	6.856	75.450
Small	117.3969	248	66.46010	131.8182	-.838	.689
Medium	124.7667	81	92.00663	139.6118	-1.221	3.812
Large	165.4454	22	37.87354	170.4545	-1.092	1.855
Total	111.8166	540	95.06467	121.6330	4.803	73.125

The mean profit or net revenue from Aman rice production increases as farmer size increases, which implies a positive impact of land size on farmers' profits. Therefore, larger farm sizes increase profit per decimal of land. In Table 6.5, the analysis of variance (ANOVA) is used to check the significance of this finding.

Table 6.5 ANOVA for mean profit and types of farmers

<table>
<tr><th colspan="3"></th><th>Sum of squares</th><th>df</th><th>Mean square</th><th>F.</th><th>Sig.</th></tr>
<tr><td rowspan="5">Aman: Net revenue (per decimal) * Types of farmer</td><td rowspan="3">Between groups</td><td>(Combined)</td><td>153636.924</td><td>3</td><td>51212.308</td><td>5.819</td><td>0.001</td></tr>
<tr><td>Linearity</td><td>140688.498</td><td>1</td><td>140688.498</td><td>15.985</td><td>0.000</td></tr>
<tr><td>Deviation from linearity</td><td>12948.426</td><td>2</td><td>6474.213</td><td>0.736</td><td>0.480</td></tr>
<tr><td colspan="2">Within groups</td><td>4717463.441</td><td>536</td><td>8801.238</td><td></td><td></td></tr>
<tr><td colspan="2">Total</td><td>4871100.365</td><td>539</td><td></td><td></td><td></td></tr>
</table>

Between group analysis shows a variation of the group means around the overall mean. Within group results reflect a variation of individual values around the group mean. Linearity reveals variation because of a linear relationship between the variables while deviation from linearity indicates variation due to a non-linear relationship between the variables (Muijs 2004). The test for combined effects has a significant value of 0.001 implying that mean profits are statistically different between the four groups of farmers. Moreover, the test for linearity has a value of 0.000 which indicates the linear relationship between mean profit and farmers' type is significant. The value of deviation from linearity indicates the strength of the linear relationship. Overall, a statistically significant association between the means of profit and different farmer groups is found. The distribution of means among different levels of irrigation is examined in Table 6.6.

Table 6.6 Mean profit vs. irrigation coverage

Percentage of land under irrigation facilities	Mean	No.	Std Deviation	Median	Skewness	Kurtosis
No irrigation	121.5132	29	90.01777	130.6061	-0.203	0.024
<50%	104.0044	134	84.19162	125.7576	-0.733	0.178
50–75%	102.3648	80	68.99376	123.7229	-0.847	0.068
> 75%	116.9403	297	105.58039	118.1818	6.572	86.681
Total	111.8166	540	95.06467	121.6330	4.803	73.125

The means of profit are different between farmers with different levels of irrigation coverage. Farmers with over 75% of their land under irrigation have a higher mean profit than farmers with less than 75% irrigation coverage. However, mean profit is highest for the farmers having no irrigation. Irrigation coverage, thus, does not seem to affect net revenue positively for Aman rice. This may be due to the fact that Aman is mainly rain-fed. Another reason could be such that farmers are not adequately served by irrigation services. However, the mean difference is not statistically significant (Table 6.7). The significance for the combined test between groups has a value of greater than 10%, indicating that none of the groups' means differ from the others.

Table 6.7 ANOVA for profit and irrigation coverage

			Sum of squares	df	Mean square	F	Sig.
Aman : Net revenue (per decimal) *Percentage of land under irrigation facilities	Between groups	(Combined)	25848.664	3	8616.221	0.953	0.415
		Linearity	7643.216	1	7643.216	0.846	0.358
		Deviation from linearity	18205.447	2	9102.724	1.007	0.366
	Within groups		4845251.702	536	9039.649		
	Total		4871100.365	539			

Furthermore, the significance values for the tests of linearity and deviation from linearity implies that neither a linear nor non-linear relationship exist between profit and irrigation for Aman rice production. Since irrigation coverage is not statistically significant for mean profit, a biplot of profit and farmers' type provides a better understanding of their relationship. Figure 6.1 illustrates the symmetrical normalization for this purpose.

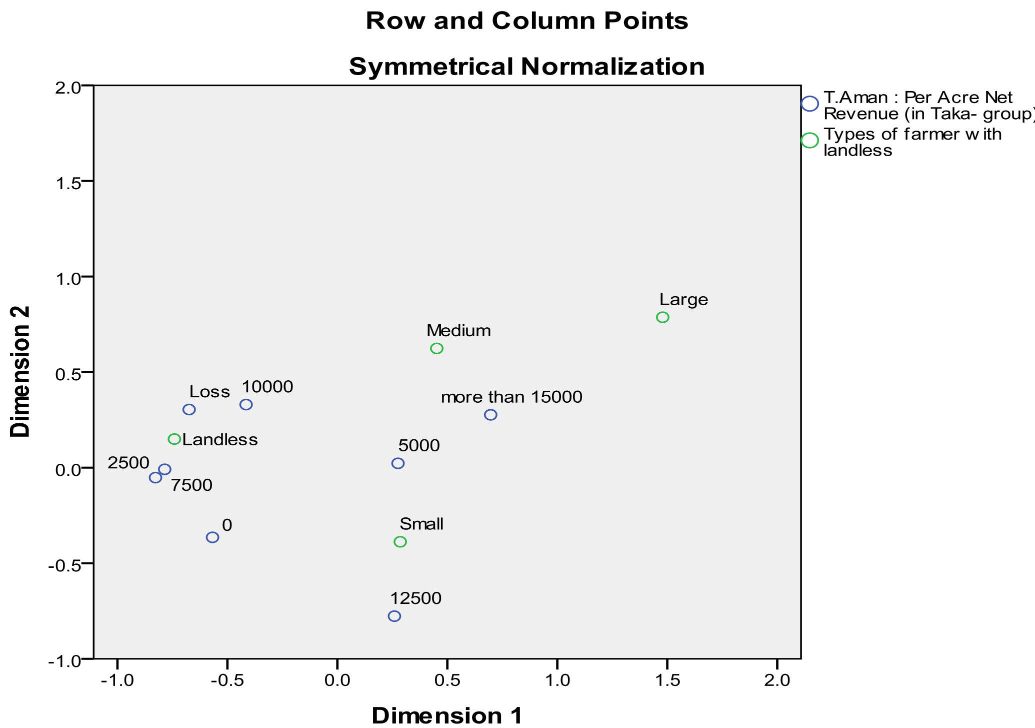


Figure 6.1 Biplot of net revenue and different farms type

Figure 6.1 shows that large and medium farmers receive net revenue of more than Tk. 15 000/acre while small farmers receive net revenue of Tk. 5000/acre. Landless farmers are very close to experiencing losses (i.e. negative profits). These results are consistent with earlier findings.

6.5.5 Production losses due to climate change

The impact of climate change and the effects of extreme events such as drought are not well understood in the Rajshahi district. Based on discussions and key informant interviews, Ahmed and Chowdhury (2006) reported that small and landless farmers were the most vulnerable to climate change in two nearby drought-prone districts, Nawabganj and Naoganj, also in northwest Bangladesh. Another study by FAO (2006) documented that Aman was the most vulnerable rice variety and production losses ranged from 10% to 75% in the same districts. The sample Aman farmers were asked about their perception of crop damage and actual production losses experienced in the last production year. The results of farmers' perception of crop damage are presented in Figure 6.2.

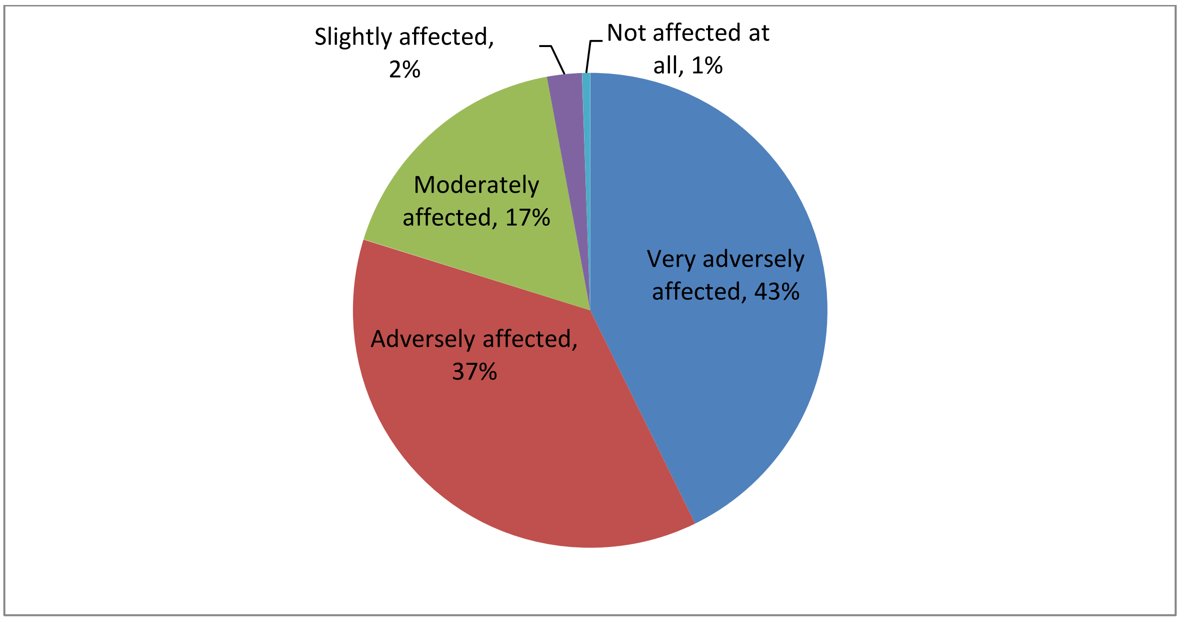


Figure 6.2 Farmers perception about crop damage

Almost 80% farmers reported that their crop was damaged either very severely or severely by climatic factors. The remaining 20% were either moderately or slightly affected. A very insignificant percentage of farmers were only slightly affected. Farmers were also asked to provide their opinion on the amount of production losses for Aman rice. These views are presented in Figure 6.3 while descriptive statistics of production loss are reported in Table 6.8. It can be seen that the mean production loss was 37%, whilst the maximum value was 90%.

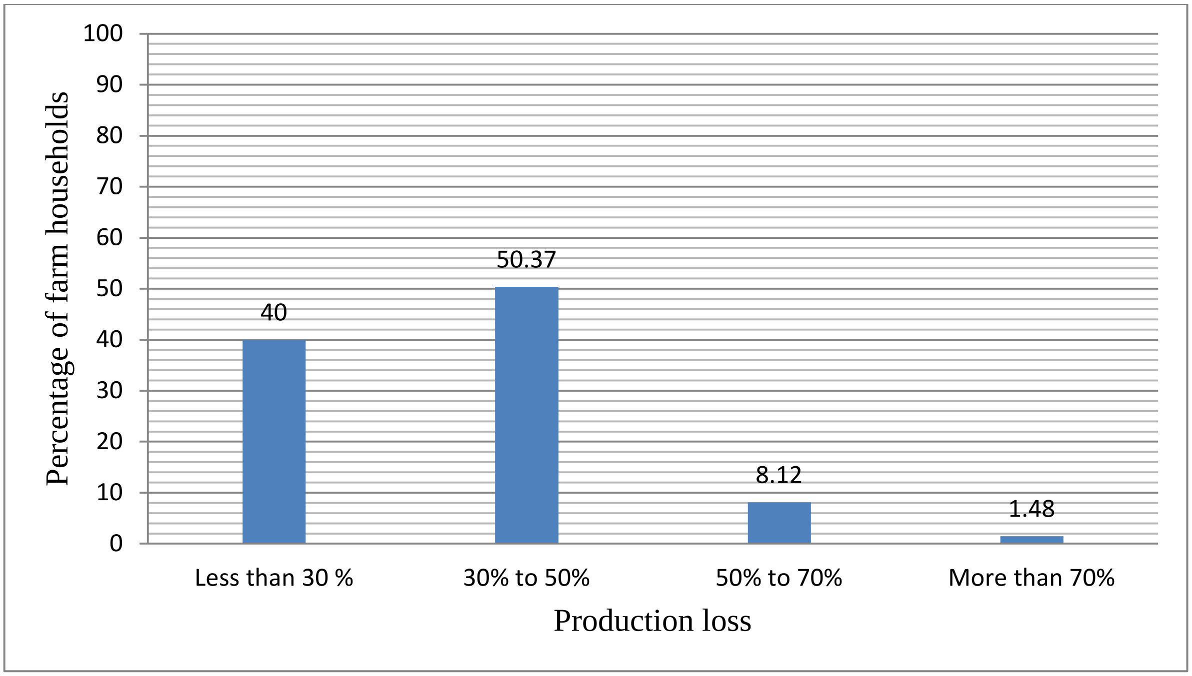


Figure 6.3 Production loss of Aman rice

Table 6.8 Descriptive statistics of production loss for Aman

Variable	No.	Minimum	Maximum	Mean	Std Deviation	Variance
Production loss - Aman (%)	542	2	90	36.54	14.641	214.35

More than 50% of farmers reported that they incurred a 30% to 50% production loss due to high temperatures and very low rainfall. Just 40% of farmers had less than 30% production loss. On average, nearly two-thirds of the farmers faced production losses of between 30% to 90%.

6.5.5.1 Determinants of production losses: chi-square test and independent sample t-test

The strength of the association between production losses and the relevant non-climatic determinants is now examined. First, the chi-square test to assess the relationship between production losses and its determinants and then independent sample t-test are employed to evaluate the mean difference of production losses between two groups of variables. To apply the chi-square test, transformation of production loss from a continuous variable to a categorical one is done using the frequency distribution. Table 6.9 outlines the results.

Table 6.9 Association between production losses and its factors

Variables	**Pearson chi-square test**		**Symmetric measures (phi)**		**Directional measures (uncertainty coefficient)**	
	Value	P-value	Value	P-value	Value	P-value
Gender	.301	.960	.024	.960	.001	.922
Age	28.51***	.005	.229	.005	.015	.067
Education	15.94	.194	.171	.194	.012	.181
Occupation	11.42	.493	.145	.493	.012	.449
Farm income	32.81**	.018	.246	.018	.023	.014
Non-farm income	22.25	.101	.203	.101	.019	.261
Household size	3.49	.942	.080	.942	.004	.887
Household assets	36.40***	.006	.259	.006	.022	.024
Farm size	14.00	.729	.161	.729	.011	.609
Farmer type	32.30***	.000	.244	.000	.029	.000
Tenure status	8.52**	.036	.125	.036	.010	.034
Farming experience	11.21	.511	.144	.511	.008	.540
Livestock ownership	1.35	.718	.050	.718	.003	.567
Access to extension	3.19	.362	.077	.362	.004	.350
Farmer-to-farmer	2.23	.526	.064	.526	.007	.258
Access to weather information	19.23	.000	.188	.000	.022	.000
Access to subsidies	4.47	.214	.091	.214	.007	.200
Access to irrigation water	10.36**	.016	.138	.016	.009	.127
Irrigated land (%)	25.90**	.011	.219	.011	.019	.021
Access to electricity	4.38	.223	.090	.223	.005	.247
Crop selling place	4.98	.173	.096	.173	.008	.102
Membership status	4.40	.222	.090	.222	.005	.265
Years' of involvement	45.01	.958	.529	.958	.085	.878
Distance to local market	33.66***	.001	.249	.001	.027	.001
Distance to urban market	88.69***	.000	.405	.000	.061	.000

***Significant at 1% probability level, ** Significant at 5% probability level,* Significant at 10 % probability level

The variables that have a statistically significant relationship with production losses include age of household head, farm income, household assets, farmer type, tenure status, access to weather information, access to irrigation water, percentage of total land under irrigation, distance of local and urban markets from home. However, the levels of significance are not the same for all these factors. Among the statistically significant variables, age of household head, household assets, farmer type, and distance from local and urban market are significant at the 1% level while the remaining variables are significant at the 5% level. This chi-square test cannot reveal the difference in production losses between two groups. The independent sample t-test is used to show the difference between groups, and the results are set out in Table 6.10.

Table 6.10 Comparing the means of production losses between groups

Variables	**Independent sample t-test for equality of means when equal variance assumed**		**Mean (%)**	
	Value	P-value	First	Second
Gender (male vs. female)	.861	.389	37	33
Age (higher vs. lower)	-2.44**	.015	34	38
Education (literate & illiterate)	-.558	.577	36	37
Occupation (agriculture vs. non-agriculture)	-.717	.473	37	38
Farm income (higher income vs. lower income)	-2.37**	.018	35	38
Non-farm income	-1.74*	.083	35	37
Household size (higher vs. lower)	1.15	.249	37	36
Household asset (higher vs. lower)	-3.22***	.001	33	38
Farm size (higher vs. lower)	-1.26	.209	35	37
Farmer type (large and medium vs. small)	-4.12***	.000	31	38
Tenure status (Yes vs. No)	-2.69***	.007	35	39
Farming experience(higher vs. lower)	-2.23**	.026	35	38
Integration of farms (Yes vs. No)	-.147	.884	37	37
Access to extension (Yes vs. No)	-1.24	.216	35	37
Farmer-to-farmer (Yes vs. No)	2.07**	.039	37	30
Access to weather information (Yes vs. No)	1.04	.298	37	36
Access to credit (Yes vs. No)	1.75*	.080	38	35
Access to subsidies (Yes vs. No)	.954	.341	35	37
Access to irrigation (Yes vs. No)	-2.32**	.021	36	43
Irrigated land (%) (higher vs. lower)	-4.23***	.000	34	40
Access to electricity (Yes vs. No)	-1.60	.110	36	38
Crop selling place (local vs. urban)	-.325	.746	37	37
Membership status (Yes vs. No)	1.76*	.078	38	36
Years' of involvement (higher vs. lower)	-.065	.948	38	38
Distance to local market (higher vs. lower)	1.29	.198	37	36
Distance to urban market (higher vs. lower)	3.84***	.000	39	34

***Significant at 1% probability level, ** Significant at 5% probability level,* Significant at 10% probability level
Note: Continuous variables were converted into two groups using their mean (above mean and below mean) in order to apply the t-test.

By looking at the last two columns in Table 6.10, it is observed that there is a difference between the means of production loss between groups of almost all variables aside from integration of farms, crop selling place and years of household heads' involvement in a group. However, the mean difference for all the variables is not statistically significant. The variables that have produced statistically significant differences in the means of production loss are age, farm income, non-farm-income, household asset, farmer type, tenure status, farming experience, farmer-to-farmer extension service, access to credit, access to irrigation water, percentage of total land under irrigation, membership status and distance of urban market from home. As expected, farmers with higher age, higher farm income, higher non-farm income and higher household assets have lower production losses. Small and landless farmers have higher production losses as compared to large and medium farmers. The mean difference of production losses for these two groups of farmers is statistically significant at the 1% level. Tenure status and farming experience also play positive roles in reducing production losses. Farmers who have tenure status and have more farming experience faced lower production losses. From the viewpoint of farmers' accessibility to institutional facilities, farmers with irrigation water and more land under irrigation have lower production losses. Farmers who have access to farmer-to-farmer extension services, agricultural credit and membership of an organisation or group are faced with higher production losses which are contrary to expectations. This is possibly because of small credit markets, farmer-to-farmer incorrect advice and not availing themselves support from community organisations.

6.5.5.2 Analysis of mean production losses between more than two groups of a variable: mean procedure and ANOVA

The independent sample t-test is unable to compare the means of production losses for more than two groups of a variable. ANOVA was used to compare the means of production losses with more than two categories and the results are presented in Table 6.11.

Table 6.11 Production losses for different types of farmers

Types of farmer	**Mean**	**No.**	**Std Deviation**	**Median**	**Kurtosis**	**Skewness**
Landless	38.84	190	14.399	40.00	-.008	.170
Small	36.98	249	13.991	35.00	.585	.381
Medium	33.06	81	15.602	30.00	-.474	.386
Large	24.68	22	13.160	20.00	.763	1.290
Total	36.54	542	14.641	35.00	.011	.286

The results in this table indicate that mean production loss decreases as farmer type changes from landless to small, small to medium and medium to large. This finding is consistent with the literature (see, for instance, FAO 2006). To check the significance of the results, ANOVA was used.

Table 6.12 ANOVA for the means of production losses for the different groups

			Sum of squares	**df**	**Mean square**	**F**	**Sig.**
Production loss - Aman (%) * Types of farmer	Between groups	(Combined)	5123.17	3	1707.73	8.29***	0.000
		Linearity	4375.40	1	4375.40	21.23***	0.000
		Deviation from linearity	747.77	2	373.88	1.815	0.164
	Within groups		110841.26	538	206.02		
	Total		115964.437	541			

Table 6.12 contains tests for the linear, non-linear and combined relationship between production losses and different types of farmers. The test for between groups (combined) has a significance value of 0.00 which indicates that at least one of the groups differs from the others. The test for linearity has a P-value of 0.000 implying that there is a linear relationship between production losses and farm types while the P-value of deviation from linearity confirms that there is a linear relationship.

The same analysis can be repeated for the percentage of total land under irrigation and production losses. It is hypothesised that farmers having more land under irrigation usually experience less production losses. Results using the mean procedure are set out in Table 6.13.

Table 6.13 Production losses at various level of percentage of total land under irrigation

Percentage of total land under irrigation facilities	**Mean**	**No.**	**Std. deviation**	**Median**	**Kurtosis**	**Skewness**
No irrigation	42.66	29	17.315	45.00	.200	.454
< 50%	40.02	134	15.463	40.00	.413	.570
50–75%	37.10	80	14.396	40.00	-.497	.188
> 75%	34.24	299	13.618	35.00	-.825	-.042
Total	36.54	542	14.641	35.00	.011	.286

Table 6.13 reveals that mean production losses decrease as the percentage of land under irrigation increases. However, the spread of values is approximately constant across different levels of irrigation. Values of skewness are less than 1 which suggests a symmetrical distribution of production losses. The mean and median values are approximately equal which also supports a symmetrical distribution. The ANOVA results for the statistical significance level of the relationship are reported in Table 6.14.

Table 6.14 ANOVA for the means of production loss vs. irrigation coverage

			Sum of squares	**df**	**Mean square**	**F**	**Sig.**
Production loss - Aman (in %) * total land under irrigation (%)	Between groups	(Combined)	4310.575	3	1436.858	6.923	.000
		Linearity	4309.308	1	4309.308	20.764	.000
		Deviation from linearity	1.268	2	.634	.003	.997
	Within groups		111653.862	538	207.535		
	Total		115964.437	541			

The combined significance value of 0.000 implies that at least one of the groups is different from the others. The significance value for the linearity test ensures that the relationship between the two variables is linear while the P-value for deviation from linearity also confirms that a non-linear relationship does not exist.

A biplot under correspondence analysis can make the distribution of production loss between different levels of irrigation and farmer types more visible (Figure 6.4).

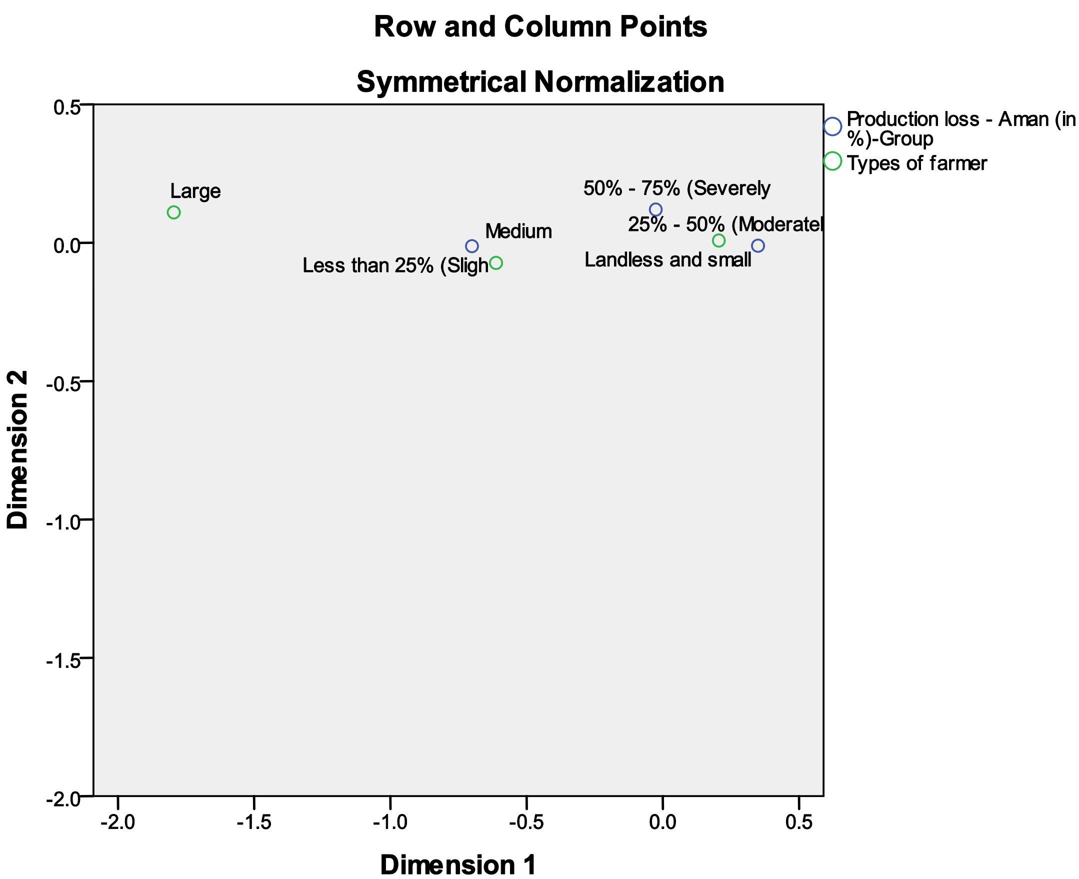


Figure 6.4 Symmetrical normalisation for production losses vs. types of farms

This symmetrical normalisation is a clearer way to see the relationship between production loss and farmer types. It can be seen that large and medium farmers are near to the minimum production loss category while small and landless farmers are very close to both moderate and severe production losses. This biplot of symmetrical normalisation is consistent with the theoretical expectation that large farmers face less production losses than both medium and small farmers while small and landless farmers are hardest hit.

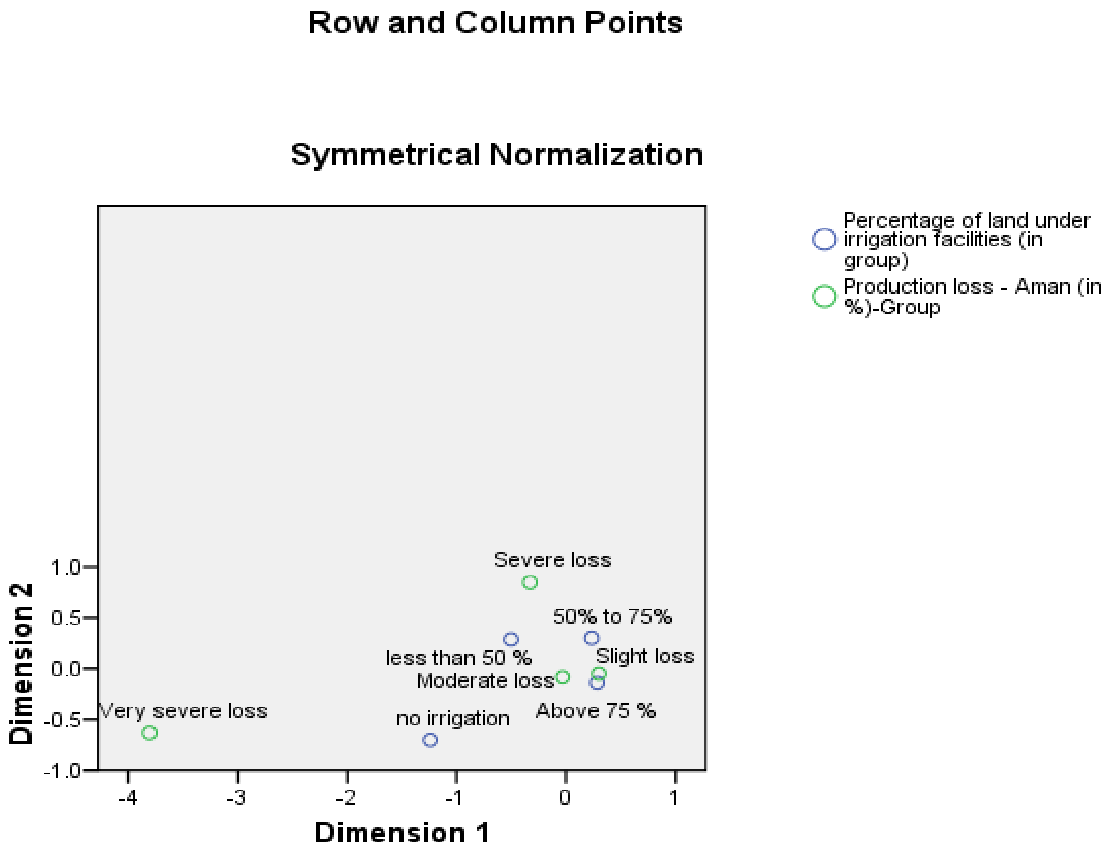


Figure 6.5 Biplot showing relationship between production losses and irrigation levels

The biplot in Figure 6.5 shows the relationship between production losses and levels of irrigation. Row and column points that are nearer together are more alike than points that are further away from each other. It can be seen that over 70% irrigation (highest category of irrigation) is strongly associated with the minimum level of production losses indicating farmers with more irrigated land experience the lowest production losses. Less than 50% land under irrigation is close to both moderate and severe production loss. These results imply that the more irrigated land a farmer has results in less production losses being experienced.

Thus far, the focus of the analysis has been on bivariate analysis (i.e., the association between two variables). These associations are only suggestive, not conclusive, as bivariate analysis is unable to establish the cause-and-effect relationship between two variables (Muijs 2004). Moreover, many of the variables examined here are likely to be related to one another. To examine the empirical relationships involving profit or production losses and other socio-demographic, farm characteristics and institutional factors, the focus of this chapter turns to multiple regression analysis.

6.5.6 Profit and its determinants: multiple regression analysis

Both mean and median regressions are applied to assess empirically the possible determinants of farm net revenue from rice production. Factors to be included in the model have been identified from the literature (Kurukulasuriya & Ajwad 2007; Kabubo-Mariara & Karanja 2007; Moula 2009; Wang et al. 2009). Table 6.15 presents a summary of the variables, and the hypotheses that will be tested (i.e. their expected effect on net revenue).

Table 6.15 Explanatory variables and their expected sign

Factors	**Expected sign**	**Sources**
Gender of the household head (male=1, female=0)	+	Kurukulasuriya & Ajwad 2007
Age of the household head (years)	+	Kurukulasuriya & Ajwad 2007
Years of schooling of the household head	+	Kurukulasuriya & Ajwad 2007; Kabubo-Mariara & Karanja 2007
Agriculture is the main occupation of household head (agriculture=1, others=0)	+	Kabubo-Mariara & Karanja 2007
Household farm income (Taka)	+	Nhemacha& Hassan 2007
Household size (number of people)	+/-	Kurukulasuriya & Ajwad 2007; Kabubo-Mariara & Karanja 2007; Charles 2009
Household assets (Taka)	+	Bryan et al. 2009
Farm size (in decimal)	+/-	Benhin 2008; Charles 2009
Household land tenure (yes=1, no=0)	+	Kurukulasuriya & Ajwad 2007
Livestock ownership (yes=1, no=0)	+	Kabubo-Mariara & Karanja 2007
Farming experience of household head (years)	+	Kurukulasuriya & Ajwad 2007
Household access to agricultural extension service (yes=1, no=0)	+	Charles 2009
Household access to weather information (yes=1, no=0) (%)	+	Gbetibouo 2009
Household access to agricultural credit (yes=1, no=0)	+	Gbetibouo 2009
Household access to agricultural subsidies (yes=1, no=0)		Kurukulasuriya & Ajwad 2007
Percentage of household total land under irrigation (per cent)	+	Kabubo-Mariara & Karanja 2007; Benhin 2008; Charles 2009
Household access to electricity (yes=1, no=0)	+	Charles 2009
Produce/crop selling place (local market=1, urban market/others=0)	+/-	Kurukulasuriya & Ajwad 2007
Distance of local market from household home (km)	+/-	Deressa & Hassan 2009
Distance of urban market from household home (km)	+/-	Deressa & Hassan 2009
Household head membership status in an organization/association (yes=1, no=0)	+	Paul 1998; Wang et al. 2009

The descriptive statistics of these variables are presented in Appendix III. This appendix provides a general picture of the dataset for the entire sample and five important sub-samples (small farms, integrated farms, non-integrated farms, irrigated farms and non-irrigated farms). It was not possible to estimate regression coefficients for large farmers because of their small sample size.

6.5.6.1 Determinants of profit under climate change

Estimation procedure

Statistical and econometric software STATA (Version 10) was used to estimate the parameters of the multiple regressions. Cross-sectional data analyses usually involve two problems: heteroscedasticity in the error term and multicollinearity among explanatory variables (Greene 2003; Benhin 2008; Cameron & Trivedi 2009).

The variance inflation factor was used to detect the problem of multicollinearity. The Breusch-Pagan test was used for checking heteroscedasticity and a robust variance estimator was used to deal with the problem. Furthermore, median regression was also estimated to address the issues of heteroscedasticity and outliers. This is because mean regression (OLS) is sensitive to outliers and the net revenue data was found to have outliers. Therefore, both median and robust OLS regressions are estimated to overcome these problems.

6.5.6.2 Estimation results and discussions

Table 6.16 shows the results from the mean and median regressions for all farms and the sub-samples mentioned earlier. In terms of F and R^2 values, the overall mean regression for all farms is statistically significant and the explanatory variables are jointly important in impacting net revenue.

Table 6.16 Regression results for the determinants of net revenue

Variables	All farms		Small farms		Integrated farms		Non-integrated farms	Irrigated farms	
	Mean regression (robust)	Median regression	Mean regression (robust)	Median regression	Mean regression (robust)	Median regression	Mean regression (robust)	Mean regression (robust)	Median regression
Gender of the household head (male=1, female=0)	-.0864**	-.0467	-1080**	-.0941*	-.0831**	-.0555	-.0488	-.0854**	-.0577
Age of the household head (years)	.0005	.0011	.0013	.0016*	.0002	.0007	-.0040	.0003	.0011
Years of schooling of the household head	.0007	.0024	.0057**	.0040*	.0039*	.0036*	-.0007	.0023	.0033
Agriculture is the main occupation of household head (agriculture=1, others=0)	-.0232	.0025	-.0119	.0102	.0050	.0238	-.0543	-.0067	.0314
Household yearly farm income (Taka)	6.730***	4.28***	9.1900***	7.2800***	6.6700***	4.6300***	1.250**	6.6500***	4.400***
Household size (number of people)	-.0084	-.0029	-.0026	-.0015	-.0094	-.0046	.0047	-.0077	-.0026
Household asset (Taka)	3.1200	2.4500	-3.5800	-2.0200	4.6900	8.9500	-7.2800	3.3600	6.5300
Farm size (in decimal)	-.0003***	-.0002***	-0.0003***	-.0004***	-.0003***	-.0002***	-.0004*	-.0002***	-.00019***
Household land tenure (yes=1, no=0)	.0412*	.0793***	.0527**	.0679***	.0297	.0703***	.1512	.0479**	.0822***
Farming experience of household head	.0003	-0.0005	.0003	-.0013	.0005	-.0004	.0031	.0005	-.0003
Household access to agricultural extension service (yes=1, no=0)	.0513**	.05639***	.0584**	.0702***	.0497**	.0552***	.1012	.0555**	.0689***
Farmer to farmer extension (yes=1, no=0)	.0204	.0228	.0505	.0266	.0106	.0261	-.0397	.0147	.0117
Household access to weather information (yes=1, no=0)	-.0693**	-.0656***	-.0772***	-.0450**	-.0814***	-.0590***	-.0245	-.0723**	-.0690***
Household access to agricultural credit (yes=1, no=0) (%)	-.0246	-.0145	-.0376	-.0471**	-.0165	-.0079	-.0307	-.0197	-.0223
Household access to agricultural subsidies (yes=1, no=0)	.0055	-.0106	-.0179	.0011	-.0069	-.0153	.0318	-.0044	-.0191
Percentage of household total land under irrigation (%)	-0.0001	-.0002	-.0001	-.0005**	-.0002	-.0002	-.0011	.0002	.0000
Household access to electricity (yes=1, no=0)	0.0350	.0578 ***	.0335	.0472**	.0161	.0366*	.1568	.0360	.0364*
Produce/crop selling place (local market=1, urban market/others=0)	.1416***	.1258***	.1357***	.1039***	.1256***	.1005***	.2959***	.1414***	.1231***
Distance of local market from household home (km)	.0255***	.0142**	.0196***	.0147**	.0215***	.0128**	.0732**	.0221***	.0127**
Distance of urban market from household home (km)	-0.0067**	-0.0056***	-.0063**	-.0056***	-.0059**	-.0058***	-.0182*	-.0069**	-.0063***
Household head membership status in an organization/association (yes=1, no=0)	-0.0034	-0.0407*	.0170	-.0322	-.0045	-.0438*	-.0181	-.0078	-.0433
Constant	3.8530***	5.8100***	5.8058***	5.8938***	5.9069***	5.87***	5.82***	5.84***	5.80***
Number of observation	540	540	437	437	479	479	61	511	511
R^2	0.18	0.19	0.34	0.21	0.17	0.18	0.51	0.17	0.20
F	8.71***	-	8.13***	-	7.55***	-	4.68***	8.02***	-
Mean VIF (Variance Inflation Factor)	1.72	-	1.63	-	1.75	-	2.93	1.78	-

***Significant at 1% probability level, ** Significant at 5% probability level,* Significant at 10% probability level

The results prove that a good number of the explanatory variables are statistically significant and the sign on the estimated parameters are as expected, aside from a few examples. The variables that have individually significant effects on net revenue are: gender of the household head, household yearly total income, farm size, tenure status, household access to extension services, household access to weather information, availability of crop selling place, distance of local market from home and distance of urban market from home.

Gender has a negative and significant impact on net revenue which implies that the net revenue of households with male heads is not more profitable than female-led households. Kurukulasuriya and Ajwad (2007) reported contrasting findings for this variable. Household income is significantly and positively associated with net revenue indicating that farmers with higher income levels have better capacity to use better production technologies in their farming and are better equipped to overcome the negative impact of climate change. Farm size appears to have a strong positive impact on net revenue indicating that large-scale farmers are able to diversify and apply better production technologies. This is consistent with the findings of Benhin (2008) and Charles (2009). Land tenure has positive and statistically significant effects on net revenue as ownership decreases the uncertainty of reaping the benefits of capital and labour investment. This positive impact of land tenure is also in line with the results of Kurukulasuriya and Ajwad (2007) and Charles (2009). Access to agricultural extension services has a positive and statistically significant influence on farm profit. This is supported by Charles (2009). This implies that farmers with extension services are able to apply the appropriate management practices under changing climatic conditions. Access to weather forecast information has a significantly negative effect on farm net revenue which is contrary to expectations. One probable explanation is that weather information in Bangladesh is mostly misleading. As a result, farmers who depend on climate forecasts for crop management are disadvantaged. A negative impact of weather information on farming activities was also found in South Africa (Gbetibouo 2009). The availability of crop selling place is an important determinant of net revenue (Kurukulasuriya & Ajwad 2007). Crop selling at local markets positively affects farm net revenue. Distance of local market from households' home is also highly significant and has a positive impact whilst distance of an urban market from home has negative and significant impacts on farm net revenue. This is possibly due to the fact that farmers have to spend time and incur travel costs when market places are situated far from their home or farm plots.

Turning to the median regression results, it can be seen that variables that are significant in mean regression also are significant in median regression. In addition to this, two new variables (household access to electricity and household head membership of a group) have become statistically significant with median regression. Access to electricity having a strong positive impact on farm net revenue is also supported by Charles (2009). But membership status of household head is negatively related with net revenue. The reason for this is possibly that farmers who are members of organisations receive misleading farm management advice from the organisation. The median regression results are more informative in terms of the number of significant explanatory variables than the mean regression and it has higher explanatory power.

The statistically significant variables for the sub-samples of small and landless farms under the mean robust regression are gender of the heads of household, years of education of household's head, household yearly income, farm size, tenure status, household access to extension services, access to weather information, crop selling place, and distance of local and nearby urban market from home. The direction and significance of the relation of these variables on net revenue is similar to the full sample mean regression model except for years of education and farm size. Schooling years of household head was insignificant in the full sample model while it has significant positive impact on net revenue for small farms. This is because 78.3% of illiterate household heads are small and landless farmers. Moreover, household heads with higher educational levels are capable of adopting new technologies (Kurukulasuriya & Ajwad 2007). Farm size had a positive impact on net revenue in the full sample model while it has a negative impact on net revenue for small farmers. The reason for this negative sign is that small and landless farmers are usually tenants and do not have sufficient capital to invest in technologies. There is an evidence of the negative impact of small farm size on farm profit in the literature (Kabubo-Mariara & Karanja 2007). Now a comparison of the results of mean regression with that of median regression for the same sub-samples confirms that the numbers of significant variables for median regression is higher than for mean regression. Four more variables (age of household head, household access to agricultural credit, percentage of total land under irrigation and access to electricity) are statistically significant in the median regression. The age of household head and household access to electricity are positively associated with net revenue while household access to agricultural credit and irrigation coverage of total land have a negative impact on net revenue.

For the sub-sample of integrated farms, the statistically significant variables in mean regression are gender of the household head, years of schooling of household head, household yearly income, farm size, access to extension services, access to weather information, crop selling place, and distance of local and urban market from home. In addition, another three variables are found to be significant in the median regression: tenure status, access to electricity and household membership status in a group. The direction of the relationship of these variables with net revenue is similar with the signs obtained for small sample farms.

For the non-integrated farms, the variables that have a statistically significant impact on net revenue are household yearly income, farm size, crop selling place, and distance of local and urban market from home. Household income, crop selling place and distance of local market from home have positive effects while farm size and distance of nearby urban market from home have negative impacts on net revenue. Median regression for non-integrated farms was not conducted because of the small sample size.

For irrigated farms, both mean and median regressions were estimated. The variables that have a statistically significant impact on net revenue for both mean and median regression are household yearly income, farm size, land tenure status, access to extension service, access to weather information, crop selling place, distance of local and nearby urban markets from home. In addition, gender of the household head is significant in mean regression while household access to electricity is significant in median regression. The number of statistically significant variables is the same regardless of the method used.

The variables that are not statistically significant for net revenue are whether agriculture is the main occupation, household assets and size, farming experience of household head, farmer-to-farmer extension services and access to subsidies. However, these variables have the theoretically expected signs. The analysis now turns to assessment of the determinants of crop damage in the face of climate change.

6.5.7 Determinants of production losses: multiple regression analysis

The extent of production losses varies between farmers. Therefore, it is important to assess the determinants of production losses using the same set of explanatory variables. The dependent variable for this analysis is production loss as a percentage of total rice production. In Table 6.17 two regression models of production loss on socio-economic, farm and institutional characteristics are estimated. Regressions for five samples are reported (all farms, small farms, integrated farms, non-integrated farms and irrigated farms). It was not possible to undertake regression analysis for the large farmers' sub-sample because of the very small sample size of this group. The probability of F-value for all models implies that the models are statistically significant. Moreover, R^2, the goodness of fit, for all the models ranges between 0.11 and 0.68 which is reasonable for farm-level cross-sectional data.

Table 6.17 Regression results for the determinants of production loss

Variables	All farms		Small farms		Integrated farms		Non-integrated farms	Irrigated farms	
	Mean regression	Median regression	Mean regression (robust)	Median regression	Mean regression	Median regression	Mean regression	Mean regression	Median regression
Gender of the household head (male=1, female=0)	3.5272	3.3388	6.3867	3.0725	6.9464*	12.0511**	-16.750**	3.0023	2.9258
Age of the household head (years)	-.1099	-.1713**	-.1146	-.1877**	-.0915	-.1783	-.5932**	-.0894	-.1829*
Years of schooling of the household head	-.1030	-.1046	-.1304	-.0420	-.1854	-.3321	1.0956**	-.0458	-.0937
Agriculture is the main occupation of household head(agriculture=1, others=0)	-3.6230	-3.4850	-7.0966**	-5.0683	-3.8362	-2.3038	3.5979	-2.5876	-3.9260
Household yearly farm income (Taka.)	-.0001**	-.0001***	-8.4600	-4.2400	-.0001	-.0001	-.0001**	-.0001*	-.0001**
Household size (number of people)	.2654	.1402	.2563	.1700	.1729	.0450	2.8550**	.2918	.1922
Household assets (Taka)	-.0001**	-.0001**	-.0001*	-.0001**	-.0001**	-.0001*	5.0200	-.0000**	-.0001**
Farm size (in decimal)	.0014	.0050	.0082	.0047	.00207	.0041	.0027	.0001	.0048
Household land tenure (yes=1, no=0)	-1.8927	-3.1663**	-1.8032	-3.0881*	-1.3012	-2.2424	-6.1897	-1.7786	-3.2934*
Farming experience of household head	.0642	.1079	.0359	.0751	.0439	.0926	.3241	.06222	.1283
Household access to agricultural extension service (yes=1, no=0)	-1.9477	-1.6032	-1.5756	-2.0649	-3.1184*	-3.9593*	4.4691	-1.7521	-1.1489
Farmer to farmer extension (yes=1, no=0)	4.3097	-.4102	4.8019*	1.5782	2.3517	-2.9548	26.2062***	4.2985	-.1366
Household access to weather information (yes=1, no=0)	.3238	-.1205	-.8295	-.2341	1.1599	1.9443	-.5685	.2460	-.3084
Household access to agricultural credit (yes=1, no=0) (%)	.5870	.1557	.5676	-1.0429	-.2789	.9615	7.0392	.2981	-.7186
Household access to agricultural subsidies (yes=1, no=0)	-2.4587	-3.0683	-4.1247*	-2.9743	-2.3619	-3.4662	-1.1815	-3.0088	-3.3168
Percentage of household total land under irrigation (%)	-.0251	.0113	-.0126	.0160	-.0182	0.0470	-.2239***	-.0215	.0172
Household access to electricity (yes=1, no=0)	.7483	3.1063**	1.4277	4.1790**	1.6036	4.5171**	.2700	.2831	3.2406
Produce/crop selling place	-6.3431***	-10.4718***	-6.9574**	-10.4135***	-6.9712***	-9.1593***	-3.4939	-7.355***	-11.050***
Distance of local market from household home (km)	.0361	-.1102	-.4672	-.1906	-.0236	.1646	.1564	-.0017	-.1475
Distance of urban market from household home (km)	1.0264***	1.3861***	1.1602***	1.4494***	1.0687***	1.4737***	.5145	1.0706***	1.3824***
Household head membership status	-.3368	-.9746	-.8772	1.0936	.7208	-1.1268	-4.1784	-.3140	-.5176
Constant	32.9148***	36.3490	31.9955***	34.1106***	30.2691***	23.1684**	45.7660***	31.661***	36.8582***
Number of observation	542	542	439	439	481	481	61	513	513
R^2	0.19	0.12	0.20	0.11	0.18	0.11	0.68	0.18	0.11
F	5.64***	-	4.72***	-	4.83***	-	4.05 ***	5.15***	-
Breusch-Pagan prob.	0.4729	-	-	-	0.6478	-	0.5773	0.2802	-
Mean VIF(Variance Inflation Factor)	1.73	-	1.63	-	1.73	-	2.93	1.75	-

***Significant at % probability level, ** Significant at 5% probability level,* Significant at 10% probability level.

The results for the all farms' mean regression model reveal that many of the explanatory variables have the expected signs and some are statistically significant. The statistically significant variables are household yearly income, household assets, crop selling place and distance of urban market from home. These variables, excluding distance of nearby urban market from home, have negative signs which imply they are loss decreasing factors. The distance of nearby urban markets appears as a loss increasing factor. Furthermore, the Breusch-Pagan probabilities of chi-square and mean VIF value indicate that the all farms model is free from heteroscedasticity and multicollinearity. The results from median regression for the all farms model produced a higher number of significant variables than the mean regression. The statistically significant variables under median regression are age of household head, household yearly income, household asset, land tenure, household access to electricity, crop selling place at local market, and distance of nearby urban market from home. However, all variables except household access to electricity and distance of nearby urban market are production loss decreasing factors.

The results for small farms identify many significant variables. Most importantly, three new variables that were not significant in earlier regressions (either for profit in the previous section or production loss for the all farms model in this section) are now significant: agriculture as the main occupation, farmer-to-farmer extension and household access to subsidies. Access to subsidies and agriculture being the main occupation are negatively associated with production loss whilst farmer-to-farmer extension is positively associated with production loss.

For integrated farms, the statistically common significant variables for both mean and median regressions are gender of household, household assets, household access to agricultural extension, crop selling place and distance of nearby urban market from home. The direction of the relationship in both regressions is the same. However, household access to electricity under median regression has become statistically significant as a loss increasing input.

For non-integrated farms, only mean regression is estimated (as it was not possible to conduct median regression). The variables with a significantly negative impact on production loss are gender and age of household head, household yearly income and percentage of land under irrigation. Years of schooling of household head, household size and farmer-to-farmer extension have a positive and significant impact on production loss.

For the irrigated farm sub-sample, the common significant variables for both regressions were household income, household assets, crop selling place and distance of nearby urban market from home. One other variable, land tenure, is significant in the median regression only.

6.6 Concluding comments

The first objective of this chapter was to assess the difference in profit and production losses from climate change for Aman rice production. Different sub-samples were examined: small vs. large farmers, integrated vs. non-integrated farms and irrigated vs. non-irrigated farms. Evidence from bivariate statistics such as chi-square tests and independent sample t-tests reveals that there is considerable variation of profit and production losses among those sub-samples. For example, mean profit is significantly higher for large and medium farmers than for small and landless farmers while this latter group has higher production losses. Integrated farms have higher net revenue than non-integrated farms and this difference is statistically significant. However, there is no statistically significant difference in mean production losses between integrated and non-integrated farms. Farms that have a higher proportion of land under irrigation earn higher profits than farms with lower irrigation coverage, but the mean difference in net revenue is not statistically significant. However, the mean production losses between irrigated and non-irrigated farms are significantly different: the crop losses for highly irrigated farms are lower than those for lowly irrigated farms.

The second important objective of this chapter was to analyse the determinants of profit and production losses using mean and median regression. To avoid heteroscedasticity, median regression and robust mean regression were used. The potential multicollinearity problem was resolved with the use of the variance inflation factor. Overall, all models are statistically significant for the regressions of profit and production losses on various socio-economic, institutional and farm characteristics. For profit determinants, many variables were statistically significant for the full and all sub-sample models. The significant variables that affect farm profit are gender, age, years of schooling of household head, household yearly total income, household assets, farm size, land tenure, household access to agricultural extension services, weather information, agricultural credit and electricity, percentage of land under irrigation, crop selling place, distance of local and nearby urban markets from home and membership status in a group of household head. Age and education of the household head, agriculture as the main occupation, yearly income, household assets, land tenure, access to subsidy, access to extension services, access to electricity, farmer-to-farmer extension, percentage of land under irrigation, crop selling place and distance of nearby urban market from home all appear as statistically significant variables across the full and sub-group models. All of these variables, excluding access to electricity and distance to nearby urban market from home, are production loss decreasing factors.

Another important finding is the comparison between mean and median regression outputs. The number of significant variables under the full and all sub-group models is higher for median regression than for mean regression. This empirically confirms the methodological superiority of median regression over mean regression when using cross-sectional data. This is because median regression is not as greatly affected by outliers in cross-sectional data as is mean regression (Kabubo-Mariara & Karanja 2007; Benhin 2008). This finding is therefore an important contribution to the existing literature.

The analysis in this chapter is based on 15 out of many thousands of villages in the area. One therefore needs to apply caution in generalising the results and outcomes. Analysis in this chapter provides support for many expected relationships and hypotheses in the literature. Moreover, there are indications that some of the observed patterns may be applicable to other drought-affected areas in Bangladesh and in developing countries.

Chapter 7 Rice Farmers' Adaptation Strategies to Climate Change: Evidence from Farm Level Data

7.1 Introduction

This chapter addresses research question four which asks how farmers adapt to changing climatic conditions, particularly drought. Farmers first perceive the adverse effects of climate change at the farm production level and then take adaptive actions to mute these adverse effects (Bryan et al. 2009) as adaptive measures are able to reduce vulnerability (Reidsma et al. 2010). Therefore, impact and adaptation are interlinked. In Chapter 6 it was evident that farmers incurred significant amounts of production losses due to climate change. This chapter is focused on what adaptation strategies have been practiced by farmers in the study area to reduce their food production losses due to climate change.

The specific research questions investigated in this chapter are: (a) What are farmers' perceptions of climate change in a very severe drought-prone area of Bangladesh?, (b) What are the major adaptation strategies in the study area?, (c) What are the determinants of farmers' adaptive choices? and (d) What are the barriers to effective adaptation to climate change? These four research questions will be addressed using micro data at the farm level. The organisation of this chapter is as follows. Section 7.2 provides a brief overview of the literature. The theoretical framework is outlined in section 7.3. The methodology is presented in section 7.4. Section 7.5 reports and discusses the results while section 7.6 concludes the chapter.

7.2 Adaptation and agriculture: a brief overview of the literature

Climate change affects crop agriculture adversely, particularly in countries in the lower latitudes of the world (Bryan et al. 2009; Liu et al. 2010; Teixeira et al. 2011). Adaptation is seen as an essential policy option as compared to mitigation to limit the negative effects of climate change (Stern 2006; Kurukulasuriya & Mendelsohn 2008; Reidsma et al. 2009). This is because mitigation has an insignificant impact on the current stock of greenhouse gases in the short run and, moreover, it requires collective and global actions (Stern 2006).

There have been several studies examining the potential effects of climate change on agriculture globally (Adam et al. 1990; Mendelsohn et al. 1994; Adams et al. 1995, 1999; Iglesias et al. 2000; Kabubo-Mariara & Karanja 2007; Kurukulasuriya & Ajwad 2007; Wang et al. 2009). The earlier studies assumed either no or little adaptation at an aggregate level. However, farmers' adaptation has been under researched especially at the farm level. Furthermore, an analysis of the determinants of adaptation strategies is limited in the climate change impact literature. Nevertheless, economic rationality implies that addressing climate change requires adaptive strategies and farmers usually make adjustments in their production processes to overcome any negatives experienced (Kaufmann 1998). Adaptation is very important if farmers are to counter the potential unfavourable impacts of climate change (Kabubo-Mariara & Karanja 2007; Stern 2007; Hassan & Nhemachena 2008; Reidsma et al. 2010). Adaptive measures are able to protect the livelihoods of poor farmers and ensure food security by reducing the potential negative impacts and reinforcing the advantages associated with climate change (IPCC 2001; Bradshaw et al. 2004; Reid et al. 2007; Bryan et al. 2009).

There is a growing number of study on farm level adaptation strategies and their determinants globally (Seo & Mendelsohn 2008; Bryan et al. 2009; Reidsma et al. 2010). However, adaptation in agriculture varies across countries. Different adaptation strategies are practiced by farmers depending on the climatic conditions, farm types and other conditions such as political, economic and institutional factors (Deressa et al. 2009; Reidsma et al. 2010; Hisali 2011). More precisely, adaptation choices are context specific and change from area to area and over time (Smit & Wandel 2006). Therefore, country or area specific studies of climate change adaptation are required. In this context, research studies for Bangladesh are very limited (Paul 1998; Ali 1999; Ahmed & Chowdhury 2006; FAO 2006; Rashid & Islam 2007).

Paul (1998) documented some adjustment measures such as crop replacement, irrigation, gap filling and the inter-cropping of wheat and kaon (a local food crop). Ali (1999) identified some adaptive measures such as the construction of embankments and cyclone shelters, and the introduction of new rice varieties suitable to higher salinity levels and temperatures. Rashid and Islam (2007) identified drought, flood, soil salinity and cyclones as the major extreme climatic events which adversely affect agricultural operations and production. Changes in behavioural patterns, human practices and international actions are suggested as anticipatory adaptive measures. Based on focus group discussions and key informant interviews, Ahmed and Chowdhury (2006) and FAO (2006) identified the excavation of DTWs which facilitated irrigation, the excavation of ponds, switching to mango farming, the cultivation of short-duration and drought-tolerant crop varieties and homestead gardening as major adaptation strategies for the Chapai-Nawabgonj and Naogaon districts of northwest Bangladesh. However, none of these studies analysed the determinants of farmers' adaptation strategies alongside the farmers' perception of climate change and the barriers to adaptation which are crucial for devising effective adaptation policies. Moreover, farm level adaptation strategies in the Rajshahi district have not been studied. Therefore, the objective of this chapter is to examine, using a detailed farm level dataset, farmers' perception of climate change, barriers to adaptation and factors affecting adaptation choices in rice production systems by using the case of farmers in Rajshahi, a severely drought-prone district of Bangladesh.

7.3 Theoretical framework

Crop models or climate impact assessment techniques have been the most frequently used approaches to understanding the relationship between climate change and agriculture. Crop models are used to estimate the potential effects of future long-term climate change scenarios (Carter et al 1994; Esterling et al. 2007). Farmers' responses to climate variability and extreme climate events in these models are simply hypothetical, and either no adaptation or optimum adaptation is presumed (Rosenzweig & Parry 1994). Furthermore, climate scenarios under these models are inevitably not the scenarios to which farmers are most susceptible.

A complementary approach, vulnerability theory, is used to explore the relationship between agricultural systems, the susceptibility to climate change and extreme events and farmers' adaptation explicitly (Reid et al. 2007). The term 'vulnerability' generally represents 'the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes' (IPCC 2001, p. 21). The vulnerability of an agricultural system is explained as a function of exposure sensitivity, which indicates the susceptibility of a system to be affected by climate stimulus, and the adaptive capacity of the system (Reid et al. 2007). According to the theory, vulnerability is positively related with exposure sensitivity while there is an adverse relationship between vulnerability and adaptive capacity which is the ability of a system, region or community to adapt to the impact of climate change (Reid et al. 2007; Li et al. 2010). More precisely, if exposure sensitivity increases, vulnerability also increases but increased adaptations are possible to alleviate vulnerability. Exposure sensitivity is not homogenous. It will vary from farm to farm as the characteristics of the farms that make them more or less vulnerable to particular climatic changes and extreme events are different. Vulnerabilities to climate change vary also because of socio-demographic, environmental, institutional and social characteristics that are either exogenous or endogenous to the community (Diaz 2008).

Farmers' adaptive capacity to climate change is influenced by socio-economic, institutional and social factors. Socio-economic characteristics include age, education, gender, household size, farm size, farming experience and wealth (i.e., household assets) (Deressa et al. 2009; Gbetibouo 2009). Institutional factors consist of access to extension services, climate information and credit, and tenure status (Deressa et al. 2008; Hassan & Nhemachena, 2008; Bryan et al. 2009; Deressa et al. 2009; Gbetibouo 2009). Finally, social capital includes farmer-to-farmer extension services and the number of relatives living close by (Deressa et al. 2008; Deressa et al. 2009). These determinants may assist or restrict adaptation choices. In the case of agricultural systems, farmers are the first people confronting climate variability and change. It is thus essential to comprehend farmers' perceptions of and adaptations to climatic changes in order to diminish vulnerability and to enhance the overall resilience of the system (Reid et al. 2007; Li et al. 2010).

7.4 Methodology

7.4.1 Study area

The adaptation part of this study took place in the same villages of Rajshahi district as earlier. District level analysis of climate data in Chapter 5 reveals that average annual rainfall across Rajshahi varies from 839 mm to 2241 mm. Moreover, the district average total rainfall for the 1964–2009 period is 1505 mm compared to 2408 mm for the whole country. Furthermore, the temperature in the district is as high as 44°C in May and as low as 6°C in January. In terms of extreme climate events, the district is severely drought-affected but is almost free from cyclones and floods (Ahmed & Chowdhury 2006; FAO 2006).

7.4.2 Data sources

Micro data from a farm level survey conducted by the researcher is the main source of data for this analysis. The sample comprised the same 550 households who were selected randomly from the 15 selected villages discussed in Chapter 3. This part used data on socio-demographic characteristics (age, gender, education and household size), farm characteristics (farm size and tenure status), institutional accessibility (access to extension, weather information, credit, subsidy and irrigation facility) and farmers' perceptions about climate change, adaptation strategies and barriers to adaptation. Moreover, climate data from BMD (2010) is used to make a comparison of climate change in Rajshahi with that of Bangladesh. The time period for this analysis is from 1964 to 2009 as climate data for the district is available for only this period.

7.4.3 Theory of random utility and a micro-econometric model

Provided that various adaptive options are practised by farmers, the selection of the choice model can be either a multinomial probit (MNP) or a multinomial logit (MNL) model. This study uses the MNL model to analyse the determinants that affect farmers' choices of adaptation strategies. This is because this model gives more precise estimation results than the MNP model (Kropko, 2007). Moreover, the MNL model has been successfully and commonly used in some recent studies (Hassan & Nhemachena 2008; Kurukulasuriya & Mendelsohn 2008; Deressa et al. 2009) while the MNP model is not usually used largely because of the practical difficulty involved in its estimation process (Cheng & Long 2007).

Farmers' choice of adaptation strategies is a discrete and mutually exclusive choice. In the context of the current study, a farmer can select a strategy among eight alternatives: (i) more irrigation, (ii) short-duration rice, (iii) supplementary irrigation, (iv) changing planting date, (v) agro-forestry, (vi) use of different crop varieties, (vii) non-rice crops and (viii) no adaptation. It is assumed that the selection of one of these strategies is independent of the other strategies. The choice of one strategy is characterised by various socio-demographic factors such as age, education, tenure status, access to climate information, extension services and subsidies.

The theoretical underpinning that a farmer chooses among different alternatives lies in the theory of random utility. In this theory, the utility of each alternative is modelled as a linear function of observed characteristics (farmer and/or alternative specific) plus an additive error term. Furthermore, farmers are assumed to select the alternative that has the highest utility. More particularly, the utility a farmer *i* from alternatives j and k is given by

$$U_{ij} = V_{ij} + \varepsilon_{ij} \tag{7.1}$$

$$U_{ik} = V_{ik} + \varepsilon_{ik} \tag{7.2}$$

respectively; where V_{ij} and V_{ik} imply the deterministic or systematic component of the utility, and ε_{ij} and ε_{ik} represent the stochastic component which represents the uncertainty. According to utility maximization, farmer i will, thus, only chooses a particular alternative j if $U_{ij} > U_{ik}$ for all k ≠ j.

A common formulation of Equations (7.1) and (7.2) is as follows, assuming $V_{(\,)}$ is a linear function of x_i, observed factors to the farmer's utility:

$$U_{ij} = x_i\beta_j + \varepsilon_{ij} \tag{7.3}$$

$$U_{ik} = x_i\beta_k + \varepsilon_{ik} \tag{7.4}$$

Then, if we denote $Y_i = j$ and the farmer's choice of alternative j, it can be written that

$$\begin{aligned} \text{Prob}[Y_i = j|x] &= \text{Prob}\ [U_{ij} > U_{ik}] \\ &= \text{Prob}\ [x_i\beta_j + \varepsilon_{ij} - x_i\beta_k - \varepsilon_{ik} > 0|x] \\ &= \text{Prob}\ [x_i(\beta_j - \beta_k) + \varepsilon_{ij} - \varepsilon_{ik} > 0|x] \\ &= \text{Prob}\ [x_i\beta + \varepsilon > 0|x] \end{aligned}$$

where β is a vector of unknown coefficients that can be explained as the net impacts of a vector of explanatory variables influencing choice of adaptation and ε is a random error term.

Assume that ε for all alternatives is independent and identically distributed (i.i.d) conditional on x_i, with the Type I extreme value distribution. Then, the probability that a farmer will choose alternative j is given by Equation (7.5):

$$\text{Prob } (Y_i = j) = \frac{e^{\beta_j x_i}}{\sum_{k=1}^{8} e^{\beta_k x_i}} \qquad (7.5)$$

This is the MNL model (Greene 2003). The MNL model significantly requires the assumption of independence of irrelevant alternatives (IIA) to hold in order to obtain unbiased and consistent parameter estimates. The IIA assumption necessitates that the probability of adopting a particular adaptation strategy by a given farm household requires independence from the probability of selecting another adaptation strategy.

The numerator is the utility (i.e., net benefit) from choice j and the denominator is the sum of utilities of all alternative choices. The probability of selecting a specific adaptation strategy is equal to the probability of that specific alternative being higher than or equal to the utilities of all other alternatives in the set of strategies. The parameters of this model can be estimated using maximum likelihood methods. However, the parameter estimates of the MNL model merely show the direction of the impact of the explanatory variables on the dependent variable. The real extent of changes or probabilities is not represented by the estimates. Moreover, parameter estimates are hard to interpret since they are derived from non-linear estimates (Greene 2003). Therefore, the MNL model parameters are transferred into relative risk ratios (RRR). This RRR measures the effects on the relative odds of one outcome being selected relative to the baseline outcome for a unit change in any of the explanatory variables.

7.5 Research results and discussion

7.5.1 Overview of climate change in Rajshahi and comparison to Bangladesh

The Rajshahi district is in the western climatic sub-zone (Zone E) which is characterized by very hot summers and relatively low rainfall (Islam & Neelim 2010). Data on maximum temperature, minimum temperature and rainfall for the 1964–2009 period has been analysed in Chapter 4 to assess the changes in these climate variables. A comparison of the Rajshahi district with the whole country was also made. Data source was the Bangladesh Meteorological Department. Figure 7.1 shows that there is an increasing trend in maximum temperature for both the Rajshahi district and Bangladesh over the period. The growth in maximum temperatures in the Rajshahi district is higher than that for Bangladesh.

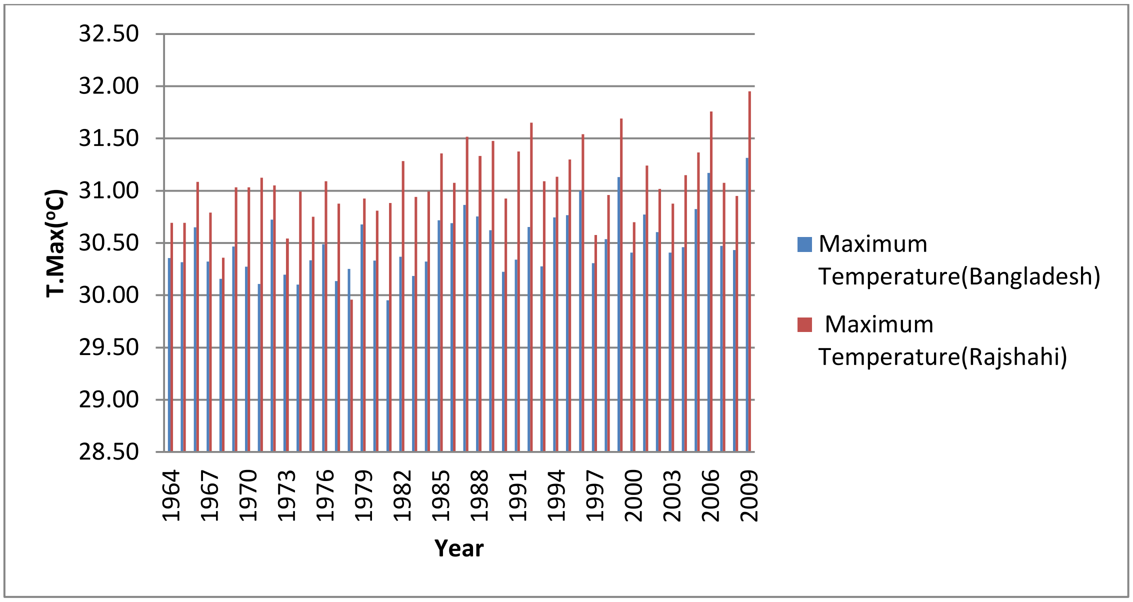


Figure 7.1 Trends in maximum temperature

Although the minimum temperature in Bangladesh has increased over time, it has decreased in the Rajshahi district as shown in Figure 7.2.

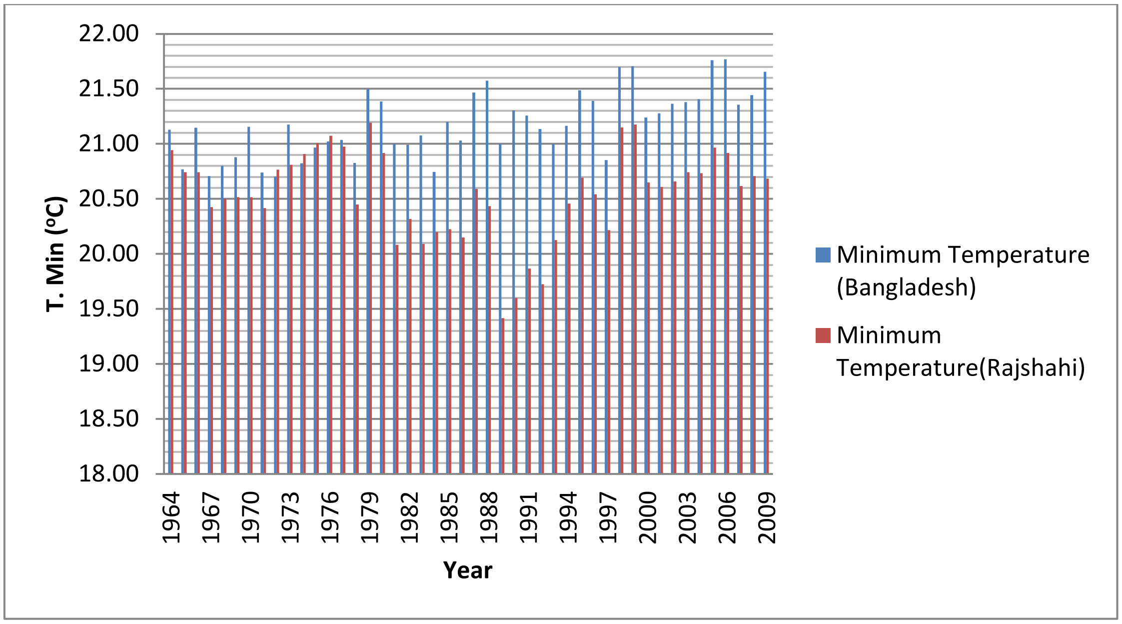


Figure 7.2 Trend in minimum temperature

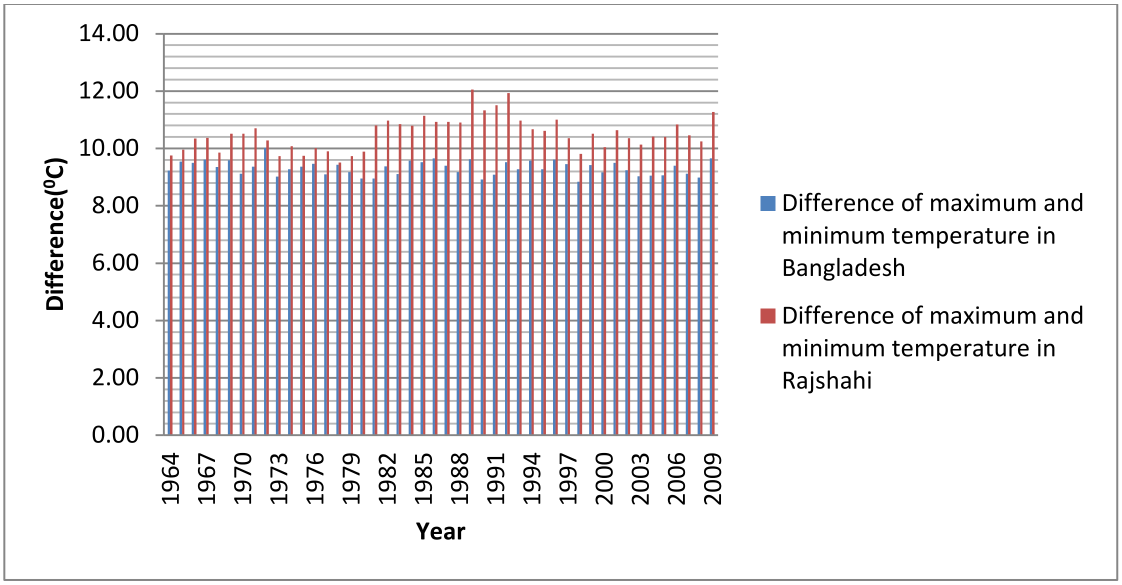


Figure 7.3 Difference of maximum and minimum temperature

The difference between maximum and minimum temperature is always higher for the Rajshahi district as compared to the whole of Bangladesh as depicted in Figure 7.3.

The total mean annual rainfall has increased for Bangladesh while it has decreased for Rajshahi. Annual total rainfall in Rajshahi is far below that of the whole country as illustrated in Figure 7.4.

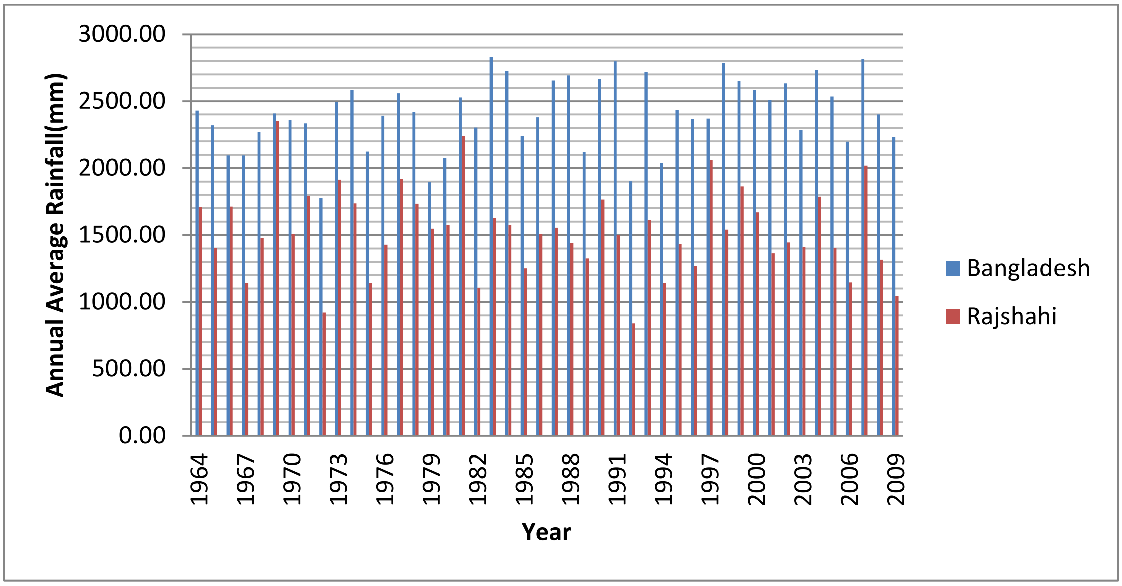


Figure 7.4 Trend in annual average total rainfall

In addition to the changes in maximum temperature, minimum temperature and annual rainfall, the frequency and severity of droughts have increased in recent times in the Rajshahi district.

7.5.2 Farmer's perception of climate change

Farmers should perceive first that there is climate change in order to take necessary adaptive strategies (Bryan et al. 2009). The surveyed farm household heads were asked about their perceptions of changes in various climate variables over the past 20 years. The major components were yearly temperature, rainfall, drought, and the availability of groundwater and surface water. Perceptions on climatic components were divided into four categories: increased, decreased, remaining same and don't know. Farmers' perceptions on each climatic parameter change are presented below.

Temperature changes

The results in Figure 7.5 signify that 97% of household heads have noticed rising temperatures while only an insignificant 0.55% noticed a decrease in temperature. Temperature remained unchanged for 1% of household heads while another 1% of household heads had no knowledge about it. Most of the farmers' perceptions are in accordance with the analysis of official data in the previous section.

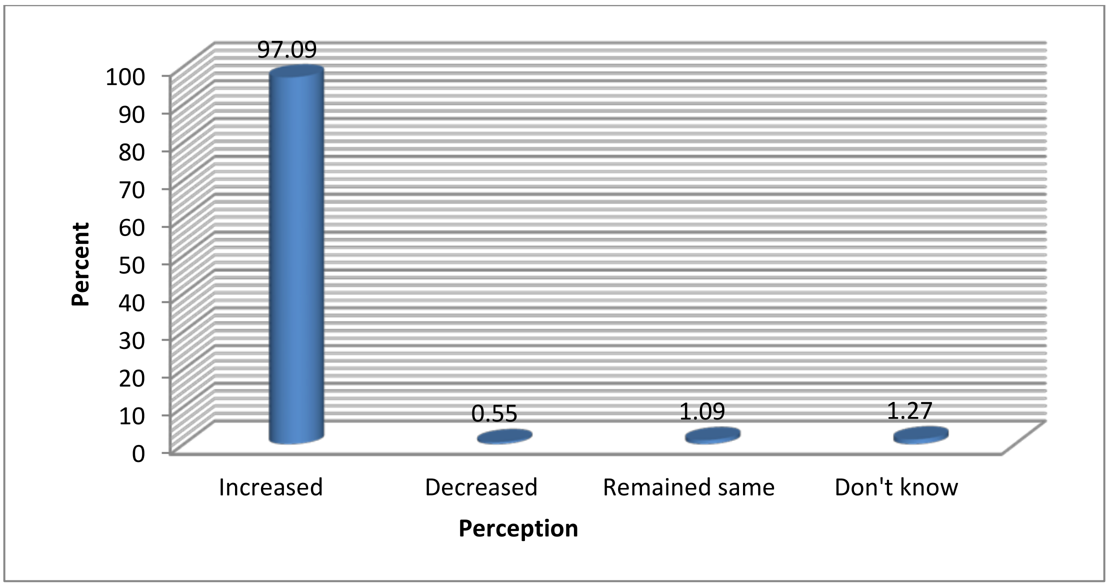


Figure 7.5 Farmers' perceptions of yearly temperature changes over the last 20 years

Rainfall changes

The results in Figure 7.6 indicate that 99% of household heads observed a decline in total yearly rainfall. No household heads perceived an increase in rainfall while rainfall remained the same to 0.36% of households. Analysis of official rainfall data in Section 4.1 is consistent with the perception of the majority of household heads.

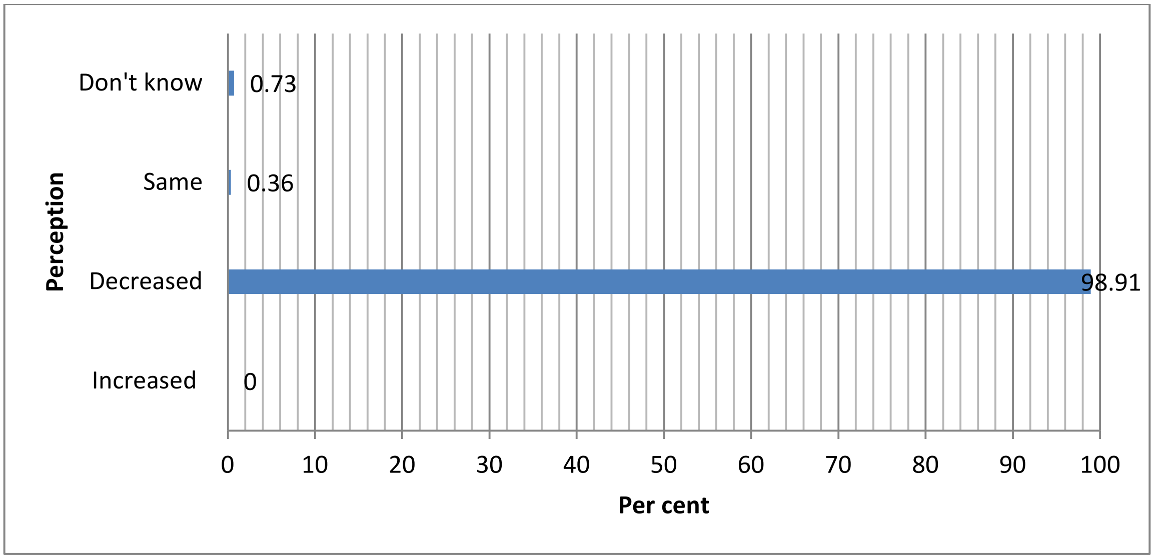


Figure 7.6 Farmers' perceptions of yearly rainfall changes over the last 20 years

Changes in droughts

The study area is a drought-prone area. Other extreme events such as cyclone and floods are almost non-existent. Accordingly, farmers' perception of droughts is reported in Figure 7.6. Nearly 100% of households noticed that frequency of drought has increased over the last 20 years.

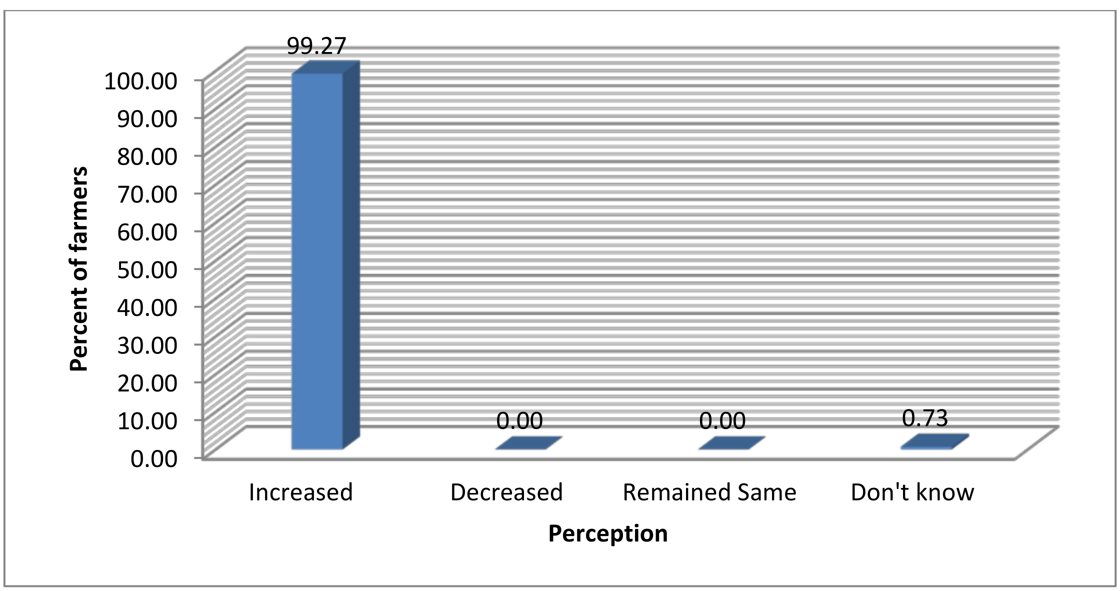


Figure 7.6 Farmers perceptions of yearly drought over the last 20 years

Changes in other climatic parameters

Other important climate parameters include groundwater, surface water, heat waves and colder weather. Farmers were also asked about these over the past 20 years. Farmers' views on these parameters are shown in Table 7.1. Almost 100% of the household heads perceived that availability of both groundwater and surface water had decreased. The severity of heatwaves had increased for nearly 100% of household heads while the perception on the severity of colder weather is diverse.

Table 7.1 Farmers perceptions of other climate parameters over last 20 years

Farmers' perception	**Other climate parameters (yearly)**			
	Availability of groundwater (%)	Availability of surface water (%)	Severity of heatwave (%)	Severity of colder weather (%)
Increased	0	0	98.90	43.45
Decreased	99.64	98.90	0.36	40
Remained same	0.36	1.10	0.37	8
Don't know	0	0	0.37	8.55

7.5.3 Farm-level adaptation strategies

It is useful to discover adaptation strategies in order to obtain an understanding of an agricultural system's adaptive capacity (Reid et al. 2007). Farmers in the study area were asked to reveal their major adaptive strategies in response to changing climate. These are summarized in Figure 7.7.

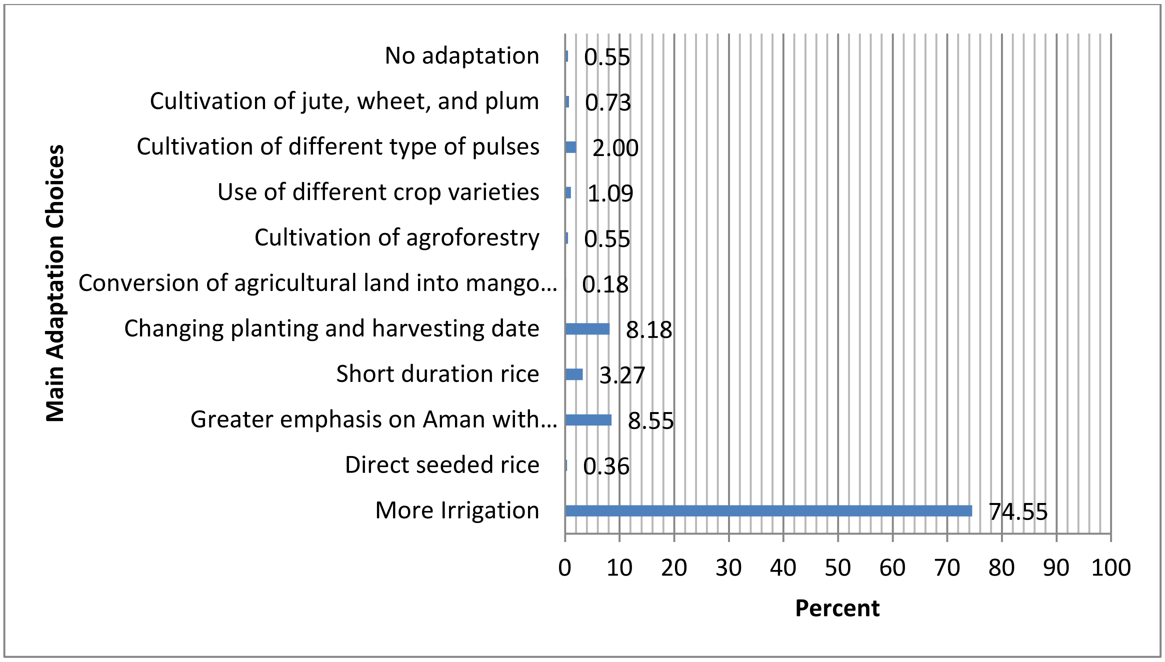


Figure 7.7 Farmers' main adaption strategies

Farmers have adopted a variety of adaptation strategies including irrigation, direct seeded rice, greater emphasis on Aman rice with supplementary irrigation, short-duration rice varieties, changing planting and harvesting dates, the conversion of paddy land into mango orchards, agro-forestry, using different crop varieties, the cultivation of various pulses and the cultivation of jute and wheat. Irrigation is the most commonly used method (75%). Other main adaptive choices are changing the planting date and supplementary irrigation for Aman rice. In addition to the main adaptation strategies farmers were asked about their secondary adjustment measures which are presented in Figure 7.8.

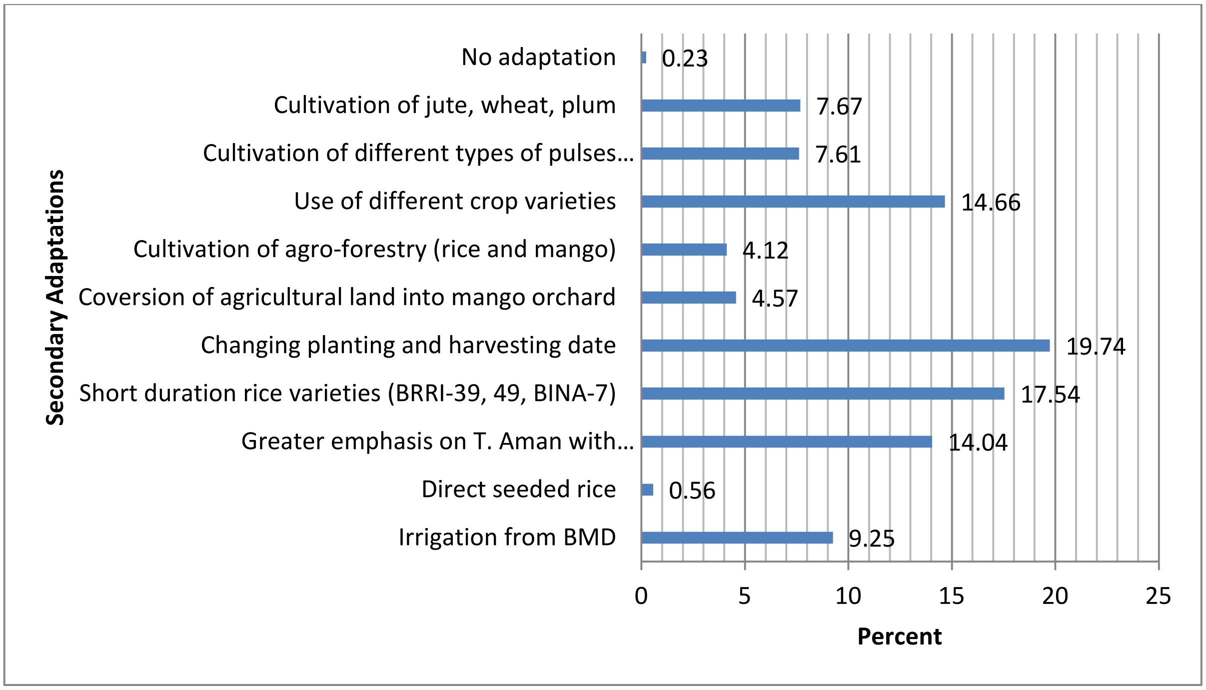


Figure 7.8 Farmers' secondary adaptation measures

Changing planting date, cultivation of short-duration rice, using different crop varieties and supplementary irrigation for Aman rice are important secondary adaptation strategies. The main and secondary adaptation choices mentioned by farmers are very similar to those found in other studies for adjacent districts (Ahmed & Chowdhury 2006; FAO 2006). The adoption of these adaptation strategies implies that the farmers in the study area are risk -averse.

7.5.4 Adapt to the adaptation

Famers take other adjustment measures after adaptation has taken place (Mertz 2009). This is because adaptation incurs costs. Adaptive strategies might resolve one problem but they sometimes create other problems which necessitate an 'adapt to adaptations' (Paul 1998; Mertz 2009). Farmers in the study area do take other adjustment measures after adaptation (Figure 7.9). The results reveal that 28% of households took loans from rural usury lenders and relatives, 26% sold their livestock and nearly 17% used their previous savings in order to undertake adaptation measures. Other adapt to adaptation measures included the sale of other assets, mortgaging of land, borrowing institutional micro-credit, and family members migrating to urban areas in search of additional income sources.

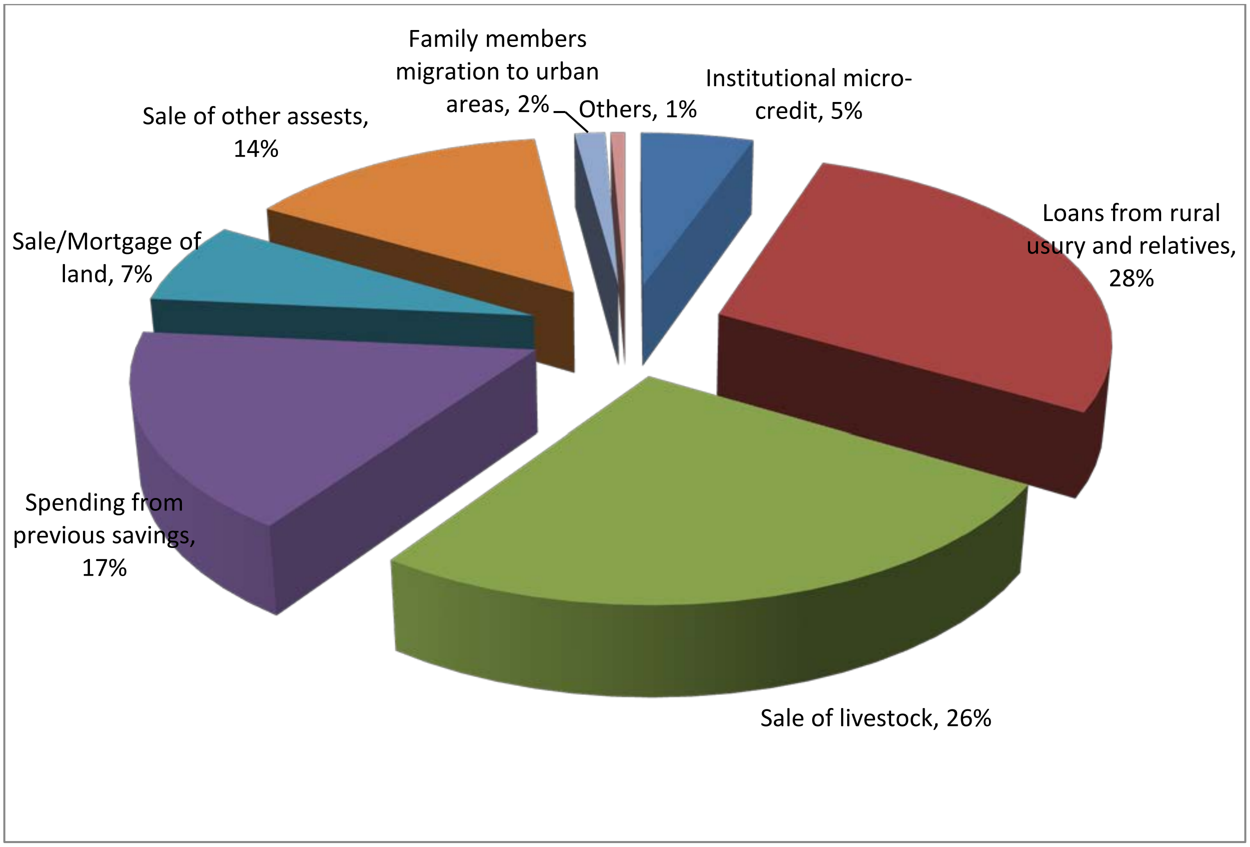


Figure 7.9 Measures for adapt to adaptation

7.5.5 Barriers to adaptation

Factors such as accessibility and usefulness of climate information, the institutional environment and the socio-economic situation of households affect farmers' capacity to adapt to climate change (Roncoli et al. 2002; Eakin 2003; Ziervogel et al. 2006; Agarwal 2008). Farmers perceived barriers to the adoption of various adaptation strategies (Figure

7.10). Farmers outlined the most important barriers as a lack of weather information, a lack of knowledge on appropriate adaptation strategies and a lack of credit (money or saving). Other important barriers are a lack of own land, a lack of irrigation water and labour shortages.

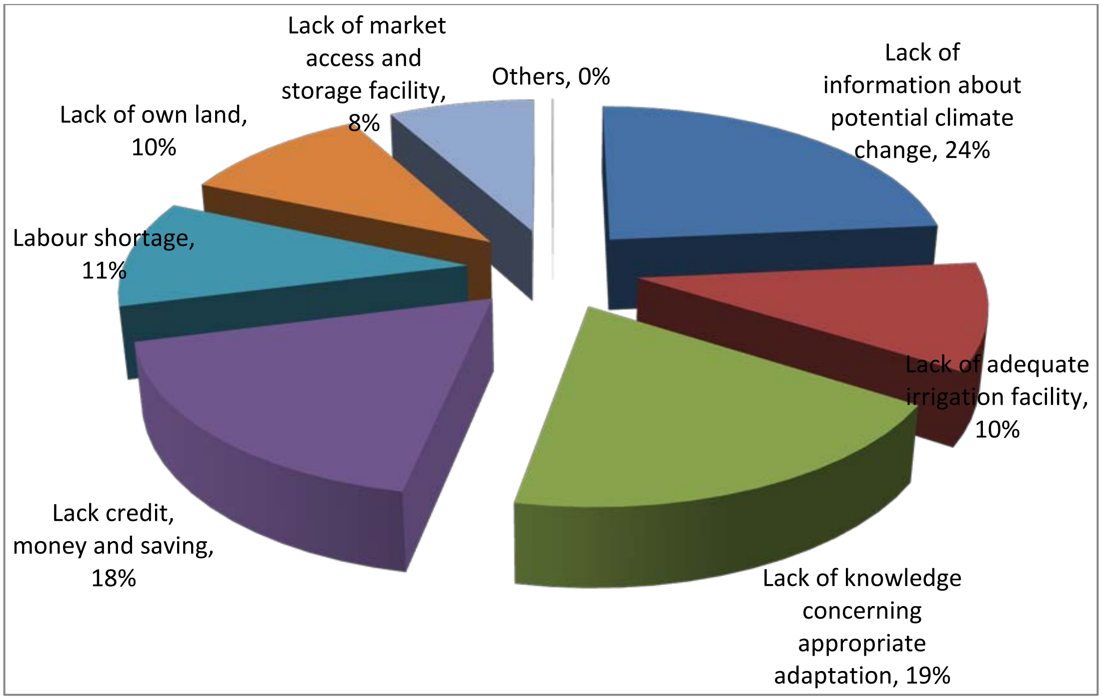


Figure 7.10 Barriers to adaptation

7.5.6 Determinants of adaptations: evidence from the MNL model

Model variables

The adaptation MNL model with the 11 choices as shown in Figure 7.7 failed to produce realistic results in terms of statistical significance of the parameter estimates and marginal effects. Following Gbetibouo (2009), the model was reorganised by categorising closely related strategies into the same group. The merging of direct-seeded rice with short-duration rice, the integration of conversion of agricultural land into mango orchard with agro-forestry, and the cultivation of jute, wheat, plum and different types of pulses were grouped into non-rice crops. Consequently, the options finally included in the MNL model had eight categories: (i) more irrigation, (ii) short-duration rice, (iii) greater emphasis on supplementary irrigation for Aman rice, (iv) changing planting date, (v) agro-forestry, (vi) use of different crop varieties, (vii) non-rice crops and (viii) no adaptation (Figure 7.11). However, the last category is the reference category in our analysis. The dependent variable of the MNL model is thus the choice of adaptation having eight categories.

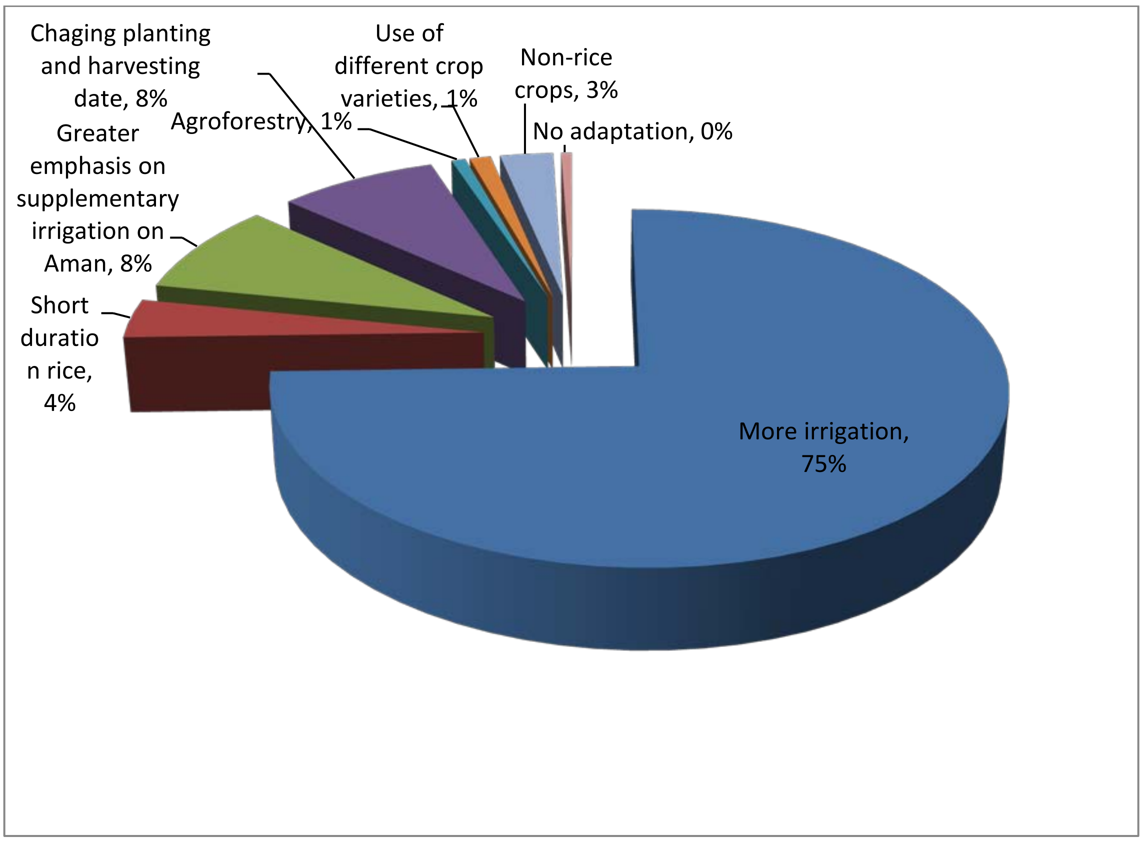


Figure 7.11 Farmers' main adaptation choices

The explanatory variables for this study have been selected on the basis of the available literature. They include household, farm and institutional characteristics of gender, age and education of household head, household size, household assets, farm income, farm size, tenure status, farming experience, livestock ownership, access to institutional extension services, farmer-to-farmer extension, information on climate change, access to credit, subsidy, electricity and distance to market (Table 7.2).

Table 7.2 Explanatory variables hypothesised to affect adaptation strategies

Variables	Value	Expected sign	Citations
Gender of household head	1=male, 0=female	+/-	Nhemacha & Hassan 2007; Deressa et al. 2009; Gbetibouo 2009
Age of household head	Years	+/-	Nhemacha & Hassan 2007; Deressa et al. 2009; Hisali et al. 2011; Seo & Mendelsohn 2008; Gbetibouo 2009
Education of household head	Years	+	Deressa et al. 2009; Seo & Mendelsohn 2008
Household size	Number	+	Nhemacha & Hassan 2007; Bryan et al. 2009; Deressa et al. 2009; Gbetibouo 2009; Seo & Mendelsohn 2008
Farm income	Tk.	+	Nhemacha & Hassan 2007; Deressa et al. 2009
Household assets	Tk.	+	Bryan et al. 2009; Gbetibouo 2009
Farm/land size/land area	Decimal	+	Nhemacha & Hassan 2007; Bryan et al. 2009; Deressa et al. 2009; Gbetibouo 2009
Tenure status	1=own, 0=otherwise	+	Bryan et al. 2009; Gbetibouo 2009
Farming experience	Years	+	Gbetibouo 2009
Livestock ownership	1=Yes, 0= No	+	Deressa et al. 2009
Access to extension (institutional)	1=Yes, 0= No	+	Nhemacha & Hassan 2007; Bryan et al. 2009; Deressa et al. 2009; Gbetibouo 2009; Hisali et al. 2011
Farmer-to-farmer extension	1=Yes, 0= No	+	Deressa et al. 2009
Information on climate change	1=Yes, 0= No	+	Bryan et al. 2009; Deressa et al. 2009; Gbetibouo 2009
Credit access	1=Yes, 0= No	+	Nhemacha & Hassan 2007; Bryan et al. 2009; Deressa et al. 2009; Gbetibouo 2009; Hisali et al. 2011
Access to subsidies	1=Yes, 0= No	+	Kurukulasuriya & Ajwad 2007
Access to electricity	1=Yes, 0= No	+	Nhemacha & Hassan 2007; Charles 2009
Distance to market	Kilometres	-	Bryan et al. 2009; Deressa et al. 2009; Hisali et al. 2011

Results from the MNL model and discussions

The MNL model with eight categories of adaptation choices was run and tested for the IIA assumption by applying the Hausman test. The results of the Hausman test are set out in Table 7.3. All P-values for omitted variables are 1.00 indicating that the model has passed the assumption. If the chi-square value is less than 0.00, the estimated model does not meet the asymptotic assumptions of the test. Negative test statistics are very common in empirical work (Cheng & Long 2007). Hausman and McFadden (1984) noted this possibility and concluded that a negative result was evidence that the assumption of IIA had not been violated.

Table 7.3 Hausman test of IIA assumption for the MNL model

Omitted	Chi-square	d.f.	P > chi-square	Evidence for H_0
More irrigation	0.052	6	1.000	Yes
Short-duration rice	- 82.386	18	1.000	Yes
Supplementary irrigation	- 49.955	13	1.000	Yes
Changing planting date	- 84.181	16	1.000	Yes
Agro-forestry	- 74.813	15	1.000	Yes
Use of different varieties	- 46.435	13	1.000	Yes
Non-rice crops	- 50.571	13	1.000	Yes
No adaptation	- 53.806	15	1.000	Yes

Ho: odds (outcome-J vs. Outcome-K) are independent of other alternatives

Therefore, the use of the MNL model for adaptation strategies is justified. Probabilities of chi-square values are positive which indicate that the use of MNL model for the dataset is valid.

As most of the explanatory variables are dummies, the RRR can be explained as the relative probability of choosing alternative j to no adaptation which is the base category (or comparison group). Following Yip et al. (1998) and Hisali et al. (2011), RRR is presented for each adaptation choice (choice j) given a particular characteristic (x_i) in Table 7.4 as well as factors that guide farm household choice of an adaptation choice in the face of climate change. The probability value of LR chi-square implies that all variables are jointly significant though some variables are not individually statistically significant. Following Bryan et al. (2009), only the statistically significant variables affecting adaptation choices are discussed here.

Gender of household head

The results show that male-led households increase the chances of more irrigation, the use of short-duration rice and non-rice crops as opposed to using no adaptation. This is probably because male-led households are more informed about new technology than female-led households (Asfaw & Admassie 2004; Deressa et al. 2009).

Age of household head

Age of the household head is a proxy for experience and affects adaptation strategies to climate change (Deressa et al. 2009). Our results reveal that age is significant for short-duration rice and the value of RRR indicates a unit increase in age of household head increases the possibility of the use of short-duration rice. This finding is consistent with Kebede et al. (1990) and Deressa et al. (2009).

Education of household head

Higher levels of education are positively related to the adoption of improved technologies: farmers with more schooling are expected to adapt better to climatic changes and extreme climate events (Norris & Batie 1987; Lin 1991; Maddison 2006; Deressa et al. 2009). Years of education of household head is a significant determinant for all adaptation strategies excluding short-duration rice. The values of RRR indicate that the education of the household head increases the chances of adopting irrigation, supplementary irrigation, changing planting date, agro-forestry, different crop varieties and non-rice crop relative to the choice of no adaptation.

Table 7.4 Relative risk ratios of the MNL model for rice farmers' adaptation

Explanatory variables/ Adaptive strategies	Irrigation		Short-duration rice		Supplementary irrigation		Changing planting date		Agro-forestry		Different crop varieties		Non-rice crop	
	RRR	P level	RRR	P level	RRR	P level	RRR	P level	RRR	P level	RRR	P level	RRR	P level
Gender of household head	6.69e-09*	0.098	5.05e-09*	0.095	8.026	-	1.09e-08	0.109	0.117	1.000	2.656	0.938	2.85e-09*	0.083
Age of household head	9.725	0.237	37.680*	0.097	18.578	0.157	18.084	0.182	10.947	0.457	53.192	0.139	14.205	0.262
Education of household head	2.577**	0.042	1.751	0.283	2.504*	0.061	4.017***	0.005	10.506***	0.009	3.414**	0.039	4.742***	0.010
Household size	0.300	0.244	0.148	0.103	0.255	0.213	0.573	0.616	0.524	0.652	0.128	0.128	0.182	0.188
Yearly farm income	12.531***	0.001	6.317**	0.026	8.559***	0.008	4.573	0.069	10.760**	0.031	5.304*	0.074	4.649*	0.075
Household asset	0.652	0.356	0.706	0.512	0.700	0.471	0.606	0.322	0.674	0.509	0.280**	0.028	0.747	0.599
Farm size	0.377	0.145	0.586	0.495	0.355	0.156	0.358	0.170	1.714	0.643	7.468**	0.048	0.532	0.458
Tenure status	4.332	0.133	7.169*	0.081	5.340	0.106	3.171	0.266	1.36e+08	0.998	12.909*	0.096	10.186*	0.073
Farming experience	0.129*	0.053	0.094**	0.041	0.116*	0.054	0.156	0.113	0.197	0.335	0.119	0.130	0.164	0.137
Livestock ownership	1.917	0.509	6.780	0.179	3.588	0.292	1.258	0.835	8.48e+07	0.998	0.963	0.976	1.375	0.790
Access to extension	1.676	0.550	1.102	0.923	1.383	0.730	0.274	0.230	7.425	0.112	1.352	0.789	1.516	0.694
Farmer-to-farmer extension	8.078	0.126	1.60e+10***	0.003	9.07e+08**	0.046	9.169	0.146	17.459	0.167	12.211	0.214	1.42e+10	-
Information on climate change	1.096	0.915	0.881	0.901	0.533	0.506	0.642	0.653	0.937	0.959	1.333	0.814	1.611	0.673
Credit access	3.840	0.124	8.672**	0.031	2.204	0.414	1.900	0.531	1.715	0.679	2.689	0.394	3.880	0.198
Access to subsidies	0.172*	0.058	0.247	0.217	0.284	0.242	0.147	0.173	0.183	0.299	0.876	0.918	0.336	0.352
Access to electricity	2.360	0.267	1.254	0.809	2.630	0.262	7.648**	0.026	1.04e+08	0.998	7.432	0.154	2.480	0.398
Distance to market	0.389	0.181	0.472	0.350	0.717	0.656	0.973	0.971	1.694	0.598	0.285	0.156	0.251	0.108
Model Summary														
Base outcome	: No adaptation													
Number of observations	: 550													
LR chi-square	: 244.32													
Prob> chi-square	: 0.000													
Log likelihood	: -497.77													
Pseudo-R^2	: 0.20													

***Significant at 1% probability level, ** Significant at 5% probability level,* Significant at 10 % probability level.
RRR = relative risk ratio

Household yearly farm income

Annual farm income is an indicator of financial capacity which strengthens the adoption of agricultural technology (Knowler & Bradshaw 2007). Farm income is the most significant variable for all adaptive choices. Farm income enhances the possibility of using irrigation, short-duration rice, supplementary irrigation, changing planting date, agro-forestry, different crop varieties and non-rice crops. Therefore, farm income has a positive and significant effect on all adaptive strategies. This is in line with the findings of Deressa et al. (2009).

Household assets

Households with more assets are in a better position to adopt new farming technologies (Shiferaw & Holden 1998) and are more likely to adapt to perceived climate change (Bryan et al. 2009). In this study, household assets are statistically significant for the choice of different crop varieties. However, household assets reduce the odds of using different crop varieties as opposed to a no adaptation strategy.

Farm size

Farm size increases the chances of adopting different crop varieties as opposed to a no adaptation strategy. In particular, farm size increases the relative risk of different crop varieties relative to no adaptation by 7.5 times. This is due to the fact that large farmers are more likely to adapt because they are equipped with more capital and other resources. The positive effects of farm size on adopting different adaptation strategies found here are consistent with other studies (Bryan et al. 2009; Gbetibouo 2009).

Tenure status

Tenure status (i.e., land ownership) is commonly believed to encourage the adoption of new technologies. Tenure status increases the chances of using short-duration rice and different crop varieties, and the cultivation of non-rice crop as opposed to no adaptation. In particular, tenure status increases the relative risk of short-duration rice by seven times, and enlarges the relative risk of different crop varieties by twelve times and increases the relative risk of cultivation of non-rice crops by ten times. This positive impact of tenure status on adaptation choices is consistent with studies by Bryan et al. (2009), Gbetibouo (2009) and Hisali et al. (2011).

Farming experience

The level of farming experience of the household head increases the possibility of undertaking different adaptation strategies since experienced farmers are knowledgeable and better informed on climate change (Nhemachema & Hassan 2007; Deressa et al. 2009; Gbetibouo 2009). Farm experience here is statistically significant for three adaptation strategies: irrigation, short-duration rice and supplementary irrigation. However, farming experience reduces the odds of the use of these three strategies in relation to no adaptation.

Farmer-to-farmer extension

Access to farmer-to-farmer extension services represents a form of social capital and private social networks. It therefore acts as a platform for information about new agricultural and adaptive technologies (Katungi 2007; Katungi et al. 2008). Having access to farmer-to-farmer extension increases the chances of using short-duration rice and supplementary irrigation as compared to no adaptation. More specifically, access to extension services increase the relative risk of using short-duration rice by 1.5 times and increase the relative risk of supplementary irrigation by nine times relative to no adaptation. Deressa et al. (2009) also reported the positive impact of farmer-to-farmer extension services on the adoption of various adaptation strategies in the face of climate change.

Credit access

Household access to credit indicates the availability of funds which is positively related to the level of adoption of adaptive strategies (Yirga & Hasan 2010). Access to credit has a positive and significant impact on the likelihood of using short-duration rice varieties. In particular, households having access to credit have an eight times higher chance of using short-duration rice as opposed to no adaptation. The positive effect of credit on adaptation is in line with the findings of Deressa et al. (2009) and Hisali et al. (2011).

Access to subsidies

Access to subsidies positively affects farm profitability (Kurukulasuriya & Ajwad 2007). It increases farmers' ability to adapt to climate change. However, the results reveal that access to subsidies is statistically insignificant for most of the adaptation strategies apart from irrigation. This is possibly because farmers receive a subsidy on fuel for running irrigation pumps which affects irrigation utilization. Access to subsidies decreases the likelihood of using irrigation by 0.172 times as opposed to no adaptation. A comparison of this finding cannot be made: no study has used access to subsidies as a determinant of adaptation.

Access to electricity

Household access to electricity is an important determinant of farmers' adaptation to climate change (Kurukulasuriya & Mendelsohn 2008). The results suggest that access to electricity increases the likelihood of changing planting date by seven times as compared to a no adaption strategy. The positive effect of access to electricity on adaptation is consistent with Nhemachena and Hassan (2007).

Other determinants

Determinants that are insignificant under the MNL model but have an expected relation with the choices of adaptation include household size, livestock ownership, access to institutional extension services, access to information on climate change (weather information) and distance to market. Of these, household size and distance to market reduce the chances of using different adaptation options while livestock ownership and access to institutional extension services and to weather information increases the likelihood of using most of the adaptation strategies.

7.6 Concluding comments

The objective of this chapter was to examine farmers' perceptions of climate change, adaptation strategies undertaken by them, and barriers to adaptation. This was achieved by conducting a micro-econometric analysis of the determinants of farmers' adaptation choices based on farm level micro data. Evidence from official data has revealed that temperatures have risen and rainfall has decreased in the Rajshahi district over almost the last 50 years. Farmers' perceptions of climate change are also consistent with official records and other studies. Almost 98% of farm households have taken adaptive measures to limit the adverse impact of climate change on rice farming. The main adaptive strategies of farmers are more irrigation, short-duration rice, supplementary irrigation, changing planting date, agro-forestry, using different crop varieties and using non-rice crops. In the adoption of adaptation strategies, farmers had other adjustment mechanisms: loans from rural usury lenders and relatives, sale of livestock and using previous savings. Farmers also identified the main barriers to adaptation as a lack of accurate weather information, a lack of money (credit or savings) and a lack of knowledge on appropriate adaptation strategies.

The MNL model was utilised with micro data at the farm household level to evaluate the determinants of farmers' adaptation choices in the face of climate change. In the model, the dependent variable is the choice of adaptation strategy which was of eight types, while explanatory variables include socio-demographic, farm characteristics, institutional accessibility and social factors. The model was tested for the IIA assumption using the Hausman test which provided evidence of non-violation of the assumption. This also justified the application of the MNL to the micro dataset. The RRR results specify that gender, age and education of household head, household annual farm income, household assets, farm size, tenure status, farming experience, farmer-to-farmer extension services, access to subsidies, access to credit and access to electricity have a statistically significant impact on the different adaptation strategies. However, these significant variables (excluding household assets, farming experience and access to subsidies) are expected to enhance farmers' adaptive capacities. Therefore, government policy should target improving these significant determinants to boost farmers' adaptation and hence to reduce vulnerability. For example, investment in education, supply of enough agricultural inputs at affordable prices that raises farm income, creation of more financial institutions at the rural level, affordable credit for small farmers and forming social groups to improve farmer-to-farmer extension can be undertaken as appropriate policy options in order to minimise the adverse effects of climate change in the drought prone district of Bangladesh.

Chapter 8 Summary of Findings, Policy Implications and Directions for Further Research

8.1 Introduction

This study has investigated the effects of climate change on rice production in Bangladesh at three levels – aggregate (i.e., national), disaggregated (i.e., district or climate zone) and micro (i.e., farm). Based on aggregate time series data, cross-sectional time series data and a micro dataset from surveying 550 farmers in a severely drought-prone area, the analytical part of this thesis covered the four major areas:

- An overview of climate change in Bangladesh and rice yield responses to it using national level time series data;
- Climate change impact on rice yields using disaggregated district level data;
- Climate change impact on rice production using farm level survey data; and
- An analysis of rice farmers' adaptation strategies to climate change using farm level survey data.

The organisation of this chapter is as follows. Section 8.2 summarises the main findings to answer the four research questions. Section 8.3 provides some policy recommendations based on the findings. The contribution of this research to the literature is explained in Section 8.4 and Section 8.5 presents further research directions.

8.2 Summary of findings

This section briefly sets out the major findings to answer the four research questions of this study.

Research question 1

What is the impact of climate change on rice production at the aggregate-level?

The findings under research question 1 are in two parts. The first part was concerned with the evidence of climate change in Bangladesh using aggregate level data. Using different statistical techniques of descriptive statistics, linear trend model and quantile regression, an examination of the yearly maximum and minimum temperature and rainfall provided an indication of changing climate over the last six decades in Bangladesh. The time trend is statistically significant for all three climate variables. However, the increase in minimum temperature is higher than that of maximum temperature. These results are consistent with Islam and Neelim (2010). However, the results from this study are more robust in terms of the statistical techniques used. More importantly, quantile regression has provided much more detailed information on the changes in climate variables over the time period examined.

The second important part of research question 1 was to explore the relationship between yields of three rice varieties (Aus, Aman and Boro) and climate variables using aggregate level time series data for the 1972–2009 period. Two types of regression – linear and median – were used to examine the distribution of rice yield data. The overall findings confirm that climate variables have had significant effects on rice yields but that the effects vary among the varieties. For Aus and Boro, both maximum and minimum temperatures are statistically significant. However, average minimum temperature is found to affect Aus rice production adversely whilst maximum temperature is negatively related to Boro rice yield. All three climate variables are statistically significant for Aman rice. Nonetheless, the impact of maximum temperature and rainfall is more pronounced compared to minimum temperature, which adversely affects Aman rice yield. One interesting finding is that rainfall is significant only for Aman rice which is the only rice that grows completely in rain-fed conditions in Bangladesh.

Research question 2

How does the change in major climate variables affect rice production across district or agro-climatic zones?

The first of the findings under research question 2 shows that climate variability varies across all seven climate zones in Bangladesh. Annual mean maximum temperature is highest in the western zone while it is the lowest in the northern part of the northern zone. The zones having the highest relative variability in maximum temperature are the northeast and the northern part of the north. For annual mean minimum temperature, the zones of the southeast, northeast, northern part of the north and west experienced the highest variability. In the case of rainfall, the western zone receives the lowest annual mean total rainfall. Variability in rainfall is also higher for the western and the northern part of the north zones. Overall, there have been significant variations in the three climate variables across districts and climate zones. However, the changes are more pronounced in the defined climate zones. Furthermore, the western zone (i.e., the greater Rajshahi district) has the highest maximum temperature and the lowest annual rainfall which makes that zone the most severely drought-prone area of Bangladesh.

Using the Just-Pope production function as an analytical framework, answering the second part of the research question 2 required assessing the impact of climate variables on the mean and variability in the yields of Aus, Aman and Boro rice for the 1972–2009 period. The results reveal that the effects of changes in climate variables on rice yield differ across varieties. Maximum temperature is positively related to Aus and Aman mean rice yield in the linear model while the relationship is negative in the quadratic model. The elasticity values obtained from the variance function imply that maximum temperature is risk increasing for Aus and Aman rice, while risk decreasing for Boro rice production. However, the impact of minimum temperature on yield variability differs. An increase in minimum temperature is likely to reduce the yield variability for Aus and Aman rice production while it will increase for Boro rice. Therefore, minimum temperature has become risk increasing for Boro rice while risk decreasing for Aus and Aman rice. Finally, the impacts of rainfall on yield variability are positive for Aman and negative for Aus and Boro. This confirms that the rainfall is risk increasing for Aman rice while risk decreasing for Aus and Boro rice.

Moreover, the changes in rice yield for three scenarios (2030, 2050 and 2100) were estimated using the calculated percentage changes in maximum temperature, minimum temperature and rainfall. The results show that future climate change is likely to increase the variability of yield for all three rice crops. However, rain-fed Aman rice will exhibit higher variability than the other two varieties: Aus (partially rain-fed) and Boro (completely irrigated).

These results offer additional evidence of the concern about productivity losses in the face of climate change. Moreover, most of the regional dummy variables for climate zones are statistically significant with differential impacts on rice yield. This confirms that different climate zones are impacted differently by climate change.

Research question 3

How do rice farmers perceive climate changes' impact on rice production and what are the determinants of net revenue changes as a result of changes in rice production?

In research question 3, the first objective was to explore the difference in profit and production losses from Aman rice production between different sub-groups of farmers such as small vs. large farms, integrated vs. non-integrated farms and irrigated vs. non-irrigated farms. Farm level survey data from 550 farm households in a severely drought prone region was collected. Evidence from various bivariate statistical analyses reveals considerable variations of profit and production losses among those sub-groups. For example, mean profit is significantly higher for large and medium farmers compared to small and landless farmers, with the latter group experiencing higher production losses. Integrated farms, combining livestock rearing with rice cultivation, have higher net revenue compared to non-integrated farms, and this difference is statistically significant. However, there is no statistically significant difference in mean production losses between these two sub-groups. Farms that have a higher proportion of land under irrigation obtain higher profits than those farms with lower irrigation coverage. However, the mean difference in profit is not statistically significant. Furthermore, mean production losses of irrigated and non-irrigated farms are significantly different. Rice production losses for highly irrigated farms are lower than for lowly irrigated farms.

The second important part of research question 3 was to analyse the determinants of profit and production losses using mean and median regression analysis. To overcome the problem of heteroscedasticity, median regression and robust mean regression were used. The problem of multicollinearity was checked with the use of the variance inflation factor. Overall results indicate that all models are statistically significant for regressions of both profit and production losses on various socio-economic, institutional and farm characteristics. For the determinants of profit, a good number of variables are statistically significant for the full and all sub-group models (and across the sub-groups). The significant variables that affect farm profit include gender, age, years of schooling of household head, household yearly total income, household assets, farm size, land tenure, household access to agricultural extension services, weather information, agricultural credit, electricity, percentage of land under irrigation, distance to crop selling place, distance to local or nearby urban market and membership status in a group of household heads. Age and education level of the household head, agriculture as the main occupation, yearly income, household assets, land tenure, access to subsidy, extension services, electricity, farmer-to-farmer extension, percentage of land under irrigation, crop selling at local market and distance to urban markets are statistically significant variables across the full and sub-sample models. All of these variables, except for access to electricity and distance to nearby urban market, are production loss decreasing factors.

Another important finding is a comparison between mean and median regression outputs. The number of significant variables under the full and all sub-group models is higher for median regression than that for mean regression. This has empirically confirmed the methodological superiority of median regression over mean regression when using cross-sectional data in the presence of outliers.

Research question 4

What are the determinants of farmers' adaptation choices in the face of perceived climate change?

The objectives of research question 4 was to document farmers' perceptions of climate change and to analyse the determinants of farmers' adaptation strategies in the face of climate change. This analysis was also based on farm level micro data from 550 farm household heads. Farmers' perceptions about climate change reveal that temperature has increased and rainfall has decreased over the last 20 years. A simple graphical analysis of time series climate data for the same area confirms farmers' perceptions. The survey results also reveal that nearly 98% of farm households adopted adaptive measures to limit the adverse impact of climate change on rice production. The major adaptive strategies are increased irrigation, cultivation of short-duration rice, supplementary irrigation, changing planting date, agro-forestry, using different crop varieties and using non-rice crops. Farmers also took other adjustment mechanisms including obtaining loans from rural usury and relatives, sale of livestock and spending previous savings. Farmers identified the main barriers to adaptation as a lack of accurate weather information, a lack of money (or credit or savings) and a lack of knowledge on appropriate adaptation strategies.

The most important finding concerned the analysis of the determinants of farmers' adaptation choices in the face of climate change. In doing so, a MNL model was used where the dependent variable was the choice of adaptation strategies with eight categories indentified. The explanatory variables in this model included socio-demographic, farm characteristics, institutional accessibility and social factors. The model was tested for the

IIA assumption using the Hausman test which provided evidence of non-violation of the assumption which justified the application of the MNL to the micro dataset. Moreover, a correlation coefficient matrix confirmed that the model was free from the problem of multicollinearity. The most important finding comes from the RRR that indicates gender, age and education of household head, household annual farm income, household asset, farm size, tenure status, farming experience, farmer-to-farmer extension services, access to subsidies, access to credit, and access to electricity are all statistically significant determinants of different adaptation strategies. Therefore, these significant variables (excluding household assets, farming experience and access to subsidies) have the potential to enhance farmers' adaptive capacity.

8.3 Policy implications and recommendations

This study has assessed the impact of climate change on rice farming at three different but interlinked levels. In doing so, various standard econometric techniques were used and the results were reported in Chapters 4 to 7 and summarized in section 8.2. Based on those results, the following specific recommendations are made for maintaining or improving rice production in Bangladesh in the face of climate change:

- The analysis at the aggregate level revealed that temperature has had negative impacts on all three rice crops: Aus, Aman and Boro. More precisely, maximum temperature impacted Boro rice yield and minimum temperature affected both Aus and Aman rice yield, adversely. Given these adverse effects of temperature on rice, the policy makers should take necessary steps for the development of temperature or heat-tolerant rice varieties. The plant breeding division of the

Bangladesh Rice Research Institute (BRRI) can play the vital role in this case. There are some ongoing projects on varietal development, particularly for drought-prone areas. However, there should be further provision of financial resources for BRRI researchers to speed up the variety development process.

- The analysis at disaggregated climate zone levels revealed that maximum temperature is risk increasing for Aus and Aman rice. This is in line with expectations since these rice crops grow in the summer and monsoon seasons, respectively, when temperature is highest. The policy makers should emphasise development and use of heat-tolerant rice varieties for Aus and Aman. Minimum temperature is risk increasing for Boro rice yields. It is noteworthy that Boro grows in winter when minimum temperatures are relatively cold. Therefore, development and use of cold-tolerant rice varieties for Boro should also receive priority from policy makers. Finally, rainfall appears as risk increasing for Aman rice. This is because there is flooding almost every year during the Aman rice production period. This finding warrants the development and utilisation of flood or submergence-tolerant rice varieties for Aman rice. There is already the use of developed submergence-tolerant high yielding Aman varieties such as Swarna Sub1, BR11 Sub1 and IR64 Sub1 for flood-prone low lying areas. These varieties can survive under water for up to 12 days without much yield reduction (Hossain & Seraj 2008).
- The analysis at the climate zone level also reveals that various climate zones are impacted differently by climate change. This, in turn, suggests region specific or climate zone specific adaptation policies to lessen the adverse effects of climate

change. Possible policies may include development and use of drought-tolerant rice varieties for western and northwestern zones, submergence-tolerant rice for flood-prone zones, salinity-tolerant rice for the southwest zone and cold-tolerant rice for the northeast zone. Regional research stations of BRRI in these zones should take the leading role in these developments. Wide dissemination of information on these varieties among farmers is necessary for the adoption of new varieties. SAAOs at field level can take responsibility for this activity.

- The analysis at the farm level on the impact of high temperatures and very low rainfall on Aman rice production indicates that farmers face production losses ranging from 2% to 90% with a mean value of 37%. Since the study area is in the very severe drought-prone region and rice is the main livelihood activity for the local people, it is thus very important to develop drought-tolerant rice varieties. In this context, BRRI has recently developed two drought-tolerant, high-yielding and short-duration rice varieties – BRRI Dhan-56 and BRRI Dhan-57 – for Aman production in the most drought-affected areas of Bangladesh. Now is the time to disseminate information about the use of these two varieties among farmers. Field level SAAOs can play a vital role in increasing uptake of these varieties by farmers. Moreover, government agencies such as the Bangladesh Agricultural Development Corporation (BADC) and NGOs at the field level can be involved in introducing these varieties to farmers so that they are encouraged to adopt the varieties quickly. Training of agricultural extension personnel working at Union and Upazila levels on new technologies and access to web-based materials might improve information dissemination. It is also necessary to establish Agricultural

Information Centres at the local level for the rapid dissemination of knowledge and modern technologies.

- Farmers can cope with drought by attempting to conserve soil moisture and nutrients. Crop rotation and no or minimum tillage can be practiced as methods of protecting water and nutrients in the soil.
- One interesting finding was that integrated farms (farms with livestock along with rice) have higher net revenue than non-integrated farms (farms with only rice cultivation). This should encourage farmers to choose integrated (mixed) farm production and shift from non-integrated (specialised) ones. Therefore, government policy should include introducing and subsidising drought-tolerant livestock and poultry such as sheep, ducks and pigeons to farmers, particularly small and landless farmers. This will increase and diversify their incomes to help cope with the impact of climate change on rice cultivation.
- It was found that production losses for highly irrigated farms were lower than those of less irrigated farms. Irrigation, thus, has potential to diminish production losses in the face of climate change. However, the expansion of groundwater based irrigation has already become almost impossible and unsustainable due to decreasing groundwater tables. Farmers' perceptions about the lack of availability of groundwater also support this view. Therefore, several things could be done for irrigation-based rice production:
    - In the short-run, the mass adoption of Alternate Wetting and Drying (AWD) irrigation technology could be an effective method to save groundwater in irrigated rice production systems. The basic idea

behind the technology is that the roots of the rice plant are sufficiently supplied with water for some days after the first flooding even though the field has no ponded water (Rejesus et al. 2012). The technology requires a 25 cm long PVC pipe or hollow bamboo pieces. AWD saves scarce water (around 30%) and hence reduces irrigation costs in terms of energy and labour use without any reduction in yields and profit (Rejesus et al. 2012; Zou et al. 2012). The technology has been used successfully in The Philippines, China and India (Rejesus et al. 2012; Zou et al. 2012). However, the use of this technology is so far limited in Bangladesh. Therefore, the dissemination of information about AWD to the farmers should be very beneficial. This could be done through mass training programs for farmers at the sub-district level organised by the Department of Agricultural Extension. The field water PVC tube could be supplied freely or with a subsidy by government to farmers during the training programme and use of the technology could be monitored by the SAAOs.

- Policy makers should place more emphasis on Aus and Aman rice (as they are mainly rain-fed crops) by allowing supplementary irrigation and using good quality HYVs to increase overall rice production. The government must exploit the potential of hybrid rice technology to further increase rice production.
- Dry season production of rice and pulses are competing crops and the former is at least 1.5 times more water intensive than the latter (BARC 2001). A gradual shift from irrigated rice to less water consuming non-

rice crops such as pulses and vegetables could possibly overcome some of the water problem.

    - In the long run, the construction of the proposed Uttor (North) Irrigation Project by making a barrage on the River Padma (this will reserve water in the canal like a dam) could be a sustainable source of irrigation water for the study area.

- Household access to weather information could also enhance adaptive strategies and reduce the adverse effects of climate change. However, the analysis shows that more than 50% of the farmers in the study area do not get any information regarding weather while the remaining farmers get mostly inaccurate and irregular weather forecasts. Weather forecasts could be made available on a regular basis through cell phone systems, television and/or radio. The Bangladesh Space Research and Remote Sensing Organization can take a leading role in this activity.
- Farmers with a higher education level receive more net revenue than more lowly educated farmers as a result of production losses for farmers with more years of schooling being lower than farmers with fewer schooling years. Therefore, policy makers should emphasise the need for education to increase the capability of farm households to accept and to implement modern adaptive technologies. Government could introduce and implement an agricultural education policy so that low and uneducated farmers, particularly younger farmers, receive suitable knowledge on extension services and new technologies. Alternatively, the existing extension services could be reformed so that SAAOs spend more time on field visits to assist in improving farmers' understanding.

- Tenure status, access to subsides and access to extension services was found to reduce climate-related production losses. Government policy thus needs to consider these factors. It is very difficult to give tenure status to those who are extremely poor. However, an effective land reform programme might include (i) the distribution of Khas (government-owned fallow) land among landless and marginal farmers wherever possible, and (ii) imposing a ceiling on rents for the fixed rent system. The system of access to agricultural subsidies needs to improve so that small and marginal farmers can also receive government subsidies. According to informal discussions with farmers during the survey, most of the beneficiaries are large farmers who have political power. Only 10% of small farmers receive any form of subsidy. Moreover, there is misappropriation of subsidy money. This 'perverse subsidy' culture needs to change. A recent initiative to allow farmers to open a bank account with Taka 10 could be a good avenue by which policy makers could ensure a fairer distribution of subsidies to farmers. Survey results also show that only 35% of farmers receive extension services. This can be improved by more frequent field visits from SAAOs.
- According to the MNL model, gender, age and education of household head, household annual farm income, farm size, tenure status, farmer-to-farmer extension services, access to credit and access to electricity have a statistically significant impact on different adaptation strategies to reduce the impact of climate change. Therefore, government policy should target improving these determinants to boost farmers' adaptation and, hence, to reduce their vulnerability. For example, supplying enough inputs at affordable prices that raises income,

creating more financial institutions at the rural level to provide affordable credit for small farmers and facilitating group discussions to improve farmer-to-farmer extension could be undertaken.

8.4 Contribution of this research

The contributions of this study are manifold. These are discussed below:

Overall contribution

Bangladesh is one of the countries most vulnerable to climate change. Rice farming is the mainstay of Bangladesh's economy and the primary food source for its people and it is susceptible to climate change. However, prior to this study there had been no comprehensive study on the impact of climate change on rice production using standard econometric tools. The overall contribution of this study is that it is the first to analyse the impact of climate change at the aggregate, disaggregate and farm levels with the use of richer and extended datasets. This study, thus, contributes to the literature in general and for Bangladesh in particular.

Contribution of aggregate level analysis

The first specific contribution of this thesis was to explore the aggregate impact of climate change on rice yield using both mean and median regression. Previous studies using time series data did not check the stationarity properties of data which is a precondition before running regressions with time series data and hence they suffered from spurious results. However, this study has verified the unit root properties of the dataset. Thus its results are more robust than previous studies. The policy contribution of this part of the study is that policy makers should design strategies for the development of temperature-tolerant rice varieties to overcome increasing climate change vulnerabilities.

Contribution of disaggregate level analysis

The second specific contribution of this study is that it has assessed the past and future impact of climate change on Aus, Aman and Boro rice yields using climate zone level time series data (i.e., panel data). This is the first study that has employed both maximum and minimum temperature as temperature-related climate variables in a panel data framework. Moreover, past studies using panel data evaluated the impact of climate change on a particular crop (or a group of crops) as a whole. However, different varieties of a crop are impacted differently by climate change which warrants the crop-variety specific research that has been carried out here. The results from this analysis have important policy implications for the allocation of agricultural land for different varieties of rice and for devising appropriate climate zone specific (area specific) adaptation policies to reduce rice yield variability and to assist in attaining and maintaining food security.

Contribution of farm level analysis

The third tier of analysis of this study was assessing the impact of climate change and adaptation at the micro-level using a farm level dataset from a large number of farm households. The survey part of the study was divided into two sections: impact and adaptation.

The impact contribution

This is the first study that has compared the net revenue or profit (and perceived production losses) of rice farmers under changing climate conditions. This analysis used various socio-economic and institutional characteristics as variables. For example, the comparison of net revenue from rice between integrated vs. non-integrated farms using an independent t-test implies that the government should facilitate an enabling environment in favour of integrated farms since they have higher profitability than non-integrated farms.

The determinants of net revenue or profit of different types of farmers were assessed using the farm level data. Previous studies used aggregate level data either at county or district level; an exception was a study by Kurukulasuriya and Ajwad (2007) for Sri Lanka which only focused on smallholder farmers. Moreover, the variables examined for significance here are more than in previous studies. Furthermore, this study has compared the determinants of net revenue or profit and production losses using both mean and median regression. The results from the median regression are more robust when there are outliers. This study has also confirmed that median regression performed better compared to mean regression in the case of extreme values. This is a significant methodological contribution. Moreover, the determinants that appeared as statistically significant have important policy applications.

Previous cross-sectional studies analysed all samples together and few studies divided the samples into irrigated and non-irrigated or large farms and small farms. However, this study has analysed samples as all farms, small farms, integrated farms, non-integrated farms, irrigated farms and non-irrigated farms, using both mean and median regression. Therefore, it has produced more information on significant variables across the sub-groups which have the potential to contribute policy formulation.

Some important diagnostic tests such as VIF for the problem of multicollinearity and the Brusch-Pagan test for the problem of heteroscedasticity were carefully handled in this study. Therefore, the obtained results are robust.

The adaptation contribution

This study documented farmers' perceptions about climate change. This is important as farmers first need to perceive climate change before they can adopt adaptation measures to reduce their vulnerability.

This is the first study that has employed a MNL model to analyse the determinants of farm level adaptation measures to limit the impact of climate change in Bangladesh. Therefore, it is a significant contribution to understanding the economics of climate change and farmers' adaptation strategies. The results have produced some statistically significant variables for different adaptation strategies which have potential to inform policy makers. For example, a policy that guarantees farmers' access to affordable credit will increase their financial capability enabling them to meet expenditures related to their adaptive measures. Likewise, policies that ensure farmers' access to extension services have the potential to increase farmers' awareness of climate change and their knowledge of appropriate adaptation measures. These policies will help reduce farmer vulnerabilities. More importantly, specific policies designed to promote adaptation at the farm level will help ensure food security of the country.

Overall theoretical contribution

The theoretical contribution of this study is that it has adapted the theory of production function, the theory of Just-Pope stochastic production function, the theory of profit maximization, the theory of random utility and the theory of vulnerability to a new and important setting. This is the first study that has validated the wider application of these theories in the context of individual rice crops' responses to climate change and farmers' adaptation.

8.5 Future research focus

The aggregate and disaggregated level analyses of this study emphasised the effects of climate change on three major rice varieties: Aus, Aman, and Boro. However, there are two main types – traditional and HYVs – within Aus, Aman and Boro rice varieties. According to the literature, climate change affects different rice varieties heterogeneously. More specifically, HYVs are more vulnerable to the impact of climate change than traditional types. Future studies, thus, can be undertaken with a focus on determining whether traditional types or HYVs are more vulnerable to climate change. Moreover, the impact of rainfall distribution on the phenology of rice plant can also be assessed at both aggregate and disaggregate levels.

The survey part of this research focused on the most severe drought-prone area of Bangladesh. However, the literature indicates different regions are impacted differently by changes in climate. This warrants area/region specific research to generate a more complete picture of the impact of climate change. Therefore, future research can be undertaken in the flood, cyclone and salinity affected areas of Bangladesh. This then may provide an avenue for policy makers to devise region specific adaptation policies which will have potential to address the adverse effects more effectively. Furthermore, production loss analysis in this study was based on survey data. Future studies can thus focus on a comparison between survey data and published data to estimate rice production losses.

Future studies might also cover other agricultural crops such as wheat, jute and vegetables to produce a more accurate picture of the impact of climate change on Bangladesh agriculture. Moreover, non-rice crops such as maize, chickpea and other vegetables are an integral part of agriculture and horticulture. Separate research can be done on non-rice crops' responses to climate change.

Livestock is an important part of non-crop agriculture. The livestock population is affected by drought, heatwaves, cold waves, floods and cyclones almost every year. Future studies might also fruitfully focus on this aspect.

Given that water is already a critically scarce resource in the drought-prone regions of Bangladesh, there is obviously a strong need for an analysis of the impact of climate change on groundwater and surface water. The groundwater table is reducing all over Bangladesh and making irrigation more difficult. Therefore, research should be carried out urgently on alternative irrigation possibilities such as AWD irrigation technology.

The survey part of this research used a questionnaire to interview farmers. Results derived from the responses to the questionnaires can be further investigated using focus group discussions with different stakeholders, interviews with officials at the field level and relevant officers, particularly agricultural extension officers, in the areas surveyed. This might be another way to see if there are differences in responses using different methods of data collection.

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Appendix I District level time series data on rice yields and climate variables

District	Year	Aus rice				Aman rice				Boro rice			
		yield	maxt	mint	train	yield	maxt	mint	train	yield	maxt	mint	train
Chittagong	1972	485.56	31.58	24.86	1501	548.97	30.47	22.43	1288	1140.27	29.10	18.73	109
Chittagong	1973	406.28	31.58	24.82	1689	525.59	29.68	22.58	1758	1208.52	29.47	19.02	666
Chittagong	1974	560.52	30.64	24.28	2838	641.85	29.47	22.65	2195	1055.99	28.70	18.50	568
Chittagong	1975	725.06	31.66	24.66	1905	612.59	29.35	22.00	1888	984.00	29.17	18.85	321
Chittagong	1976	664.76	31.78	24.04	2294	675.55	30.13	22.02	1607	962.29	29.50	18.75	201
Chittagong	1977	520.11	30.10	23.80	2162	682.81	30.00	22.17	1294	841.30	28.80	18.28	761
Chittagong	1978	727.35	31.76	23.96	1930	515.02	30.62	22.53	1275	951.25	29.37	18.15	419
Chittagong	1979	709.60	31.38	25.02	2275	589.16	29.88	22.67	1938	970.11	29.40	19.33	296
Chittagong	1980	570.29	31.40	24.56	2248	644.75	29.90	22.15	1833	1116.87	29.00	18.82	582
Chittagong	1981	664.00	30.74	24.06	2146	734.42	30.23	22.38	1340	1091.02	28.58	18.48	781
Chittagong	1982	626.46	31.18	24.58	2288	637.01	29.58	22.17	1791	1198.23	29.10	18.73	221
Chittagong	1983	605.45	31.54	24.22	2734	668.43	30.07	22.37	2336	1050.69	28.27	18.32	632
Chittagong	1984	615.24	31.32	24.22	2276	738.27	30.32	21.87	1427	1119.88	28.92	18.32	556
Chittagong	1985	612.88	31.40	24.52	2471	731.14	30.33	22.17	1690	911.11	29.20	19.27	767
Chittagong	1986	642.11	31.78	24.70	2347	765.66	30.40	22.62	1666	959.85	29.70	19.12	324
Chittagong	1987	88.23	31.50	24.94	2741	780.87	30.65	22.78	2409	977.12	29.40	19.57	470
Chittagong	1988	279.70	31.74	24.80	2028	770.75	30.77	23.05	1514	1010.83	29.92	19.88	662
Chittagong	1989	543.37	31.98	25.20	1818	687.48	30.10	22.00	2017	971.62	29.32	19.03	304
Chittagong	1990	645.19	31.46	24.58	2276	782.66	30.40	22.78	1637	1013.71	28.88	19.22	583
Chittagong	1991	725.78	31.46	25.04	2512	816.51	30.05	22.48	1858	648.22	29.48	19.50	638
Chittagong	1992	842.12	32.02	24.98	1391	877.04	30.18	22.52	1457	961.90	28.58	19.47	281
Chittagong	1993	888.15	31.46	24.04	2714	930.85	30.32	22.10	1552	919.66	29.07	18.43	1061
Chittagong	1994	762.11	31.94	25.06	1828	946.52	30.75	22.53	998	975.91	29.47	18.92	679
Chittagong	1995	621.67	32.22	25.84	1909	999.64	30.65	23.40	1736	972.28	29.82	19.53	349
Chittagong	1996	665.20	32.20	25.18	2010	996.12	31.10	23.03	1746	1058.40	29.97	19.82	683
Chittagong	1997	653.23	31.78	24.94	2148	898.80	30.93	22.67	2133	936.82	28.88	18.68	464
Chittagong	1998	598.02	32.24	25.48	3187	905.09	31.78	23.75	2924	967.67	29.57	19.40	808

Chittagong	1999	684.57	32.24	25.24	2704	877.91	31.02	23.02	1883	1055.90	30.90	20.02	570
Chittagong	2000	747.31	31.26	24.68	2583	927.85	30.85	22.47	1950	1085.58	30.00	19.13	772
Chittagong	2001	815.45	31.70	25.12	2422	1067.41	30.95	22.97	1716	1099.28	30.57	18.25	480
Chittagong	2002	798.82	31.26	24.78	2163	1045.79	30.82	22.90	1716	1126.55	30.67	19.47	409
Chittagong	2003	841.27	31.94	25.34	2206	1035.99	31.47	22.82	1142	1217.24	30.27	19.52	484
Chittagong	2004	854.44	31.84	25.26	2125	1062.36	30.90	22.43	1840	1147.13	30.18	19.88	446
Chittagong	2005	898.26	32.34	25.44	1752	1032.68	31.22	22.98	1767	1143.96	30.82	20.23	339
Chittagong	2006	876.35	32.54	25.30	1830	1048.85	31.38	22.95	1178	1145.54	31.20	20.10	909
Chittagong	2007	948.65	32.00	25.12	2958	1018.61	30.95	22.75	2848	1137.65	30.27	19.23	539
Chittagong	2008	940.76	31.02	25.10	2503	1004.88	29.67	22.87	2172	1344.92	28.62	19.97	322
Chittagong	2009	988.72	31.46	25.42	2858	1047.61	29.93	23.12	2535	1255.81	29.67	19.93	492
Commilla	1972	338.27	32.12	25.42	1329	459.48	30.98	22.30	718	820.51	29.78	18.37	384
Commilla	1973	319.97	31.62	24.60	1476	434.04	29.52	21.98	955	863.06	28.93	17.90	610
Commilla	1974	492.65	30.74	24.40	1959	561.37	29.52	22.58	1691	940.32	28.70	17.68	521
Commilla	1975	148.40	31.40	24.68	1196	329.56	29.17	22.13	1227	885.12	29.38	18.18	327
Commilla	1976	404.29	30.80	24.56	1783	546.83	29.53	21.77	1075	912.20	29.10	18.00	369
Commilla	1977	414.47	30.12	24.36	1719	478.47	29.78	22.00	872	2412.28	28.22	17.60	841
Commilla	1978	479.87	31.72	24.64	1622	513.25	30.13	21.90	1244	899.34	29.40	17.93	467
Commilla	1979	510.31	32.30	25.30	872	478.18	30.00	22.48	1192	824.07	29.50	18.30	105
Commilla	1980	457.98	31.42	24.66	1606	485.49	30.03	21.62	1296	1020.10	29.02	18.25	604
Commilla	1981	471.75	30.14	24.16	1929	508.43	30.02	21.53	900	968.03	27.72	17.43	1010
Commilla	1982	469.25	31.48	24.46	1921	462.75	29.82	21.45	983	1166.67	29.03	17.08	609
Commilla	1983	478.30	31.50	24.70	1492	493.99	30.23	22.20	1571	1118.20	28.70	17.88	536
Commilla	1984	484.65	31.70	24.68	2001	525.49	30.37	21.43	1261	1037.06	29.38	17.55	752
Commilla	1985	437.98	31.88	24.76	1269	521.52	30.60	21.58	841	1126.60	29.65	18.52	536
Commilla	1986	388.44	32.32	24.18	1271	542.42	30.47	22.08	1347	1047.91	29.83	17.65	480
Commilla	1987	470.48	31.76	25.04	1365	539.92	30.30	22.52	1360	1079.27	29.63	18.35	387
Commilla	1988	201.15	31.42	24.96	1697	82.56	30.32	22.63	1340	1121.80	29.63	18.63	530
Commilla	1989	586.48	32.20	24.98	1004	603.87	30.08	21.35	808	1103.19	29.30	17.78	289
Commilla	1990	523.77	31.64	24.28	1447	736.79	30.40	21.82	1119	1140.24	28.78	17.97	786

Commilla	1991	575.76	31.52	24.32	1843	679.85	29.73	21.52	1584	1114.19	29.02	17.78	1113
Commilla	1992	609.15	32.80	24.48	824	639.02	30.95	21.30	785	1134.44	28.97	17.67	214
Commilla	1993	572.48	31.38	24.30	2140	671.57	30.32	21.90	1292	1088.06	29.10	17.20	1004
Commilla	1994	533.02	32.30	24.66	1127	609.44	30.90	21.13	473	1144.38	29.25	17.60	480
Commilla	1995	459.61	32.26	24.62	1742	605.80	30.42	22.23	1300	1007.90	29.57	17.12	473
Commilla	1996	467.85	32.16	24.74	1397	789.05	30.68	21.65	967	1061.34	29.77	18.25	678
Commilla	1997	524.40	31.72	23.44	1643	817.95	30.17	21.37	1289	1088.81	28.37	16.98	525
Commilla	1998	531.53	31.58	24.62	1881	757.28	30.67	22.85	1637	1154.52	28.37	17.43	781
Commilla	1999	493.34	31.96	25.20	1649	735.09	30.35	22.35	1763	1265.64	30.27	18.87	238
Commilla	2000	538.69	32.06	24.84	1562	830.81	30.90	21.77	765	1289.43	28.82	17.80	984
Commilla	2001	740.56	32.26	24.78	1440	812.04	30.90	22.35	987	1298.41	29.57	17.63	373
Commilla	2002	736.70	31.82	24.48	1740	821.46	30.70	21.98	1284	1298.42	29.37	17.92	536
Commilla	2003	731.28	32.46	24.66	1367	837.18	30.92	21.78	699	1258.13	28.92	17.65	502
Commilla	2004	1515.96	32.44	24.68	1509	829.46	30.47	21.80	1399	1312.13	29.32	18.43	371
Commilla	2005	677.70	32.66	24.66	1422	712.33	30.65	22.12	1558	1390.23	29.68	18.35	608
Commilla	2006	705.20	32.76	24.88	1503	792.99	30.85	22.20	772	930.92	30.18	18.57	724
Commilla	2007	732.71	32.08	24.88	1755	738.16	30.17	22.45	1576	1360.61	28.83	17.87	373
Commilla	2008	648.94	32.32	24.62	1478	698.99	30.43	22.32	1344	1504.79	29.18	18.42	383
Commilla	2009	777.50	33.10	25.16	1578	808.29	31.02	22.07	1243	1459.13	30.08	18.58	346
Sylhet	1972	401.29	30.14	23.08	2963	466.59	29.95	21.12	1965	610.98	27.72	16.35	983
Sylhet	1973	331.35	30.96	23.64	3035	401.84	29.92	21.52	2095	649.14	28.47	17.07	992
Sylhet	1974	421.97	29.82	23.46	3897	516.64	29.05	21.48	3152	392.04	28.05	16.50	982
Sylhet	1975	687.68	30.42	23.46	3408	470.55	28.98	21.47	2531	623.93	28.58	17.02	921
Sylhet	1976	536.44	30.12	23.36	3665	493.26	29.40	21.23	2505	642.60	28.22	17.23	868
Sylhet	1977	306.35	29.32	23.18	3192	476.11	29.50	21.55	1818	491.48	27.00	16.88	1342
Sylhet	1978	494.01	30.86	23.54	2838	513.20	30.25	21.65	1486	675.28	28.32	16.22	1040
Sylhet	1979	468.99	31.58	24.04	3014	478.37	29.52	21.68	2485	488.16	29.18	17.12	583
Sylhet	1980	415.28	30.96	23.76	2490	436.64	30.03	21.60	1399	627.66	28.17	17.03	1424
Sylhet	1981	484.41	30.50	23.54	3631	485.12	30.08	21.67	2393	747.18	27.78	17.18	1615
Sylhet	1982	495.64	30.64	23.74	3579	437.64	29.72	21.22	2015	613.43	28.35	16.88	1348

Sylhet	1983	396.43	30.54	23.70	3557	449.80	30.28	21.77	2644	650.63	27.45	16.57	1531
Sylhet	1984	364.48	31.52	23.64	2948	487.00	29.90	20.90	2328	455.57	28.68	16.58	1310
Sylhet	1985	399.00	31.14	23.46	3044	505.05	30.28	21.17	1784	739.81	28.25	17.60	1166
Sylhet	1986	388.82	31.78	22.30	2231	507.52	29.55	19.90	2288	601.71	28.85	16.17	599
Sylhet	1987	482.14	31.06	23.72	3357	496.38	30.28	21.60	2810	632.97	29.03	17.03	853
Sylhet	1988	293.16	30.88	23.46	4296	541.69	30.00	21.65	2932	623.94	28.98	17.68	1684
Sylhet	1989	537.36	31.74	23.98	3833	459.05	29.75	21.28	3647	616.54	28.63	17.07	907
Sylhet	1990	499.16	31.00	23.70	2982	581.87	30.32	22.12	2611	567.98	28.02	17.52	1281
Sylhet	1991	561.14	30.34	22.94	3467	598.00	29.73	20.95	1823	659.01	27.67	17.18	1680
Sylhet	1992	549.66	31.76	22.58	2614	637.35	30.22	20.68	1940	714.72	28.02	16.40	910
Sylhet	1993	570.98	30.56	23.32	3662	628.96	30.30	21.98	2665	667.16	27.78	17.17	1115
Sylhet	1994	517.45	32.16	24.04	2569	609.99	30.98	21.88	1706	708.43	28.62	17.25	1231
Sylhet	1995	568.54	31.94	24.24	2856	595.25	30.35	22.45	2050	689.34	28.98	17.50	645
Sylhet	1996	545.84	31.40	23.86	3018	624.36	30.67	21.95	2152	714.47	29.25	17.83	1341
Sylhet	1997	587.63	31.58	23.32	2480	685.21	30.27	21.70	2185	775.32	29.18	17.13	674
Sylhet	1998	611.43	31.08	24.06	3682	656.94	31.02	22.80	2355	815.85	28.67	17.63	1175
Sylhet	1999	513.19	32.10	24.48	2688	610.76	30.85	22.40	1873	825.66	30.78	18.53	987
Sylhet	2000	607.52	31.06	23.84	3422	708.54	30.42	21.98	2234	905.83	27.77	17.42	1485
Sylhet	2001	618.33	32.30	24.40	2605	757.03	31.02	22.40	1901	1068.33	29.13	17.70	843
Sylhet	2002	664.87	31.08	23.80	3006	768.86	30.77	22.18	1702	1050.22	29.08	17.77	1065
Sylhet	2003	645.27	32.02	24.30	2643	796.19	31.03	22.47	1678	1071.30	29.02	17.65	847
Sylhet	2004	732.63	31.42	24.22	3485	842.90	30.43	21.97	2669	990.09	29.23	18.38	1054
Sylhet	2005	537.22	31.68	23.92	3149	783.68	31.32	22.52	2182	1093.67	28.95	18.08	1627
Sylhet	2006	634.92	32.24	24.32	3073	807.59	31.53	22.58	1235	1041.88	30.10	18.67	1006
Sylhet	2007	778.63	31.50	24.26	3383	850.49	30.57	22.35	2244	727.59	28.90	17.62	1225
Sylhet	2008	702.24	32.20	24.28	2676	826.81	30.87	22.22	1821	992.81	28.95	18.33	882
Sylhet	2009	772.21	32.46	24.52	2745	906.20	31.35	22.47	1732	1189.37	30.30	18.43	1086
Dhaka	1972	369.87	32.14	25.18	1570	447.20	30.37	22.08	844	950.70	29.80	17.70	611
Dhaka	1973	289.86	31.86	25.14	1785	377.74	29.23	22.38	1245	1021.26	29.65	18.37	891
Dhaka	1974	358.60	32.26	25.30	1404	423.26	30.12	22.35	1101	1048.55	29.87	18.23	450

Dhaka	1975	360.19	32.04	25.14	1516	364.07	29.08	21.80	1452	796.63	29.87	18.02	458
Dhaka	1976	366.55	31.72	24.80	1827	513.21	29.97	22.03	994	932.01	29.90	18.32	617
Dhaka	1977	748.02	31.02	24.66	1286	432.71	29.87	22.50	836	873.18	28.92	17.87	797
Dhaka	1978	411.64	31.60	24.76	1923	759.80	30.48	22.37	1036	901.98	29.13	16.88	686
Dhaka	1979	2064.03	32.98	25.84	1181	471.72	30.18	22.98	1426	893.85	30.32	18.42	204
Dhaka	1980	394.91	32.20	25.32	1533	447.17	30.02	22.45	1245	1038.28	29.67	18.42	650
Dhaka	1981	375.02	31.62	24.86	1258	492.52	30.40	22.28	990	1158.15	28.42	17.93	742
Dhaka	1982	427.72	32.38	25.26	1254	480.18	30.10	22.28	937	1151.20	29.57	17.93	354
Dhaka	1983	447.37	32.22	25.24	1582	478.26	30.15	22.77	1209	1145.60	28.95	18.08	897
Dhaka	1984	427.23	31.78	25.38	2473	484.43	30.35	22.73	1541	1144.85	29.93	18.78	850
Dhaka	1985	414.36	32.02	25.46	1454	468.70	30.85	22.73	974	1108.05	30.55	19.55	690
Dhaka	1986	437.00	33.08	25.20	1356	491.82	30.63	22.68	1713	1104.32	30.68	18.75	486
Dhaka	1987	436.02	33.16	25.70	1643	473.57	30.88	23.17	1495	837.25	31.02	18.98	409
Dhaka	1988	120.64	32.88	25.68	1799	442.23	31.27	23.27	989	4687.30	30.95	19.30	916
Dhaka	1989	334.70	33.68	26.08	1038	394.12	30.88	22.63	963	984.61	30.85	18.53	357
Dhaka	1990	415.63	32.02	25.46	1379	554.04	30.28	23.40	1331	1061.51	28.82	19.17	549
Dhaka	1991	398.04	32.22	25.32	1565	511.34	29.73	22.90	1867	1169.28	29.35	19.30	769
Dhaka	1992	387.74	33.34	25.60	878	525.66	30.47	22.20	801	1173.18	29.60	18.87	226
Dhaka	1993	391.95	31.72	24.90	2012	540.01	30.32	22.48	1467	1105.55	29.32	17.88	814
Dhaka	1994	362.46	32.60	25.52	1120	526.26	31.25	22.25	637	1120.06	29.92	18.13	637
Dhaka	1995	340.92	33.70	26.12	1303	509.06	31.05	22.72	1123	1044.80	30.93	18.42	392
Dhaka	1996	311.58	33.32	25.60	1368	458.34	31.38	22.37	1219	1131.79	31.12	18.87	482
Dhaka	1997	353.19	32.48	24.92	1312	556.28	30.57	22.35	1243	1142.32	29.28	17.90	451
Dhaka	1998	324.28	32.78	25.90	1747	529.13	31.32	23.38	1502	1223.96	29.35	18.35	719
Dhaka	1999	316.44	32.90	26.04	1632	404.10	30.68	22.82	1577	1344.42	31.45	19.37	449
Dhaka	2000	331.85	32.30	25.20	1478	566.13	30.50	23.07	1112	1285.06	28.75	18.93	889
Dhaka	2001	376.62	32.30	25.10	1247	798.16	30.40	22.07	811	1388.15	29.68	19.07	482
Dhaka	2002	422.64	31.80	24.52	1474	763.52	30.32	22.43	954	1450.07	29.35	18.98	462
Dhaka	2003	392.01	32.86	25.46	1129	783.71	30.57	23.12	836	1429.20	28.95	18.82	429
Dhaka	2004	431.07	32.74	25.42	1291	863.78	30.28	22.58	1533	1448.69	29.88	19.80	338

Dhaka	2005	396.73	32.92	25.52	1544	654.39	30.53	23.07	1837	1542.58	30.08	19.82	541
Dhaka	2006	413.90	32.96	25.62	1190	767.29	30.95	23.23	1227	675.96	30.70	19.90	366
Dhaka	2007	375.92	33.00	25.46	2234	654.21	30.38	22.90	1868	1392.43	29.58	18.92	389
Dhaka	2008	489.42	33.12	25.70	1755	724.31	30.53	23.12	1388	1584.44	29.52	19.67	420
Dhaka	2009	548.59	33.90	26.16	1510	741.23	30.95	23.18	1534	1509.75	30.85	20.00	226
Faridpur	1972	270.00	32.58	23.98	1249	217.79	30.27	20.83	890	968.92	29.35	16.70	506
Faridpur	1973	283.58	32.44	23.72	1842	271.43	29.32	21.10	1383	1173.11	29.53	17.05	829
Faridpur	1974	282.61	32.06	23.02	1672	329.98	29.73	20.57	1336	1167.82	29.10	15.58	531
Faridpur	1975	308.00	32.22	24.76	1400	276.45	29.18	22.02	1370	923.61	29.62	16.53	389
Faridpur	1976	293.88	31.96	24.80	1469	346.05	30.00	22.30	885	912.39	29.90	18.13	524
Faridpur	1977	239.51	31.32	24.56	1465	297.68	29.55	22.87	817	908.62	29.08	17.88	464
Faridpur	1978	213.13	31.74	24.54	1198	340.88	29.90	22.72	799	995.91	28.68	17.20	279
Faridpur	1979	272.87	33.14	25.66	1176	373.93	30.32	23.35	1205	1024.22	29.90	18.72	174
Faridpur	1980	231.57	32.34	25.12	1391	307.59	29.85	22.88	1080	1044.12	29.13	18.33	651
Faridpur	1981	284.53	31.44	24.78	2070	273.86	29.72	22.52	1493	810.11	28.17	17.70	920
Faridpur	1982	272.17	32.56	25.06	1035	300.58	29.92	22.43	769	1107.20	29.42	17.70	430
Faridpur	1983	269.55	32.66	25.28	1542	311.50	29.55	23.08	1421	1220.56	29.03	17.92	654
Faridpur	1984	290.82	32.18	24.70	1998	349.16	30.05	22.17	1112	933.79	29.83	17.17	610
Faridpur	1985	230.02	32.66	24.94	1033	342.16	30.37	22.18	742	1207.56	30.57	18.28	521
Faridpur	1986	267.15	32.68	24.58	1203	382.01	30.08	22.55	1375	1156.36	30.25	17.72	418
Faridpur	1987	351.29	33.26	25.28	1407	374.60	30.37	23.07	1301	1092.58	30.80	18.27	331
Faridpur	1988	48.36	32.38	25.40	1596	306.72	30.12	23.15	939	1186.75	30.25	18.75	786
Faridpur	1989	337.82	33.08	25.36	964	260.83	29.98	22.18	799	1053.97	29.60	17.78	406
Faridpur	1990	368.20	32.02	24.84	1310	357.74	30.13	22.40	962	1183.57	28.90	18.13	738
Faridpur	1991	389.23	32.38	24.74	1197	388.01	29.77	22.00	1307	1173.46	29.60	18.12	616
Faridpur	1992	355.91	33.56	24.12	1055	437.32	30.38	20.80	812	1063.94	30.05	17.12	286
Faridpur	1993	376.49	31.94	23.62	1399	263.58	30.10	22.02	1233	1134.63	29.33	17.38	424
Faridpur	1994	334.20	32.58	24.92	1083	376.64	30.48	22.20	669	1078.22	29.75	17.88	417
Faridpur	1995	327.67	33.32	25.74	1594	365.38	30.07	22.73	1270	1003.46	30.30	18.17	343
Faridpur	1996	296.47	32.98	25.10	1438	361.45	30.42	22.48	984	1079.06	30.55	18.67	510

Faridpur	1997	335.10	32.34	24.36	1220	434.08	29.90	22.38	932	1211.06	28.77	17.62	398
Faridpur	1998	303.72	32.78	25.48	1227	429.67	30.87	23.55	1150	1200.78	28.73	18.12	467
Faridpur	1999	296.46	32.78	25.46	1475	349.31	30.27	22.78	1503	1380.14	30.92	18.97	267
Faridpur	2000	312.62	32.68	25.30	1202	497.24	30.77	22.75	1152	1411.05	29.15	18.08	690
Faridpur	2001	418.12	32.68	25.28	1196	599.07	30.72	23.05	875	1480.91	29.95	17.82	434
Faridpur	2002	386.06	32.26	25.06	1778	558.04	30.62	22.77	1332	1487.33	29.63	18.47	452
Faridpur	2003	403.60	33.34	25.66	888	526.98	30.58	22.78	685	1516.88	29.22	18.28	447
Faridpur	2004	434.48	32.94	25.62	1070	583.13	30.22	22.67	1312	1557.04	29.97	19.02	271
Faridpur	2005	343.12	33.32	25.64	974	446.89	30.27	22.75	1185	1566.58	30.27	19.20	233
Faridpur	2006	388.80	33.04	25.56	1107	519.00	30.83	22.83	1074	1561.81	30.82	18.83	346
Faridpur	2007	322.12	33.00	25.48	1573	568.37	30.33	22.87	1296	1559.47	29.52	17.98	216
Faridpur	2008	334.36	33.20	25.30	930	569.15	30.45	22.67	1000	1616.25	29.65	18.80	207
Faridpur	2009	431.86	34.04	25.68	1314	669.54	30.93	22.63	1195	1627.20	30.92	18.65	214
Mymenshing	1972	308.68	31.36	24.34	1389	508.37	30.20	21.80	901	766.05	28.08	16.93	289
Mymenshing	1973	272.58	31.76	24.32	1225	442.72	30.28	21.97	964	774.25	29.15	17.52	464
Mymenshing	1974	364.63	32.12	24.08	1366	578.22	31.00	21.78	1037	769.52	29.03	16.93	302
Mymenshing	1975	406.11	32.42	24.46	303	555.47	30.03	22.35	347	654.90	29.53	16.93	77
Mymenshing	1976	421.89	31.28	23.78	2022	582.99	29.92	21.57	1711	641.39	29.33	16.38	404
Mymenshing	1977	449.42	31.74	24.54	2276	496.10	30.05	22.12	866	554.52	29.08	17.20	1206
Mymenshing	1978	425.00	31.20	24.30	1632	498.86	30.50	22.10	845	722.30	28.48	15.87	570
Mymenshing	1979	454.50	32.78	25.10	769	529.08	30.40	22.57	526	648.08	30.27	17.38	259
Mymenshing	1980	543.68	31.74	24.72	1869	514.44	30.33	22.08	1196	647.64	29.02	17.27	836
Mymenshing	1981	551.02	31.18	24.58	1697	540.76	30.40	22.08	1324	624.93	28.08	17.17	839
Mymenshing	1982	546.97	31.82	24.72	2008	442.25	30.18	22.03	1198	813.90	28.83	17.27	467
Mymenshing	1983	472.47	31.36	24.62	2017	492.72	29.80	22.12	2023	857.07	28.18	16.98	716
Mymenshing	1984	326.72	31.18	24.76	1962	501.79	29.70	21.80	1635	883.46	28.63	17.08	532
Mymenshing	1985	453.21	31.50	24.64	1045	531.58	30.10	21.98	967	931.23	28.98	17.92	503
Mymenshing	1986	493.37	31.70	24.76	1869	582.75	29.77	22.30	2319	815.26	29.00	17.48	614
Mymenshing	1987	480.32	31.74	25.06	1739	558.54	30.03	22.65	1449	912.32	29.53	18.03	463
Mymenshing	1988	247.86	31.06	25.22	2412	613.26	30.23	22.67	1634	666.69	28.92	18.33	1001

Mymenshing	1989	443.37	32.08	25.24	1563	530.72	29.78	21.67	1679	950.90	29.02	17.00	337
Mymenshing	1990	471.06	31.26	24.08	1749	634.57	30.33	21.33	1254	941.99	28.28	16.83	657
Mymenshing	1991	293.26	31.14	22.64	1918	539.75	29.87	20.38	1452	1056.66	28.53	15.88	894
Mymenshing	1992	301.01	32.54	24.74	985	580.84	30.68	21.72	1100	1073.08	29.07	17.43	219
Mymenshing	1993	281.63	30.76	24.36	2382	639.89	30.10	22.35	1756	1025.65	27.98	17.20	658
Mymenshing	1994	370.04	31.82	24.94	1080	689.57	30.42	21.78	884	1039.39	28.65	17.22	469
Mymenshing	1995	326.44	32.04	25.18	2096	635.63	30.05	22.37	1611	924.34	28.85	17.38	415
Mymenshing	1996	314.08	32.18	24.98	981	577.62	30.70	22.12	1164	1006.06	29.57	17.88	245
Mymenshing	1997	407.37	31.10	24.20	1639	644.69	29.65	21.82	1465	1101.70	27.87	16.83	368
Mymenshing	1998	431.11	31.42	25.20	1898	454.45	30.78	23.10	1613	1178.93	28.28	17.58	548
Mymenshing	1999	379.04	31.64	25.36	1484	495.07	30.33	22.42	1439	1209.26	30.07	18.28	524
Mymenshing	2000	400.04	31.52	24.86	1656	763.45	30.28	22.37	912	1258.79	28.07	17.22	886
Mymenshing	2001	626.11	31.92	24.92	1332	821.25	30.67	22.70	999	1327.26	28.88	17.13	541
Mymenshing	2002	678.64	30.54	24.50	1874	751.79	29.93	22.30	1121	1312.24	28.10	17.63	696
Mymenshing	2003	619.01	31.66	25.02	1154	742.58	30.13	22.62	882	1348.95	27.67	17.30	521
Mymenshing	2004	699.18	31.42	24.96	1717	822.17	29.73	21.73	2449	1314.77	28.55	18.22	370
Mymenshing	2005	624.97	31.40	24.64	1811	771.98	30.23	22.13	1673	1338.38	28.27	17.92	744
Mymenshing	2006	662.08	31.78	24.96	1516	778.91	30.55	22.30	1056	1326.58	28.93	18.18	534
Mymenshing	2007	692.29	31.58	25.06	2274	761.86	30.23	22.38	1529	1292.47	27.98	17.40	404
Mymenshing	2008	692.70	31.76	25.00	1807	786.42	30.18	22.33	1128	1316.74	28.15	18.30	436
Mymenshing	2009	721.77	32.32	25.26	1385	850.48	30.52	22.32	1050	1299.43	29.20	18.08	482
Barisal	1972	279.15	32.20	25.44	1219	364.33	30.40	22.10	825	1141.37	29.58	18.20	309
Barisal	1973	351.19	31.82	25.34	1710	400.44	29.07	22.40	1732	1182.59	29.93	18.60	840
Barisal	1974	349.72	31.14	24.76	1663	370.42	29.38	22.20	1454	1017.21	29.10	17.82	603
Barisal	1975	252.28	31.66	24.78	1340	348.80	29.38	20.97	1145	960.91	29.68	17.55	350
Barisal	1976	409.70	31.62	24.22	1323	435.59	29.98	21.53	1229	963.29	29.97	18.05	311
Barisal	1977	464.84	30.70	25.16	1458	449.67	29.67	22.43	796	1177.04	29.12	17.95	509
Barisal	1978	359.99	31.60	24.70	2072	482.04	30.10	22.15	1242	927.33	29.38	17.03	643
Barisal	1979	385.00	32.50	25.64	1759	489.39	30.38	22.92	1722	886.31	30.33	18.32	197
Barisal	1980	358.58	32.14	25.54	1343	434.33	30.05	22.23	1297	925.62	29.90	18.10	350

Barisal	1981	456.32	31.02	24.74	1863	490.55	29.80	21.72	1015	833.06	28.47	18.02	907
Barisal	1982	389.60	31.88	25.12	1524	438.73	29.87	21.50	1086	972.39	29.72	18.07	328
Barisal	1983	413.18	32.28	24.98	1676	458.47	30.32	22.18	1545	963.37	29.43	17.92	494
Barisal	1984	400.06	31.66	24.96	2289	495.29	30.18	21.60	1222	952.27	29.68	17.80	403
Barisal	1985	329.88	32.32	25.16	1211	523.47	30.48	21.73	985	958.66	30.43	18.58	338
Barisal	1986	359.10	32.58	24.80	1170	543.42	30.38	22.05	1569	830.26	30.35	17.97	297
Barisal	1987	416.15	32.60	25.14	1772	553.27	30.25	22.37	1683	921.32	30.58	18.18	261
Barisal	1988	161.15	31.70	25.46	1935	1084.01	30.25	22.65	1323	910.33	30.05	19.02	576
Barisal	1989	390.21	32.10	25.44	1115	479.40	29.80	21.68	1520	935.76	29.68	18.13	268
Barisal	1990	437.38	31.74	24.72	1633	601.45	30.10	22.13	1240	1012.24	29.07	18.33	782
Barisal	1991	139.84	31.86	24.98	1531	565.98	29.73	21.83	1524	935.53	29.80	18.77	322
Barisal	1992	99.44	32.60	25.18	1021	523.00	30.33	21.80	941	985.60	29.62	18.42	308
Barisal	1993	151.77	31.86	24.62	1916	547.62	30.33	22.13	1355	1043.72	29.77	17.75	777
Barisal	1994	161.58	31.96	24.96	1430	520.64	30.45	21.62	818	1005.71	30.07	18.05	388
Barisal	1995	137.92	32.42	25.46	1672	424.46	30.47	22.05	1376	862.04	30.10	18.20	225
Barisal	1996	141.63	32.60	25.00	1303	535.73	30.87	21.83	1106	942.64	30.60	18.65	258
Barisal	1997	154.85	32.28	24.28	1240	540.05	30.67	21.68	1005	987.78	29.33	17.45	560
Barisal	1998	150.34	32.54	24.62	1770	396.86	31.05	22.62	1745	986.51	29.47	17.77	905
Barisal	1999	123.03	32.38	25.16	1423	416.71	30.50	22.08	1463	1231.00	31.15	18.58	234
Barisal	2000	208.07	32.38	24.68	1255	606.96	30.72	21.98	1018	1290.99	29.92	17.82	447
Barisal	2001	517.91	32.30	24.72	1686	648.76	30.65	22.38	1270	1289.24	30.45	17.43	319
Barisal	2002	545.55	32.10	24.88	1954	619.37	30.65	22.58	1448	1148.69	30.03	18.10	480
Barisal	2003	523.64	32.40	25.94	1139	689.53	30.58	22.82	964	1162.31	29.48	18.70	338
Barisal	2004	524.37	32.34	25.54	1248	670.81	30.23	22.30	1989	1195.84	29.92	19.17	224
Barisal	2005	506.44	32.98	25.84	1202	170.07	30.52	22.47	1357	1272.30	30.60	19.25	263
Barisal	2006	515.40	32.62	25.64	1429	510.13	30.72	22.62	1327	1234.07	31.00	19.15	319
Barisal	2007	561.92	32.56	25.62	1445	600.74	30.28	22.63	1556	1280.91	29.82	18.17	301
Barisal	2008	573.47	32.64	25.48	1226	510.22	30.38	22.52	1458	1411.81	29.97	19.02	167
Barisal	2009	587.44	33.28	26.00	1444	713.88	30.95	22.35	1403	1403.13	30.93	19.08	278
Jessore	1972	324.19	33.56	25.30	710	390.31	30.87	21.02	690	1052.26	30.67	17.00	70

Jessore	1973	313.35	33.06	25.04	1094	360.61	29.38	21.87	937	1106.58	30.80	17.60	477
Jessore	1974	349.91	32.80	24.88	1195	411.81	30.13	21.73	1122	985.92	30.12	16.60	358
Jessore	1975	382.62	33.12	25.04	854	449.04	29.83	21.38	944	1048.01	30.60	17.10	157
Jessore	1976	388.37	32.94	24.48	983	486.72	30.83	21.27	678	954.22	30.78	17.07	258
Jessore	1977	374.77	32.36	24.74	1087	449.11	30.47	21.87	787	1016.90	30.32	17.23	409
Jessore	1978	428.66	33.42	25.14	1061	470.74	30.75	21.78	902	1129.51	30.73	17.48	250
Jessore	1979	421.86	33.64	25.56	991	459.62	31.17	22.77	1326	1050.61	30.45	17.93	160
Jessore	1980	360.13	33.36	25.50	1029	467.02	30.77	22.00	822	839.06	30.50	18.17	322
Jessore	1981	390.69	32.52	24.84	1319	434.49	30.85	21.42	1068	837.12	28.95	17.40	835
Jessore	1982	381.76	33.96	25.04	980	396.91	31.15	21.25	625	1046.46	30.72	17.55	352
Jessore	1983	333.18	34.16	25.00	1218	444.07	31.07	21.92	1075	1113.33	30.45	17.48	645
Jessore	1984	302.26	33.34	25.08	1757	508.00	30.90	21.50	834	1029.88	30.98	17.55	375
Jessore	1985	363.63	33.68	25.26	1050	621.82	30.95	21.63	977	1238.90	31.63	18.72	281
Jessore	1986	395.03	33.60	24.54	1109	605.09	30.45	21.77	1542	1228.87	31.10	17.82	263
Jessore	1987	451.76	33.46	25.52	1633	572.39	30.85	22.38	1436	1204.93	30.87	18.38	286
Jessore	1988	410.63	33.28	25.66	1552	552.07	31.22	22.25	868	1325.20	31.10	18.58	566
Jessore	1989	443.56	34.16	25.58	744	602.95	30.83	21.75	713	1231.86	31.10	17.27	250
Jessore	1990	452.67	33.18	25.28	1028	764.60	31.07	21.67	937	116.50	30.05	17.55	424
Jessore	1991	619.57	34.20	25.48	1410	879.10	30.73	21.62	1340	1288.18	31.22	18.07	381
Jessore	1992	606.86	34.66	25.00	986	812.26	31.30	21.17	702	1278.52	30.90	17.63	328
Jessore	1993	701.10	33.22	25.08	1256	738.07	31.08	21.93	938	1146.25	30.40	17.40	427
Jessore	1994	505.16	33.94	25.36	1069	755.13	31.45	21.57	627	1175.73	31.30	17.55	268
Jessore	1995	593.47	34.48	26.02	856	680.39	30.77	22.07	1048	1120.02	31.18	17.70	156
Jessore	1996	680.03	33.82	25.00	1237	776.87	31.27	21.45	1108	1169.41	31.13	17.82	317
Jessore	1997	698.02	33.66	24.66	1044	774.05	31.13	21.87	1043	1207.35	29.82	17.32	299
Jessore	1998	746.70	33.96	25.86	899	724.31	32.08	22.85	770	1330.33	29.67	17.65	557
Jessore	1999	653.23	34.38	25.68	1014	724.63	31.47	22.15	1060	1338.29	32.18	18.43	163
Jessore	2000	696.88	34.26	25.28	1172	906.05	31.72	21.83	1337	1316.25	30.75	17.53	265
Jessore	2001	692.35	33.70	25.22	1270	1072.18	31.90	22.28	711	1416.26	31.18	17.15	402
Jessore	2002	674.55	33.88	25.38	1715	937.20	31.78	21.97	1120	1426.67	31.12	17.85	465

Jessore	2003	736.72	34.86	25.46	1129	984.37	31.75	22.05	1243	1440.18	30.63	17.65	270
Jessore	2004	691.36	34.54	25.18	1258	1115.61	31.38	21.62	1919	1451.86	31.25	18.03	220
Jessore	2005	806.03	35.12	25.54	892	952.99	31.50	21.75	1269	1511.20	31.65	18.33	268
Jessore	2006	748.70	34.46	25.50	1339	925.96	31.78	21.88	1200	1481.53	32.42	17.85	355
Jessore	2007	846.77	34.46	25.64	1544	898.92	31.40	21.90	1522	1647.60	30.88	17.37	308
Jessore	2008	807.07	34.48	25.06	1152	964.48	31.62	21.88	1257	1425.79	30.92	17.87	389
Jessore	2009	854.98	35.40	25.60	1094	932.31	32.03	21.32	1289	1467.30	32.42	17.78	211
Khulna	1972	421.13	33.76	25.96	1042	286.85	30.83	22.75	846	646.57	31.35	19.38	249
Khulna	1973	279.21	33.00	25.58	1171	296.35	30.47	22.68	759	740.27	30.75	18.87	499
Khulna	1974	382.90	32.46	25.58	1823	413.81	29.85	22.85	1999	659.16	30.05	18.93	549
Khulna	1975	487.63	33.02	25.58	1166	454.27	30.60	22.68	975	650.73	30.70	18.87	277
Khulna	1976	431.35	32.72	25.24	1370	496.31	30.68	23.05	1171	641.16	30.67	19.45	417
Khulna	1977	442.86	32.32	25.38	1387	488.59	30.50	23.13	885	596.47	30.32	19.15	419
Khulna	1978	423.12	32.80	25.34	1385	505.25	30.65	23.27	1222	719.28	30.23	18.52	329
Khulna	1979	457.14	33.42	26.12	1431	514.77	31.22	23.97	1329	689.93	30.52	19.87	179
Khulna	1980	439.33	32.76	26.12	1314	505.72	29.90	22.68	985	724.95	29.98	19.73	498
Khulna	1981	455.11	31.52	25.26	1503	511.76	29.98	22.55	975	726.58	28.48	18.12	933
Khulna	1982	404.90	32.80	25.70	1020	468.94	30.02	22.37	837	757.05	30.00	18.30	206
Khulna	1983	462.88	32.70	25.12	1633	492.39	29.70	22.17	1342	804.28	29.27	18.08	673
Khulna	1984	430.16	32.54	25.44	1893	1100.78	30.42	21.88	1031	846.35	30.35	17.67	363
Khulna	1985	380.23	33.12	25.56	1006	613.05	30.68	22.10	796	911.43	31.10	18.60	238
Khulna	1986	384.20	33.54	24.84	1242	581.03	30.58	22.32	1569	888.18	31.02	17.80	408
Khulna	1987	443.67	34.02	25.12	1577	489.27	31.18	22.52	1300	909.93	31.05	18.10	314
Khulna	1988	172.63	32.98	25.78	1585	573.51	30.92	22.93	930	985.02	30.92	19.03	426
Khulna	1989	468.76	33.58	25.76	815	467.67	30.72	22.45	896	854.78	30.58	17.67	250
Khulna	1990	450.01	33.20	25.50	1222	606.44	30.80	22.53	1084	865.59	30.00	18.07	597
Khulna	1991	1359.49	33.22	25.80	1139	627.07	30.45	22.38	1142	884.47	30.48	18.92	273
Khulna	1992	1889.56	33.84	24.76	803	617.82	30.75	22.03	651	852.93	30.23	17.87	410
Khulna	1993	1009.97	32.82	25.40	1496	635.57	30.87	22.73	912	1022.64	30.33	18.08	529
Khulna	1994	1096.56	33.34	25.58	886	658.77	31.12	22.65	655	910.82	30.77	18.18	236

Khulna	1995	1265.94	33.76	26.06	1508	564.43	30.97	22.27	1552	955.66	30.82	18.48	345
Khulna	1996	1607.23	33.48	25.28	1132	662.39	31.08	22.13	818	988.76	31.28	18.50	200
Khulna	1997	1533.24	32.90	24.64	1256	692.05	30.88	22.28	1206	1030.53	29.73	17.68	411
Khulna	1998	1718.62	33.32	26.02	1042	548.04	31.48	23.43	1190	1045.40	29.75	18.67	629
Khulna	1999	2209.33	33.24	25.84	1162	677.97	31.18	22.68	1339	1111.55	31.60	19.22	186
Khulna	2000	1896.00	33.56	25.00	1193	801.81	31.55	22.38	1196	1140.36	30.58	18.20	309
Khulna	2001	658.49	33.16	25.72	1106	780.90	31.27	23.37	891	1177.91	30.90	18.38	445
Khulna	2002	701.06	33.30	25.56	2024	792.04	31.40	23.03	1470	1087.31	30.83	19.02	352
Khulna	2003	704.58	33.86	26.18	981	833.49	31.20	23.15	1024	1176.25	30.27	19.05	365
Khulna	2004	717.77	33.40	26.04	1167	615.08	30.72	22.87	1323	1225.62	30.40	19.62	272
Khulna	2005	709.11	33.76	26.32	989	817.86	30.53	23.00	1459	1239.18	30.75	19.80	421
Khulna	2006	713.44	33.56	25.98	1397	755.48	30.98	23.07	1545	1232.40	31.25	19.72	254
Khulna	2007	672.27	33.54	25.94	1336	853.44	30.43	23.03	1458	1387.95	29.97	18.90	279
Khulna	2008	672.10	33.50	25.78	880	720.52	30.68	23.15	1069	1366.86	30.20	19.62	337
Khulna	2009	658.04	34.40	26.26	1301	843.68	31.18	22.85	1403	1330.42	31.25	19.83	170
Bogra	1972	275.41	33.58	25.20	976	496.80	30.25	21.77	806	685.02	30.48	17.33	173
Bogra	1973	321.06	32.42	25.10	1733	429.30	29.58	22.38	1242	884.70	29.85	17.58	466
Bogra	1974	322.54	31.62	24.78	1485	566.54	30.02	22.00	1191	847.25	28.52	16.57	445
Bogra	1975	352.97	33.14	24.94	984	577.08	30.07	21.53	1011	651.98	30.42	17.03	309
Bogra	1976	316.65	32.38	24.44	1480	521.76	30.10	21.77	1251	717.13	30.27	17.18	235
Bogra	1977	361.47	32.76	25.06	1065	535.64	30.22	22.35	936	817.99	29.85	17.27	264
Bogra	1978	358.07	31.86	24.50	1680	541.21	30.68	22.10	673	1011.73	28.92	16.52	560
Bogra	1979	413.15	34.54	25.36	1644	576.48	30.98	22.65	1915	1102.26	31.20	17.65	181
Bogra	1980	410.56	32.76	25.10	1305	551.18	30.68	22.30	931	1114.81	30.17	17.62	359
Bogra	1981	518.19	31.86	24.72	1279	623.33	30.40	21.68	1040	1185.44	28.37	17.28	588
Bogra	1982	451.65	32.82	24.88	1025	565.05	30.38	21.87	784	1180.33	29.48	17.07	206
Bogra	1983	456.50	32.70	24.76	1010	192.00	30.45	22.28	1239	1150.60	29.00	16.47	453
Bogra	1984	418.23	32.26	24.82	1678	612.80	30.35	21.90	1295	1134.25	29.45	17.20	471
Bogra	1985	435.76	32.56	24.88	1184	688.73	30.47	21.72	903	1191.26	30.10	17.92	333
Bogra	1986	471.72	32.36	24.54	1172	676.94	30.22	21.75	1632	1233.00	29.70	17.40	358

Bogra	1987	482.45	32.62	24.98	1796	648.36	30.57	22.47	1346	1073.31	30.43	18.07	333
Bogra	1988	339.19	32.70	24.76	1768	662.90	31.47	22.22	1094	1079.53	30.23	17.67	401
Bogra	1989	539.84	33.76	24.86	1088	673.60	31.02	21.67	1012	1106.76	30.07	16.50	152
Bogra	1990	517.65	32.68	24.64	1475	790.56	31.38	21.92	1315	2232.66	29.43	17.18	384
Bogra	1991	1708.60	32.68	24.54	1315	797.21	30.55	21.73	1561	1051.95	29.67	17.20	602
Bogra	1992	2732.43	33.58	24.48	820	840.99	31.25	21.70	981	1068.23	29.67	17.17	184
Bogra	1993	6151.69	32.28	24.32	1490	881.53	31.42	22.37	1034	1119.52	29.05	17.12	408
Bogra	1994	5313.52	33.66	25.04	878	872.90	31.33	22.02	805	1155.08	30.07	17.53	248
Bogra	1995	5782.10	33.36	25.66	1552	817.16	30.57	22.52	1625	1145.45	29.77	17.68	158
Bogra	1996	9714.69	33.18	25.20	1377	654.45	31.12	22.15	1020	1170.73	30.15	18.03	623
Bogra	1997	2768.62	32.68	24.60	993	697.44	30.38	22.15	821	1197.09	28.62	17.17	299
Bogra	1998	2696.89	32.76	25.42	1906	699.09	31.60	23.22	1958	1204.53	28.80	17.57	276
Bogra	1999	327.27	32.70	25.72	1292	656.27	30.93	22.73	1090	1233.75	30.42	18.52	255
Bogra	2000	3560.86	32.40	25.26	1159	760.79	30.98	22.68	1029	1214.77	28.50	17.50	559
Bogra	2001	681.70	32.88	25.30	838	828.71	30.97	22.90	855	882.56	29.33	17.38	239
Bogra	2002	671.10	31.68	24.86	1633	814.65	30.62	22.38	1345	1278.81	28.82	17.93	412
Bogra	2003	710.14	32.88	25.26	1130	834.81	30.90	22.75	872	1310.53	28.33	17.45	469
Bogra	2004	674.12	32.82	25.04	1655	880.09	30.48	22.05	1247	1339.60	29.30	18.22	272
Bogra	2005	692.17	32.98	25.04	1139	836.16	30.80	22.43	1679	1363.73	29.43	18.10	283
Bogra	2006	683.15	33.22	25.24	850	858.12	31.40	22.50	574	1351.66	29.95	18.33	348
Bogra	2007	758.99	33.20	25.40	1428	894.70	31.07	22.48	1024	1506.35	29.15	17.58	163
Bogra	2008	844.81	32.90	25.18	1474	903.54	30.82	22.60	1116	1546.54	29.15	18.28	282
Bogra	2009	835.99	33.60	25.34	1146	892.07	31.28	22.40	1022	1525.33	29.82	17.85	260
Dinajpur	1972	339.67	33.66	24.50	1012	454.03	32.35	21.08	817	894.17	29.43	15.67	214
Dinajpur	1973	301.60	32.50	24.40	1303	441.20	30.22	21.22	1173	1215.22	29.22	16.07	217
Dinajpur	1974	385.03	32.50	24.40	1303	553.35	30.22	21.22	1173	1065.93	29.22	16.07	217
Dinajpur	1975	367.64	32.50	24.40	1303	518.59	30.22	21.22	1173	934.90	29.22	16.07	217
Dinajpur	1976	375.03	32.50	24.40	1303	524.44	30.22	21.22	1173	862.26	29.23	16.08	217
Dinajpur	1977	398.03	32.50	24.40	1303	536.53	30.22	21.22	1173	898.28	29.22	16.07	217
Dinajpur	1978	364.11	32.50	24.40	1303	543.07	30.22	21.22	1173	950.95	29.22	16.07	217

Dinajpur	1979	405.32	32.50	24.40	1303	528.40	30.22	21.22	1173	842.35	29.22	16.07	217
Dinajpur	1980	370.99	32.36	24.46	1303	509.17	29.92	21.38	1173	1059.41	28.55	16.55	217
Dinajpur	1981	388.45	32.56	24.58	1780	563.23	30.33	21.40	1267	1138.80	29.10	16.32	791
Dinajpur	1982	387.05	32.76	24.06	1097	504.17	29.70	20.82	856	1091.98	29.25	15.72	222
Dinajpur	1983	420.38	32.26	23.68	1540	520.20	29.75	20.72	1592	1112.35	28.00	14.75	383
Dinajpur	1984	454.01	31.90	24.10	1536	569.96	29.67	20.43	1307	1144.20	28.42	15.78	405
Dinajpur	1985	448.04	32.36	24.52	1476	601.58	29.72	21.33	1377	1097.61	29.33	16.70	176
Dinajpur	1986	444.16	32.10	24.14	1275	618.04	29.28	21.18	1505	913.58	28.70	16.00	280
Dinajpur	1987	462.30	32.02	24.14	2548	593.59	29.43	21.63	2543	964.40	29.12	16.73	359
Dinajpur	1988	160.52	31.96	24.44	1874	581.57	30.30	21.52	1568	1008.71	29.22	17.00	306
Dinajpur	1989	422.39	32.98	24.30	1305	612.36	29.58	20.90	1221	948.57	28.95	15.55	441
Dinajpur	1990	381.85	31.92	24.46	1489	699.41	30.27	21.13	1275	1072.09	28.05	16.28	451
Dinajpur	1991	410.99	32.18	24.24	1260	750.16	29.77	21.08	1186	1115.16	28.67	16.00	494
Dinajpur	1992	430.34	33.12	23.88	1067	684.85	30.08	20.50	1332	1135.63	28.70	15.48	109
Dinajpur	1993	431.02	31.92	24.08	1668	722.58	30.60	21.78	1223	1163.37	28.02	15.73	461
Dinajpur	1994	458.50	33.62	24.70	760	717.90	30.83	20.87	607	1194.49	29.32	16.30	241
Dinajpur	1995	282.07	33.52	24.70	1406	601.89	30.00	21.22	2247	1015.14	29.80	16.05	84
Dinajpur	1996	435.09	33.08	24.32	1206	630.12	30.50	21.25	1142	1040.94	29.65	16.20	125
Dinajpur	1997	455.25	32.94	24.28	1446	648.37	29.97	21.52	1119	1068.06	28.23	15.85	225
Dinajpur	1998	464.31	32.44	25.04	1651	626.08	30.62	22.50	1811	1110.86	27.97	16.35	343
Dinajpur	1999	472.29	32.32	25.08	1708	501.55	30.17	21.92	1818	1102.27	29.68	17.28	435
Dinajpur	2000	472.12	32.38	24.70	1246	608.95	30.73	21.67	604	1108.26	27.85	15.93	495
Dinajpur	2001	733.59	33.60	24.64	1276	772.77	30.87	22.23	1426	1244.87	29.12	16.13	280
Dinajpur	2002	539.10	31.52	24.38	1967	703.39	30.47	21.65	1586	1169.09	28.53	16.95	305
Dinajpur	2003	834.79	32.40	24.56	1318	691.18	30.37	22.00	1370	1192.24	27.18	16.10	381
Dinajpur	2004	876.52	31.98	24.40	1688	751.99	30.17	21.20	1316	1269.09	27.97	16.78	463
Dinajpur	2005	779.82	32.14	24.54	1922	727.87	30.18	21.63	2096	1370.00	28.30	16.97	405
Dinajpur	2006	828.17	32.62	24.76	892	739.93	30.58	21.93	736	1319.55	28.68	17.28	335
Dinajpur	2007	744.70	32.68	24.94	1262	809.44	30.48	21.87	919	1488.35	28.20	16.65	186
Dinajpur	2008	700.26	32.30	24.60	1432	932.19	30.25	22.03	1109	1589.00	27.98	17.25	300

Dinajpur	2009	977.59	32.82	24.86	1619	963.57	30.57	21.80	1148	1528.83	28.63	17.00	420
Rajshahi	1972	299.24	33.44	25.66	672	377.99	30.85	21.77	583	748.10	30.03	17.53	130
Rajshahi	1973	326.88	32.70	25.26	1131	365.25	29.68	22.45	1163	841.89	30.22	17.13	279
Rajshahi	1974	333.46	33.22	25.30	1238	417.73	30.50	22.25	1371	957.44	29.97	17.22	193
Rajshahi	1975	361.80	33.30	25.46	795	418.59	29.77	21.92	883	826.36	30.33	17.67	190
Rajshahi	1976	359.53	33.00	24.96	1110	427.37	30.62	22.18	934	787.46	30.37	17.73	259
Rajshahi	1977	357.63	32.60	24.44	1569	434.97	30.50	22.90	882	894.71	30.33	17.38	526
Rajshahi	1978	380.32	32.22	24.58	964	462.46	29.87	22.07	936	917.30	28.95	16.80	306
Rajshahi	1979	353.40	33.40	25.46	861	456.69	30.92	22.65	1390	758.70	29.50	17.72	140
Rajshahi	1980	306.95	32.92	25.40	1102	451.15	30.78	22.40	961	880.76	29.97	17.45	266
Rajshahi	1981	363.03	33.88	24.68	1603	474.18	30.30	21.85	1406	1127.69	29.68	15.85	767
Rajshahi	1982	393.55	34.02	25.06	848	473.79	30.68	21.48	571	1004.21	30.55	16.78	273
Rajshahi	1983	326.53	33.88	24.70	1091	477.76	30.30	21.87	1402	1014.00	29.80	15.85	186
Rajshahi	1984	375.63	33.70	25.12	1044	524.29	30.48	21.30	1114	1117.81	30.55	16.75	136
Rajshahi	1985	345.90	33.74	24.68	913	516.44	30.48	21.33	745	1108.44	31.03	16.93	287
Rajshahi	1986	355.38	33.78	24.44	849	537.25	30.22	21.75	1127	1049.13	30.45	16.55	212
Rajshahi	1987	438.86	34.08	24.68	1294	513.43	30.55	21.98	1133	1066.77	31.18	17.12	198
Rajshahi	1988	88.68	33.52	24.62	1266	488.82	30.98	21.88	769	1090.35	30.65	17.13	266
Rajshahi	1989	418.19	34.68	24.56	890	579.62	30.58	20.97	892	912.08	31.00	15.47	251
Rajshahi	1990	434.48	33.48	24.22	1361	669.94	31.02	20.80	1024	103.93	29.75	15.98	478
Rajshahi	1991	3560.49	34.36	24.66	770	723.24	30.55	20.93	1069	1220.54	30.73	16.50	311
Rajshahi	1992	1688.02	34.98	24.58	648	727.76	30.98	20.90	587	1222.09	30.75	16.05	167
Rajshahi	1993	1999.07	33.40	24.54	1031	857.27	30.77	22.18	938	1197.80	30.33	16.12	218
Rajshahi	1994	1885.19	33.98	25.28	760	735.41	30.80	21.50	700	1246.21	30.37	17.02	205
Rajshahi	1995	1393.08	34.84	25.66	947	650.10	30.55	22.07	985	1131.06	30.78	16.98	157
Rajshahi	1996	1217.30	34.40	25.04	828	626.04	30.88	21.67	792	1194.87	31.07	17.23	193
Rajshahi	1997	1449.59	33.52	24.52	1582	680.35	30.02	21.97	1649	1201.70	29.27	16.48	193
Rajshahi	1998	1357.33	34.04	25.56	926	726.20	31.22	23.13	1213	1260.15	29.20	16.92	235
Rajshahi	1999	1310.49	34.20	25.76	1204	800.35	30.58	22.35	1361	1329.06	31.52	17.97	153
Rajshahi	2000	1322.10	33.50	25.26	863	824.52	30.93	22.22	1036	1311.29	29.22	16.88	412

Rajshahi	2001	615.74	33.74	25.06	1074	878.01	31.00	22.53	828	1333.60	30.23	16.57	211
Rajshahi	2002	630.76	33.14	25.06	1068	839.25	30.90	21.90	900	1310.61	29.80	17.28	322
Rajshahi	2003	641.62	34.42	25.46	767	871.25	30.90	22.38	918	1334.23	29.53	17.05	220
Rajshahi	2004	672.98	34.18	25.24	1274	869.39	30.63	21.73	1116	1362.44	30.47	17.87	163
Rajshahi	2005	740.32	34.46	25.36	880	874.36	30.62	21.93	1059	1437.35	30.53	17.82	254
Rajshahi	2006	706.65	34.18	25.24	790	871.87	31.17	22.02	725	1399.89	31.05	17.57	232
Rajshahi	2007	822.74	34.22	25.38	1546	907.03	30.93	22.02	1346	1542.51	29.82	16.87	359
Rajshahi	2008	781.14	33.88	25.08	1039	1013.77	30.73	22.05	868	1679.56	29.88	17.58	200
Rajshahi	2009	820.19	35.08	25.58	680	1020.74	31.17	21.73	750	1618.00	30.85	17.13	167
Rangpur	1972	303.73	34.88	18.40	1047	618.07	32.28	20.30	997	824.30	30.60	12.13	230
Rangpur	1973	298.84	32.06	24.10	1445	513.10	29.98	21.53	1055	894.42	28.47	15.90	442
Rangpur	1974	333.07	32.06	24.10	1536	626.68	29.98	21.53	1254	916.67	28.47	15.90	337
Rangpur	1975	298.73	32.06	24.10	1339	566.82	29.98	21.53	1045	844.81	28.47	15.90	602
Rangpur	1976	313.47	32.06	24.10	1682	562.75	29.98	21.53	1148	736.08	28.47	15.90	320
Rangpur	1977	336.13	32.06	24.10	1728	553.39	29.98	21.53	991	619.20	28.47	15.90	489
Rangpur	1978	337.32	31.60	24.80	1559	576.89	29.63	21.82	1304	104.51	29.13	16.18	447
Rangpur	1979	350.41	31.72	24.28	1651	563.23	29.02	21.88	1564	675.80	24.45	16.23	236
Rangpur	1980	308.73	31.14	24.92	1673	585.88	29.45	22.17	1263	996.22	27.92	16.85	431
Rangpur	1981	355.54	31.60	24.16	1514	602.57	30.17	21.57	1155	1051.58	27.42	16.05	659
Rangpur	1982	369.09	31.74	24.58	1668	584.57	29.50	21.68	1341	1042.17	28.20	16.17	212
Rangpur	1983	338.80	31.42	23.88	1619	609.47	29.37	21.58	1542	1047.64	27.33	15.02	395
Rangpur	1984	336.57	31.64	24.32	2838	631.06	29.57	21.00	2049	1009.18	27.97	15.85	715
Rangpur	1985	327.71	31.90	24.22	2259	661.05	29.68	21.08	1647	1012.91	28.53	16.15	687
Rangpur	1986	366.69	31.68	23.58	1534	650.71	29.23	20.87	1556	1108.97	28.17	15.38	405
Rangpur	1987	398.54	31.76	24.34	2515	639.96	29.40	21.85	2393	1031.69	28.73	16.63	316
Rangpur	1988	171.71	31.66	24.66	1903	620.26	30.13	22.00	1635	995.48	28.67	17.13	521
Rangpur	1989	442.25	32.54	24.42	1383	639.07	29.55	21.52	1297	963.66	28.28	15.67	364
Rangpur	1990	439.39	31.42	24.44	1583	735.16	29.98	21.47	1466	1080.00	27.47	16.47	628
Rangpur	1991	3525.82	31.58	24.32	1287	730.78	29.55	21.50	1562	1027.25	27.85	16.32	474
Rangpur	1992	2659.12	32.34	24.08	1296	726.16	29.85	21.33	1301	1069.45	28.10	15.85	359

Rangpur	1993	2262.22	31.42	23.90	1957	741.24	30.23	21.90	1546	1108.91	27.60	15.97	341
Rangpur	1994	1833.44	32.60	24.56	987	754.08	30.47	21.35	540	715.16	28.45	16.43	334
Rangpur	1995	1827.26	32.46	24.62	1729	749.25	29.62	21.85	2168	1101.94	28.78	16.38	172
Rangpur	1996	2097.13	32.32	24.26	1499	699.06	30.23	21.58	1324	1143.84	28.97	16.68	284
Rangpur	1997	1078.87	31.84	23.94	1480	782.02	29.68	21.32	1316	1162.73	27.38	15.85	406
Rangpur	1998	1040.38	31.86	24.84	1639	790.20	30.38	22.58	1595	1230.74	27.78	16.43	437
Rangpur	1999	948.34	31.62	24.96	2276	601.01	29.98	22.15	1913	1271.39	29.23	17.40	571
Rangpur	2000	1190.45	31.82	24.62	1535	823.13	30.23	21.78	589	1268.19	27.62	16.17	718
Rangpur	2001	431.86	32.44	24.58	1441	853.48	30.38	22.40	1714	1279.40	28.53	16.33	297
Rangpur	2002	402.58	30.74	24.26	2172	777.75	29.92	22.00	1231	1133.31	27.72	17.20	672
Rangpur	2003	650.57	31.84	24.58	1692	812.55	30.30	22.37	1386	1216.70	27.03	16.62	467
Rangpur	2004	588.75	31.30	24.32	1681	865.84	29.78	21.65	1737	175.02	27.65	17.37	594
Rangpur	2005	476.64	31.52	24.18	1863	774.60	30.05	21.87	1980	1349.10	27.93	17.22	445
Rangpur	2006	532.69	32.26	24.66	1291	820.22	30.42	22.15	755	762.06	28.35	17.48	480
Rangpur	2007	426.94	32.16	24.90	1547	897.94	30.23	22.20	1134	1525.46	27.68	16.88	335
Rangpur	2008	559.83	31.70	24.36	1419	745.35	29.92	22.17	1030	1577.67	27.63	17.38	433
Rangpur	2009	647.85	32.32	24.78	1900	909.50	30.43	22.02	1444	1517.26	28.35	17.27	437

Appendix II   The questionnaire of farm households

ID	

General information

Name of respondent[2]	:
Name of village	:
Name of Union	:
Name of Upazilla (sub-district)	:
Name of Zilla (district)	:

A. Socio-economic information

1. Is the respondent head of household: [ ] Yes [ ] No
2. Age of the respondent (in years):
3. Gender of the respondent (please tick): [ ] Male [ ] Female
4. Year of schooling of the respondent (in years):
5. Main occupation of the respondent (please write):
6. Secondary occupation of the respondent (please write):
7. Household yearly income (in Tk.)

Income from agricultural sources		*Income from non-agricultural sources*	
Items	Income (Tk.)	Items	Income (Tk.)
Rice		Service	
Wheat		Business	
Livestock		Pension	
Fishery		Remittance	
Fruits &vegetables		Others: non-agricultural (if any)	
Others: agricultural (if any)			

8. Household size (in number):

Adult member (above 15 years of age):

Child member (under 14 years of age):

Income earning member:

[2] A respondent is a family member who keeps record and takes care of farming activities. He may be either head or any other member of a family. In farming community, it is usually head of the household.

Literate member:

9. Value of household assets

Items	*Quantity*	*Brand*	*Market value*
Refrigerator			
TV			
Radio			
Cell phone			
Motor cycle			
Cycle			
Furniture			
Other assets (specify please)			

B. Farm structure

10. Farm size (in decimal)

Type of land	*Size/amount (in decimal)*
Own cultivable land	
Leased-in land	
Leased-out land	
Rented-in land	
Rented-out land	
Homestead land	

11. Do you have tenure status?

[ ] Yes [ ] No

12. How long have you been involved in farming (in years)?

13. Do you own any livestock (cow, buffalo, goat, sheep etc)?

[ ] Yes [ ] No

C. Topography and soil

14. Elevation of land (please tick): [ ] Low land [ ] High land [ ] Medium low land [ ] Medium high land

15. Soil type/quality (please tick): [ ] Clay [ ] Clay-loamy [ ] Loamy [ ] Sandy

D. Institutional accessibility

16. Do you have access to agricultural extension services particularly in rice cultivation ?

    [ ] Yes [ ] No

    If yes, then from which source?

    [ ] Government [ ] Non-government [ ] others (please specify)

17. Do you get extension services from other neighbouring farmers?

    [ ] Yes [ ] No

18. Do you get any, in advance, climate (e.g. temperature, rainfall and droughts) information from any sources?

    [ ] Yes [ ] No

19. If yes, tick from among the following sources:

    [ ] Agricultural extension office, [ ] Television, [ ] Radio, [ ] Newspapers,

    [ ] Others (please specify)

20. Do you have access to agricultural credit of government agencies or NGOs?

    [ ] Yes [ ] No

21. Do you have bank account?

    [ ] Yes [ ] No

22. If yes, did you open the 10-taka account recently?

    [ ] Yes [ ] No

23. Do you receive any agricultural subsidy (e.g. input subsidy, cash subsidy, and agriculture input assistance card) from the government?

    [ ] Yes [ ] No

24. Does your cultivable land have access to irrigation facilities?

[ ] Yes [ ] No

If yes, what is the name of your service provider?

[ ] Deep tube well by BMD [ ] Own motor or shallow tubewell [ ] others

If yes, then from which source? [ ] Groundwater [ ] surface water

25. What percentage of your total cultivable land is under irrigation? ……%
26. Do you have access to electricity at home?

    [ ] Yes [ ] No
27. Is the availability of electricity is adequate for running your irrigation pump?

    [ ] Yes [ ] No
28. Where do you normally sell your produce? [ ] Local market [ ] Urban market

    (a) What is the distance of local market from where you live? ……km

    (b) What is the distance of nearby urban township from where you live? ……km
29. What proportion of your produce do you sell in the local market? ....%
30. What proportion of your produce do you sell in the urban market? ....%
31. Where do you normally buy your agricultural inputs (such as fertilizers, seeds, pesticides, herbicides)? [ ] Local market [ ] Urban market
32. What proportion of your inputs do you buy in the local market? ....%
33. What proportion of your inputs do you buy in the urban market? ....%
34. Please provide your opinion about the supply of agricultural inputs:

Inputs	Opinion (please tick one)			
	very good	good	medium	not good
Seeds				
Fertilizer				
Pesticides, herbicides				
Labour				

35. Are you a member of any institutional group/organization/farmers' cooperation/ farmers' club?

    [ ] Yes [ ] No , If yes,

36. What is the name of the group (organization)?

37. How long you are involved in the group? ....yrs

E. Farmers' perceptions about climate change

38. Have you noticed/perceived any changing climate in your locality over last 20 years?

[ ] Yes [ ] No

If yes, identify which of the climatic variables you suppose have changed and describe how they have changed.

Climate components	Time period	Increased	Decreased	No change /same	Don't know
Temperatures	Annual				
	Winter				
	Summer				
Rainfall	Annual				
	Winter				
	Summer				
Extreme events such as drought	Annual				
Availability of groundwater	Annual				
Availability of surface water	Annual				
Severity of cold wave	Annual				
Severity of heatwave /hot days	Annual				
Others, if any (please specify)	Annual				

F. Impacts of climate change

39. Do you think Aman rice is damaged due to climate change (high temperatures, variable rainfall (mainly low) and severe droughts)?

[ ] Yes [ ] No , If yes, answer questions 44-45.

40. What is your opinion about climate related production loss?

[ ] Very adversely affected [ ] adversely affected [ ] moderately affected

[ ] slightly affected [ ] not affected at all

41. What percentages of total production loss are incurred for Aman rice? ....%

G. Farmers' adaptation to climate change

42. Have you made any changes to your farm operations due to changes in climate attributes (you have mentioned earlier) in order to reduce adverse impacts?

[ ] Yes [ ] No

If yes, (go to questions 43-44) and if no, then go to question 45.

43. What adaptive measures (adjustments) do you practice to reduce crop loss?

Adaptive measures	Please put 1 for main measure and tick (✓) for others that you practise
Use of Irrigation provided by BMDA	
Own irrigation equipment e.g. motor	
Direct-seeded rice	
Greater emphasis on Aman with supplementary irrigation	
Cultivation of different rice varities (e.g., BRRI-39,49, Bina 7)	
Changing planting date	
Tree plantation, mainly, mango orchard	
Agro-forestry (rice and mango)	
Use of different crop varieties for each year	
Cultivation of pulses (e.g., chickpea)	
Cultivation of jute, wheat and so on	
others	
No adaptation	

44. When you are practising any or some of the above adaptive measures, what other adjustments you usually make (i.e., adapt to adaptation)?

Adapt to adaptation	Please put 1 for main adjustment and tick (✓) for others that you practice
Institutional microcredit	
Credit from rural usury	

Sale of livestock	
Spending previous savings	
Sale and mortgage of some plots of land	
Sale of other assets	
Family members' migration to other areas, mainly urban	
Others	

45. What are your barriers in taking adaptive measures?

Barriers to adaptation	Please put 1 for main barrier and tick (✓) for others that you face
Lack of information about potential climate change	
Lack of adequate irrigation facility	
Lack of knowledge concerning appropriate adaptation	
Lack of credit/money/saving	
Labour shortage in need	
Lack of own land	
Lack of storage facilities	
Others (please specify)	

H. Costs and production

46. Costs and return in the previous (2010-11) production year

Items	Costs per bigha (in Tk.)
Total cultivated land (in bigha)	
Human labour cost	
Seedbed preparation and management	
Pulling of seedling and transplanting	
Land preparation	
Irrigation on planted field	
Weeding	
Fertilizer application	
Insecticide application	
Herbicides application	
Harvesting	
Hauling of harvesting paddy	

Threshing	
Drying	
Packing and storage	
Input cost	
Bullock/buffalo pair	
Power tiller	
Seed	
Fertilizer	
Green manure	
Irrigation	
Pesticides/herbicides/ insecticides	
Land rental	
Output	
Production (maund)	
By-product (straw in maund)	
Sale price of rice (Taka per maund):	
Paddy	
Straw	

Thanks for your time

Appendix III Descriptive statistics for all variables for farm-level analysis

Variables	All farms	Small arms	Irrigated farms	Integrated farms	Non-integrated farms	Non-irrigated farms
	Mean (std.dev.)/ Frequency	Mean (std.dev.)/ Frequency	Mean (std.dev.)/ Frequency	Mean (std.dev.)/ Frequency	Mean (std.dev.)/ Frequency	Mean (std.dev.)/ Frequency
Net revenue (Tk./decimal)	111.82 (95.06)	107(96.68)	111.27(95.39)	114.47(95.92)	91(86)	122(90)
Gender of the household head (male=1, female=0) (frequency)	Male= 97% Female= 3%	Male= 97.5% Female= 2.5%	Male= 97% Female= 3%	Male= 97% Female= 3%	Male= 95% Female= 5%	Male= 100 % Female= 00%
Age of the household head (years)	47.07(12.57)	46(12.11)	47(12.67)	47.23(12.55)	45.82(12.78)	47(10.87)
Years of schooling of the household head	5.09(4.37)	4.41(4.00)	5(4.34)	5(4.32)	5.58(4.73)	5.10(4.93)
Agriculture is the main occupation of household head (agriculture=1, others=0) (frequency)	Agriculture= 92% Others= 8 %	Agriculture= 92% Others= 8%	Agriculture= 91.5% Others= 8.5%	Agriculture= 93% Others= 7%	Agriculture= 82% Others= 18 %	Agriculture= 97% Others= 3%
Household yearly farm income (Tk.)	159965(15522)	122194 (108353)	164727(157736)	165818(160855)	113896(88546)	77430(58180)
Household yearly non-farm income (Tk.)	20792(48594)	19613(46278)	21114(49063)	18532(45807)	38578(64330)	15200(39846)
Household size (number of people)	5.41(2.42)	5.41(2.44)	5.45(2.45)	5.50(2.48)	4.77(1.76)	4.73(1.66)
Household assets (Tk.)	42411(90148)	27853(38793)	43298(91940)	41507(93039)	49533(63040)	27040(48035)
Farm size (in decimal)	336.38(320.67)	241(175.28)	343(326)	341(331)	299(226)	216(177)
Household land tenure (yes=1, no=0) (frequency)	Yes = 64.5% No = 35.5%	Yes = 56% No = 44%	Yes = 65% No = 35%	Yes = 65% No = 35%	Yes = 58% No = 42%	Yes = 50% No = 50%
Livestock ownership (yes=1, no=0) (frequency)	Yes = 89% No = 11%	Yes = 89% No = 11%	Yes = 89% No = 11%	Yes = 100 % No = 00%	Yes = 00% No = 100 %	Yes = 90% No = 10%
Farming experience of household head (years)	23(11)	22(11)	23(12)	23(11)	23(11.57)	23(9.50)
Household access to agricultural extension service (yes=1, no=0) (frequency)	Yes = 34.5% No = 65.5%	Yes = 31.5% No = 68.5%	Yes = 35% No = 65%	Yes = 34% No = 66%	Yes = 40% No = 60%	Yes = 23% No = 76%
Farmer to farmer extension(yes=1, no=0) (frequency)	Yes = 96.5% No = 3.5%	Yes = 97% No = 3%	Yes = 97% No = 3%	Yes = 97% No = 3%	Yes = 95% No = 5%	Yes = 93% No = 7%
Household access to weather information (yes=1, no=0) (frequency)	Yes = 46% No = 54%	Yes = 44% No = 56%	Yes = 45% No = 55%	Yes = 43% No = 57%	Yes = 64.5% No = 35.5%	Yes =50% No =50%
Household access to agricultural credit (yes=1, no=0) (frequency)	Yes = 31% No = 69%	Yes = 32% No = 68%	Yes = 32% No = 68%	Yes = 28.5% No = 71.5%	Yes = 52% No = 48%	Yes =20% No = 80%
Household access to agricultural subsidy (yes=1, no=0) (frequency)	Yes =10% No =90%	Yes =10 % No = 90%	Yes =10% No = 90%	Yes =10% No = 90%	Yes =11% No = 89%	Yes =7% No =93%
Percentage of household total land under irrigation (frequency)	72.57(30.46)	72(31)	77.76(25.68)	72(30.69)	76(28.54)	-
Household access to electricity (yes=1, no=0) (frequency)	Yes =74.5% No =25.5%	Yes = 70% No = 30%	Yes =75% No = 25%	Yes =76% No = 24%	Yes = 63% No = 37%	Yes = 63% No = 37%
Produce/crop selling place (local market=1, urban market/others=0) (frequency)	Local=77% Urban=23%	Local=75% Urban=25%	Local=76% Urban=24%	Local=77 % Urban=23%	Local=79% Urban=21%	Local=90% Urban=10%
Distance of local market from household home (km)	2.34(1.47)	2.33(1.45)	2.31(1.46)	2.42(1.50)	1.75(1.04)	2.90(1.46)
Distance of urban market from household home (km)	12.02(5.27)	11.85(5.36)	11.85(5.15)	12.10(5.12)	11.46 (6.32)	15(6)
Household head membership status in an organization/association (yes=1,no=0) (frequency)	Yes = 31% No = 69%	Yes = 32% No = 68%	Yes = 32% No = 68%	Yes = 29% No = 71%	Yes = 47% No = 53%	Yes = 17% No = 83%