Farm-level Adaptation to Climate Change in Western Bangladesh: An Analysis of Adaptation Dynamics, Profitability and Risks

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Abstract

Using long-term district-level climate data and a case study from a drought-prone village in western Bangladesh, this research explores trends in climate change, and analyses farmers' adaptation dynamics, profitability and risks. This is the first study of its kind for drought-prone areas in Bangladesh.

District-level temperature trended upwards across all seasons except in winter, while rainfall patterns were more episodic with persistent dry periods. Farmers' adaptation measures included changes in cropping systems, cropping calendar, crop varieties, agronomic practices, crop diversification and improved animal husbandry. Reducing environmental stress, ensuring self-sufficiency in staple crops (mainly rice) and other crop production practices, and enhancing economic viability of farm enterprises underpinned these adaptations. Off-farm and non-farm wage employment, temporary migration, self-employment and educating children, constituted core non-farm adaptation strategies.

Emerging cropping systems like maize/cucumber and maize/stem amaranth/rice were economically more viable than the traditional rice/rice and rice/maize systems. Despite some uncertainties, farming was preferred to off-farm work, generating higher returns to labour for all cropping systems. Limited access to stress-tolerant varieties, extension services and affordable agricultural credit, combined with high production costs, variability in crop yields and output prices constituted man barriers to adaptation. Stronger agricultural research and support services, affordable credit, community-focussed farming education and training are critically important for effective adaptation to climate change.

Keywords: Climate change, Drought severity, Farm budgeting, Risk analysis, Adaptation dynamics, Sustainability.

JEL Classification: O1, Q0, Q2, Q12, Q25

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1. Introduction

Bangladesh is one of the most vulnerable countries to climate risks because of its geophysical setting, and variability and projected future changes in climate (Yu et al., 2010; Ruane et al., 2013). Bangladesh is a highly densely populated low-lying agrarian country. Agriculture is the foundation of the economy, contributing more than 17.22% to the Gross Domestic Product (GDP), 5.4% to the export earnings and the employment of 45.6% of the total workforce (BBS, 2014a). The mean cropping intensity for Bangladesh is 190%, with rice being the staple crop, covering about 79% of net-cultivated area and being grown in three seasons a year (BBS, 2014b). However, risks from climate change to agriculture stand out as most critical production constraint among the long list of potential impacts (Yu et al., 2010; Ruane et al., 2013). The key vulnerabilities of Bangladesh and its agriculture include warming temperatures, changing rainfall patterns and associated prolonged and frequent dry periods, floods, sea level rise, frequent coastal cyclones and storm surges, lack of irrigation water, changes in groundwater aquifers and salinity levels (Yu et al., 2010; Ruane et al., 2013; WB, 2013). IPCC (2014) has predicted that the adverse impacts of climate change on agriculture in a country like Bangladesh were likely to be intense, uncertain and unprecedentedly devastating.

Overuse, degradation and changes in resource quality (e.g., soils) will intensify population pressure on an already declining area of arable land per capita and scarce water resources (Alauddin and Sharma, 2013; Yu et al., 2010). Drought is one of the extreme weather events that adversely affects agriculture and rural livelihoods in western and north-western Bangladesh (Shahid and Behrawan, 2008; Alamgir et al., 2015). Droughts result from a decrease in seasonal rainfall, delayed and premature ends to the wet-seasons, and regional extreme heat that exhausts water bodies and soil moisture through increased evaporation (WB, 2013). Increasing seasonal or year round water scarcity is a potential threat to food security, environmental quality, and overall livelihoods in many parts of South Asia, including Bangladesh (Alauddin and Sharma, 2013). Climate change may further aggravate water scarcity (Vaidya et al., 2014). Adaptation to these risks is critically important to ensure food security, reduce poverty and sustain economic growth (Ruane et al., 2013).

Although major countrywide droughts in Bangladesh usually occur about every 5 years, localised droughts occur more frequently. In the past, droughts have affected about 47% of the area and 53% of population of Bangladesh (FAO, 2006). Severe droughts affect Bangladesh, on average, every three years. A severe drought in 1973 caused local famine conditions in 1974 (Habiba et al. 2010). Droughts in 1978 and 1979 affected about

42% of the total cropped area, reducing rice production by about 2 million tonnes, while a drought in 1997 caused a reduction of about one million tonnes in food-grain production (of which about 0.6 million tonnes was wet-season rice) (Baas and Ramasamy, 2008, p.1).

Bangladesh's vulnerability to climate change risk has increased national and international awareness (Ruane et al., 2013). Bangladesh has adopted some effective disaster response systems and strategies, including the development of flooding, drought and salinity tolerant crop varieties, cyclone shelters, embankments, early warning and preparedness, and security of freshwater availability (Huq et al., 2004; Yu et al., 2010). However, mainstreaming climate change adaptation as a public policymaking processes is critically important (Alauddin and Sarker, 2014). Location and sector specific analysis of risks and vulnerabilities is a *sine qua non* for prioritising needs and appropriate adaptation options (IPCC, 2014). Therefore, understanding local perspectives, farm-level adaptation and risk management strategies are critically important for supporting smallholder farmers in climate vulnerable countries (Burke and Lobell, 2010; Anderson et al., 2014; Wright et al., 2014).

A significant body of literature has addressed climate change adaptation in drought-prone areas in Africa (Mertz et al., 2009; Stringer et al., 2009; Deressa et al., 2011; Fosu-Mensah et al., 2012; Gandure et al., 2013; Shackleton et al., 2015), Australia (Wheeler et al., 2013) and Canada (Bradshaw et al., 2004). Research on farm-level adaptation practices and constraints in Bangladesh has focused on the salinity prone south-western coastal region (Khan et al., 2014; Vivekananda et al., 2014) and drought prone areas in the north-western region (FAO, 2006; Ahmed and Chowdhury, 2006; Habiba et al.,2012; Alauddin and Sarker, 2014; Hassan et al., 2014; Alam, 2015). Using the discrete choice model Deressa et al. (2011), Alauddin and Sarker (2014) and Alam (2015) have defined the factors that facilitate adaptation. Key findings of the studies included the adoption of different stress tolerant crop varieties, crop management practices, livelihood diversification and migration, in response to climate change. Human resources (education-level and family size), physical resources (land endowment), financial resources (credit and farm income) and social capital (markets and institutional support) mainly influence adaptation decisions. A lack of access to services, physical and financial capital, and adverse environmental conditions, impede adaptation.

Recent studies (Alauddin and Sarker, 2014; Alam, 2015) have underscored the critical importance of identifying adaptation strategies for informed policy formulation. The analysis of long-term climate trends and anomalies in the means and extremes in rainfall and temperatures that test farmers' perceptions of climatic change, have received inadequate attention. The existing literature also has paid inadequate attention, not only to the evolving process of farm-level adaptation in a historical context, but also to the rigorous analysis of risks and economic viability of existing cropping systems, despite the fact that profitability and risk-return trade-off critically influence farming adaptation and production decisions (Dillon, 2003). In addition, different communities face different levels of vulnerability according to adaptive capacity, physiographic features, and economic and socio-cultural constraints. These issues underscore the need to investigate location-specific adaptation options (IPCC, 2014).

Most previous studies have relied mainly on household surveys (Deressa et al., 2011; Habiba et al., 2012; Alauddin and Sarker, 2014; Alam, 2015) and focus group discussions (FGD) (FAO, 2006; Ahmed and Chowdhury, 2006; Baas and Ramasamy, 2008). In contrast, this study investigates contemporary phenomenon, including the complex relationships involving the biophysical environment and farming adaptation within a real-life context (Yin, 2009). Information collated from key informants in a drought-prone village (Durgapur) in Damurhuda Upazilla sub-district in Chuadanga district, in western Bangladesh (Figure 1) form the empirical basis of this study. Using an anthropological approach, it analyses farmers' adaptation dynamics, profitability and risks of cropping systems and barriers to adaptation. It also explores trends in climate change based on long-term district-level climate data. Section 2 discusses the methodology of data collection and the analytical framework, while Section 3 presents empirical results based on the analysis of secondary data, farmers' adaptation strategies to climate and environmental changes, along with the drivers and constraints to adaptation, and an assessment of economic viability of major cropping systems using profitability and risk analysis. Section 4 presents the discussion, conclusions and implications of the study. This is the first study of its kind for drought-prone areas in western Bangladesh[1].

[1] Kabir et al., (2016) undertook a similar study in salinity prone areas in coastal Bangladesh.

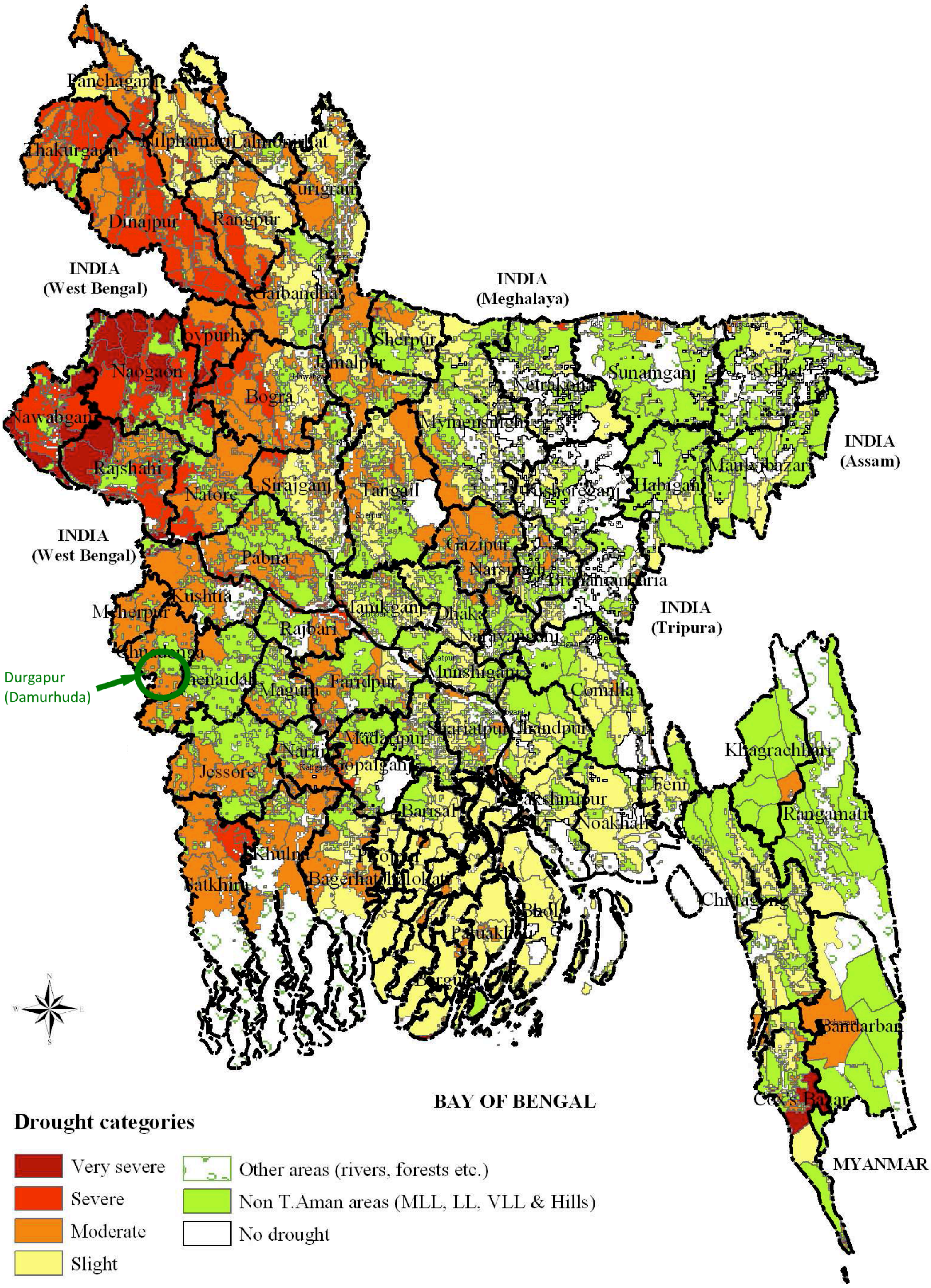


Figure 1: Drought map of Bangladesh (approximate location of study area circled).

Source: Adapted from http: //www.foodsecurityatlas.org/bgd/country/vulnerability/riskanalysis-files/Drought-Map.JPG/view

2. Data and Analytical Framework

2.1 Secondary data

Long-term (1948 to 2013) daily climate data (maximum, minimum and mean temperature and mean rainfall) for the Chuadanga District Climate Station were available from the Bangladesh Meteorological Department. The Statistical and Regional Dynamical Downscaling of Extremes (STARDEX) extremes indices software package (Haylock and Goodess, 2004) was applied to detect trends in both rainfall and temperature means and extremes. Trends and anomalies were analysed using the 1960-1990 base period, and to make comparisons of farmers' perceptions of recent changes in climatic conditions. Using Kendall's τ test, the study identified 118 temperature and rainfall trends across seasonal and annual timeframes: December to February (DJF), March to May (MAM), June to August (JJA) and September to November (SON).

2.2 Primary data collection, analysis and validation

The study village of Durgapur was selected, partly to allow a comparison with an earlier study that examined technology-environment-employment linkages of the village (Alauddin et al., 1995). While the arable area of the village is intensively used for rice and non-rice cropping systems, it is markedly affected by climatic (drought) and environmental stresses (declining groundwater table as aquifers are not fully charged due to inadequate rainfall even during the monsoon and increased incidence of pests) and market uncertainty. Alauddin and Sharma (2013) reported that increasing dependence on groundwater for irrigation in north-west part of Bangladesh has led to significant decrease the groundwater tables. In addition, the area lacks ready access to extension services due to its location (about 10 km from the sub-district headquarters). The village is located in a drought-prone agro-ecological zone (AEZ-11, dominated by medium to high topography. The long-term (1981-2010) mean annual rainfall of Chuadanga of 1,460 mm is about half the national average rainfall of 2,661 mm for Bangladesh. Mean monthly maximum temperature for the period April to September for the district is between 1 and 3 °C above the national average (BBS, 2014a).

Fieldwork took place in June 2014 and included a village census, transect walks, farmers' group discussions (FGD) and case studies with key informants in the village. The fieldwork commenced with a village census that captured the basic socio-demographic features of the village. This was followed by three FGDs with 5-7 highly experienced and knowledgeable farmers belonging to 50-65 age group of each farm household type (owners, owner cum tenants, and tenants), and six case studies (two for each farm type). The group interviews used semi-structured checklists, mostly with open-ended questions, for collecting data on farmers' perceptions of climate and environmental changes and adaptation strategies. The case studies involved face-to-face interviews with each key informant based on a pre-tested semi-structured questionnaire, generated farm-level data on input and labour-use patterns, yields, input and output prices, and seasonal variability of yields and prices of major crops. The collected data and farm budget were validated by the key informants after preliminary analysis of the data. The key informants confirmed the collected data, and recognized the farm budget as representative but suggested some minor modification in the data and budget which were adjusted accordingly.

2.3 Costs and returns for farm enterprises

Herdt (1978) distinguished between the "paid-out cost" of purchased inputs and the "unpaid cost" of family supplied inputs, including labour and returns, as "gross income" (gross benefit less paid-out costs) and "net income" (gross income less unpaid costs of family supplied inputs), respectively. Farmers used for farm enterprises purchased and home supplied inputs, hired and family labour, owned and rented-in land and machinery. Actual payments (cash and in-kind) for purchased inputs (seed, fertilizer, pesticides and fuel), rental for leased-in land, hired labour and farm machinery, accounted for total paid-out costs. In addition, the unpaid costs take account of the opportunity cost of family supplied inputs (family labour, land, farm machinery and seed) constituted the total imputed cost (TIC). Total costs (TC) comprise TPC plus TIC.

Following Dillon and Hardaker (1993), the value of produced output (main produce and by-products) of farm enterprises at actual farm gate prices, together with any in-kind gifts, have been included as gross benefits (GB). Gross income (GI) of farm enterprises equals GB less TPC, while net income (NI) amounts to GI less TIC. Gross income of family labour was derived as the ratio of GI per ha to the number of work-days of family labour per ha for each enterprise, as it represented the return to family labour relative to a benchmark wage (Kabir et al., 2016).

2.4 Risk analysis

Agricultural activities are exposed to various degrees of external risks arising from (weather and environment) and market uncertainties (Chavas et al., 2010). Enterprise budgeting is a fixed-point estimate of a farm's financial performance, where there is a limited scope of assessing implications of such uncertain events (Lien, 2003). Therefore, this study used stochastic simulation for assessing the implications of uncertain events associated with major cropping systems to examine their economic viability.

Scenario analysis used farmers' perceived typical, best and worst-case yields and prices. The best-case yield represented the favourable weather condition yield, while the worst-case yield typified that under unfavourable weather conditions. However, the study excluded extreme case situations (when productivity decreased by more than 60% according to farmers' perceptions) of crop damage because of natural calamities (droughts and cyclones) as a worst-case scenario. It employed @RISK (add-in version-6.2) with Microsoft Excel for constructing stochastic budgets via Monte Carlo simulation. The study employed triangular distribution, representing cumulative probability distribution as the variables are continuous (Hardaker et al., 2004) with 10,000 iterations to simulate each farm budget to ensure stability of the distribution (Lien, 2003).

Stochastic dominance analysis was carried out to evaluate risk-return trade-off by comparing the probability of relative risks associated with the outcomes of the alternatives through cumulative probability distributions (Anderson and Dillion, 1992; Dillon and Hardaker, 1993). The cumulative probability distribution function (CDF) of a first-degree stockhastically dominant (FSD) curve must not lie to the left of a dominated curve. The CDF of a second-degree stochastically dominant (SSD) curve lies more to the right in terms of differences in areas between a dominated curve. FSD indicated farmers preferred more income to less, while SSD indicated farmers' preference for less to more variablity between two income earning options (Anderson et al., 1988).

3. Results

3.1 Socio-demographic and physiographic features

The village census revealed 272 households with a population of 1,197 people, an average family size of 4.4 people and a 1.09:1 male - female ratio. On average about 84% of households comprised of farming families, while about 16% were landless labourers. Nearly half the farming families were owner farmers, , 39% were owner-cum tenant farmers while 12% were pure tenant farmers (landless). Most farmers were semi-subsistence in orientation with a mean farm size of 0.47 ha (Table 1). Although farming was a major occupation of nearly two thirds of the farm families, about 69% of farm families undertake off-farm work and various non-farm self-employment activities to sustain their livelihoods. Alauddin et al (1995) reported that farming was the major occupation of over 80% of farming families in the village, revealing a changing occupation pattern over time.

A cemented road connects the village with urban centres, including the district headquarter and beyond. The village is connected to the national electricity grid. Nearly 50% of houses werebuildings, 40% of which were brick with corrugated tin/terracotta roofs, 9% had mud walls with aluminium sheet roofs, and 1% had bamboo/jute stick walls with aluminium sheet/rice straw roofs. Nearly 90% of the land area in the village was arable reflecting high agricultural intensity.

Table 1: Farm-type based on land ownership in the study village

Farmer categories	Number	% of farmers	Farm size (ha)			
			Mean	Max	Min	SD
Owner	112	49	0.49	2.00	0.03	0.40
Owner cum-tenant	89	39	0.50	1.87	0.07	0.35
Tenant	28	12	0.29	1.34	0.07	0.30
Total	229	100	0.47	2.00	0.03	0.37

Source: Village census, 2014; SD standard deviation

Topographically about 55% of the arable land of the village is medium to high land (≤ 90 cm flooding depth) and 30% was medium to low (90-180 cm flooding depth). Only 10% is lowland (>180-300 cm flooding depth) while the remaining 5% is highland (above the normal flood-level) (BBS 2014a). The medium-high and highland areas have sandy loam soils, while the medium-low and lowland areas have sandy clay soils.

3.2 Climate trends

Figure 2 illustrates significant climate trends (p <.05), while Table 2 summarises supporting climate data. There appears to be a strong warming trend across all seasons except in the dry winter season (DJF). The trends in rainfall exhibit much greater seasonal variability, with declines in heavy rainfall during December-May, but with an increasing trend during September-November. The analysis also reveals that mean maximum temperatures have increased by 1°C during the pre-wet (MAM), and post-wet (SON) seasons, but have warmed by almost 2°C during the wet (JJA) period. Some declines in DJF mean maximum temperatures have also been observed. The increase in both the mean diurnal temperature and extreme diurnal temperature ranges indicates that the rate of warming in terms of maximum temperatures was higher than for minimum temperatures.

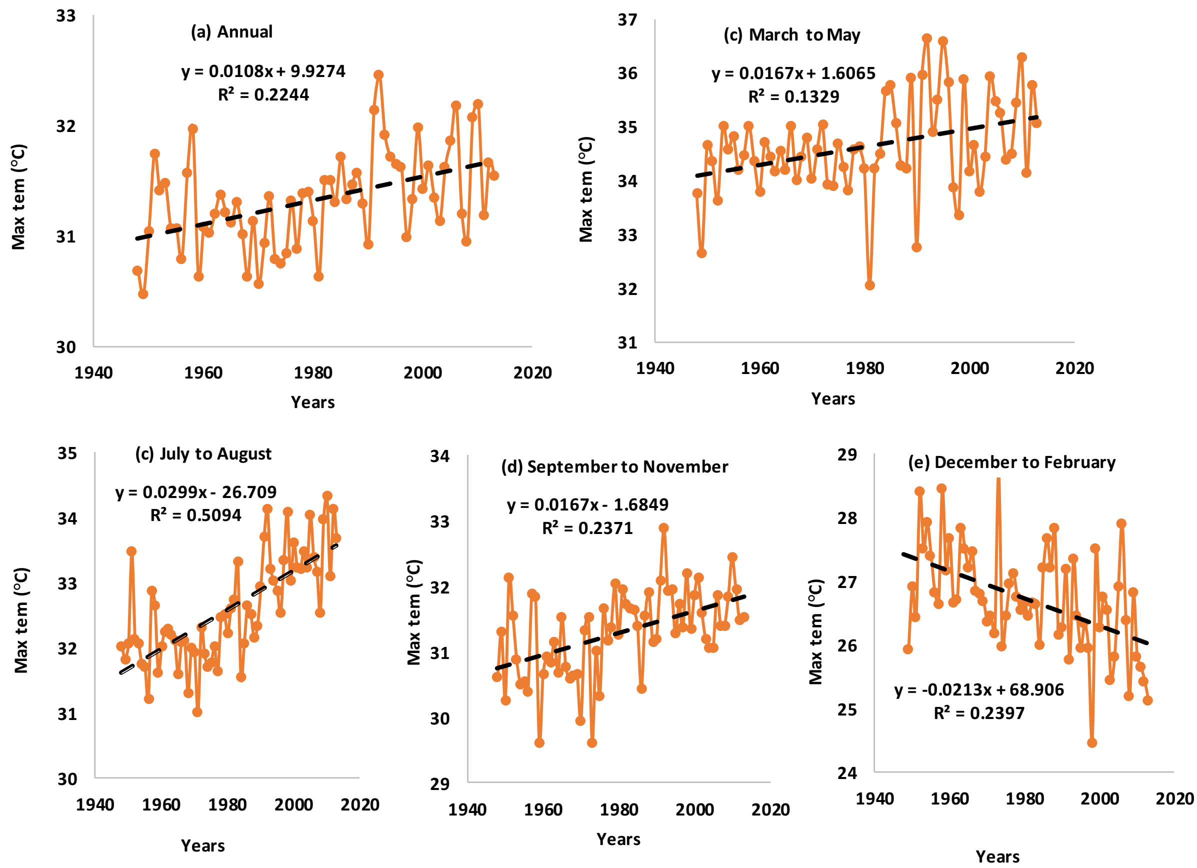


Figure 2**:** Significant trends (p <.05) of maximum temperature of annual and seasonal of Khulna.

The trend analysis reveals consistent declines in heavy rainfall events (i.e. rainfall above 80th, 90th and 95th percentiles) particularly across the March to May period, but highlights increases in heavy rainfall events (i.e., daily rainfall (mm/day) above 40th, 50th, 60th and 80th percentiles, and greatest 3, 5, 10 day totals) during September-November. For DJF, the variability in rainfall has increased for the period 1948 to 2013, with dry spell persistence, mean dry spell length and the standard deviation of wet spell lengths, all increasing. This suggests that more episodic rainfall patterns with persistent dry periods have become more typical in this location. The information illustrated in Figure 3 suggests that the proportion of days with temperatures above the long-term 90th percentile has significantly increased from about 1.7% in 1960, to 19-24% by 2013. However, the most critical changes have taken place during the wet-season (JJA), for which this trend has increased from 1-5% to approximately 35% over the same period. During the DJF, this trend has shown a decline from 15% to approximately 8% between the two points in time (Figure 3). This is coupled with an increase in the proportion of days where the maximum temperature was below the 1960 to 1990 at 10th percentile threshold, with also being a decline in the proportion of days when the maximum temperature was above the 90th percentile.

3.3 Farmers' perceptions of climate and environmental changes

The researchers recorded farmers' perceptions about changes in climate (temperature, precipitation and drought) and local environment (soil quality, ground water aquifer and pests) over the past 20 years. Farmers mentioned that, on average, the temperature has risen but with the greatest changes being in the early wet season (EWS) and wet season (WS). They perceived that the duration of winter has declined but experienced increased foggy days and intense cold for a shorter period in the dry season (DJF). The informants emphasised that substantial changes have taken place in the rainfall pattern over the past two decades, with a decline in the number of rainy days and total rainfall, but an increase in the incidence of drought during the three main cropping seasons (DS, EWS and WS). The incidence of untimely torrential rainfall was also reported to have become more frequent. Farmers believed that temperatures have increased concurrently with the decrease in rainfall over the past two decades. Farmers' perceptions appeared consistent with trends and anomalies in the both rainfall and temperature means and extremes based on the analysis of secondary data.

Farmers reported that soil fertility has been on the decline due to cultivation of highly nutrient extractive hybrid variety crops (maize and EWS rice and DS rice), poor fertilizer management and increased erosion of the sandy loam soil in response to torrential rainfall. In addition, farmers stated that the groundwater aquifer had been declining due to drought/reduced rainfall and over extraction of water for dry-season irrigated cropping. Crop pest infestations were also reported to have increased in response to the increased drought. The decline in soil fertility, reduced access to irrigation water and bio-diversity are regarded as critical environmental changes in the rural Bangladesh (Alauddin and Hossain, 2001).

Table 2: Significant linear trends (p < .05) of each climate index for each season for the Chuadanga climate station (base years 1960-1990).

Variable	DJF	MAM	JJA	SON	ANN
Mean Tmax	-0.021	0.017	0.030	0.017	0.011
Mean Tmin			0.010	0.008	0.006
Mean Tmean			0.020	0.013	0.009
Mean diurnal temperature range	-0.027	0.014	0.020		
10th percentile diurnal temperature range	-0.034	0.019	0.013	0.013	0.017
90th percentile diurnal temperature range	-0.027		0.022		-0.017
Tmax 10th percentile	-0.045		0.023	0.015	-0.011
Tmax 90th percentile	-0.022	0.038	0.034	0.020	0.023
Tmin 10th percentile			0.015	0.024	0.008
Tmin 90th percentile			0.009	0.006	0.007
Intra-annual extreme temperature range		0.067	0.042		0.082
90th Percentile Heat Wave Duration	-0.034	0.117	0.105	0.076	0.125
Cold Wave Duration			-0.022		
% days Tmax < 10th percentile	0.003		-0.001	-0.001	
% days Tmax > 90th percentile	-0.001	0.004	0.006	0.003	0.003
% days Tmin < 10th percentile			-0.001	-0.001	-0.001
% days Tmin > 90th percentile			0.001		
40th percentile of rainday amounts (mm/day)				0.044	
50th percentile of rainday amounts (mm/day)				0.076	0.026
60th percentile of rainday amounts (mm/day)		0.062		0.107	
80th percentile of rainday amounts (mm/day)				0.223	
Fraction of total precipitation above annual 20th percentile				0.001	
Fraction of total precipitation above annual 80th percentile		-0.003			
Fraction of total precipitation above annual 90th percentile		-0.002			
Fraction of total precipitation above annual 95th percentile		-0.002			
No. of days precip >= 10mm				0.052	
Max no. consecutive dry days	0.012				
Mean dry-day persistence	0.000		0.001		
Median wet spell lengths (days)			0.010		-0.006
Standard deviation wet spell lengths (days)	0.005				
Mean dry spell lengths (days)			-0.003		
Greatest 3-day total rainfall				1.138	
Greatest 5-day total rainfall				1.475	
Greatest 10-day total rainfall				1.901	
Simple Daily Intensity (rain per rainday)				0.088	

Note: DJF= December-February, MAM= March-May, JJA=June-August, SON=September-November and ANN= Annual

3.4 Farmers' adaptation perspectives

This section analyses farmers' adaptation strategies, based on information about the changes they have made in their overall farming systems and other livelihood activities, with a focus on the last two decades. It also seeks to identify key drivers of, and barriers to adaptation, and risks associated with farming.

3.4.1 Farming adaptation strategies

The evolving cropping patterns summarised in Table 3 illustrate how Durgapur farmers have been adapting to climate and environmental changes over the last four decades (1975 – 2014). During 1975-1985, farmers would mainly cultivate low yield potential, early wet season (WS) broadcast rice (30-40% of total arable area) and transplanted wet-season rice (20-25% of total arable area), mainly to meet family subsistence needs. The informants noted that many male members, including farmers, would migrate seasonally, even to India, as most farm families had an annual food deficit for 3-4 months. However, food security improved since the mid-1990s due to increased cultivation of WS rice (from 25% to 40%), cultivation of DS rice (*Boro* rice), in response to the adoption of green revolution technologies, including the use of modern varieties (MV) of rice and wheat, chemical fertilizers, pesticides and power pumps which allowed greater frequency of cropping within a calendar year. This contrasts with a low cropping intensity of 117% (far below the national average of 150.9%) during 1990-91, when the areas under WS rice, EWS and DS rice were about 25%, about 20% and about 3%, respectively (Alauddin et al., 1995; Alauddin and Hossain, 2001).

Farmers mentioned that food security and off-farm employment opportunities had improved considerably since the beginning of the new millennium, due mainly to the rapid adoption of DS high-yielding rice varieties (being planted on about 40% of total arable land after 2003, from < 10% during 1985-1995). However, farmers have experienced increased seasonal variability of crop productivity (rice and non-rice crops) since the 1990s, due mainly to increased incidence of harsher weather events and environmental stress. Farmers reported having made significant changes in land use patterns, cropping systems and crop management, based on available resources, during the past 10-15 years (Table 3).

Table 3: Evolution of cropping patterns (P), 1975-2014

Cropping Pattern (P)	Wet-season (WS)	Dry-season (DS)	Early wet-season (EWS)	% of Area
1975-1985				
P1	Fallow	Fallow	LV B. Rice	30-40
P2	LV T. Rice	Fallow	Fallow	20-25
P2	Fallow	Pulses/Oilseeds	Jute	15-20
P3	Sugarcane	Sugarcane	Sugarcane	5-10
P6	MV T. Rice	Fallow	Fallow	2-5
1985-1995				
P1	Fallow	Fallow	LV B. Rice	20-25
P2	MV T. Rice	Fallow	Fallow	10-25
P3	Fallow-	Pulses/Oilseeds	Jute	10-15
P4	LV T. Rice	Fallow	Jute	8-10
P5	Sugarcane	Sugarcane	Sugarcane	7-10
P6	Fallow	MV T. Rice	Fallow	2-10
P7	Fallow	Wheat	LV B. Rice	2-5
1995-2005				
P1	MV T. Rice	MV T. Rice	Fallow	18-20
P2	LV T. Rice	MV T. Rice	Fallow	8-10
P3	Fallow	Pulses/Oilseeds	Jute	15-20
P4	LV T. Rice	Wheat	Jute	12-20
P5	Sugarcane	Sugarcane	Sugarcane	7-10
P6	Fallow	MV T. Rice	Fallow	7-10
P7	Fallow	Fallow	LV B. Rice	5-10
2005-2014				
P1	MV T. Rice	MV T. Rice	Fallow	28-32
P2	Fallow	Hybrid maize	Hybrid T. Rice	22-25
P3	Fallow	Hybrid maize	Jute	18-20
P4	MV T. Rice	Hybrid T. Rice	Fallow	5-8
P5	Fallow	Hybrid maize	Hybrid cucumber	3-5
P6		Hybrid maize	Stem amaranth Hybrid T. Rice	3-5
P7	Fallow	Wheat	Vegetables	1-3
P8	Fallow	Vegetables	Vegetables	1-2

Source: Farmers' group discussion, 2014.
Notes: WS and EWS crops are rainfed and DS crops are irrigated. MV: Modern Variety, LV: Local Variety, T: Transplanted, B: Broadcast

Durgapur farmers have made some practical adjustments to arable land use and to cropping patterns based on their own farming experience since 2005. The information contained in Table 3 suggests that the following changes occurred:

1. Rice/rice based cropping usedonly 40% of total arable area. Highest rice yields were achieved on the clay-loam soils in the area due to the higher water holding capacity of these soils. However, 60% of

the arable land was not used for WS rice cultivation, due to the predominance of sandy loam soils which have low water holding capacity (Atwell et al., 1999).

2. Early-planted hybrid maize cultivation in the DS used 55% of total arable area (medium and high sandy loam soils). Maize gives significantly higher returns, is stress tolerant (drought and pests) and requires less irrigation than rice.

3. Farmers used about 25% of total arable area (land not suitable for WS rice) for delayed planting of EWS rice cultivation. Partially irrigated hybrid EWS rice is substantially less irrigation-intensive than DS rice and gives higher yields than most adopted inbred DS rice varieties.

4. Jute (the main cash crop) covered ≤15% of net-cropped area in the EWS, despite substantial problems with post-harvest processing of the crop due to high labour intensity and lack of access to waterbodies for retting. Farmers noted that the biomass of jute enhances soil fertility for the following season's crop which often results in improved yields.

5. Finally, farmers allocated 5-7% of the arable area for cultivation of various high value crops including vegetables.

Changes in crop planting time (early and delayed sowings), in combination with supplementary irrigation, fertilizers and pesticides, were some of the cropping innovations in the study village. EWS rice was transplanted on the fields over a month after the optimum planting time (late April-early May). Reaping the benefits of wet-season rainfall and growing crops under reduced stress conditions (no drought/storms) underpinned the change in planting dates. Farmers noted that delayed planting date did not impact on total system productivity, as the area remains fallow in the WS and does not affect EWS rice production, as the rice varieties are not photoperiod sensitive (BRRI, 2016).

Key informants indicated that, despite the possibility of low temperature crop damage (stunted growth of rice seedlings and plants), DS rice transplanting took place during mid-December to mid-January. Because delaying transplanting increased irrigation costs and chances of yield loss due to water stress and natural calamities at critical crop growth stages e.g., panicle initiation stage. Each farmer rented small areas in the large area of marshland for their rice nurseries. The seedlings grown in these areas are healthy and less affected by cold injury and produce better yields.

The planting date for maize crops has advanced from late December-January to early October. Because delaying the planting date increases irrigation costs and the chances of low grain yields due to drought, with resulting low grain prices if harvested after EWS rains. The planting time for cucumber was more flexible, around the Muslim fasting month of Ramadan when it falls. The crop was planted about a month in advance of Ramadan for harvesting when its price peaks due to high demand. Likewise, despite higher potential pest infestation in the early-planted vegetables, farmers planted winter vegetables a month earlier to take advantage of higher prices.

Conversely, it was noted that current frequency of supplementary irrigation numbered 10 - 15 to rainfed WS rice to adapt to climate change. They also increased irrigation applications to the dry-season rice, maize and other vegetables, to reduce potential yield losses due to water stress. Farmers even apply 4-7 supplementary irrigations to jute crops, and pump groundwater into the ponds and canals for retting jute. They also apply higher rates of fertilizers and pesticides to reduce the potential effects of environmental stresses (low soil fertility and pests) on their crops.

Key informants reported that farmers adopted relatively stress tolerant crops and varieties, reflecting due consideration of climate change risks, the local environment and the availability of improved technologies (particularly improved varieties). An exogenous (Indian) modern rice variety (*Swarna)* was widely adopted (grown in 85% of the WS rice cultivated area), as it was more drought and pest tolerant than other available rice varieties. In addition, a short duration rice variety (*BRRI dhan28*) replaced other rice varieties (*BRRI dhan29* and hybrid rice) in the DS because of its longer duration, despie higher yield potential. Although an EWS inbred rice variety (*BRRI dhan48*) produces good yields and attracts high prices in local markets, farmers have continued to cultivate a hybrid rice in EWS due to a lack of seed availability of the inbreed variety. Farmers cultivated hybrid maize and cucumber as they produce better yields. Farmers cultivated exogenous varieties of jute due to ready availability of seed at affordable prices from across the Indian border.

The village census revealed that there were 19 small power tractors in the village, while about 40% of farmers had diesel/electricity operated small-scale irrigation equipment. Farmers had 3-5 bore sites for their pumps due to fragmentation of the crop fields. In addition, some farmers jointly purchased large power pumps and established deep tube-wells (DTW) for irrigation. The informants stated that the irrigation pumps and Chinese tractors facilitated agricultural intensification and increased crop production by reducing the risk of crop failure.

About 62% of farmers reared cross breed/hybrid variety beef cattle and 72% reared goats to increase their incomes. The mean cattle number per household was 1.2 but ranged from 1 to 4, while mean goat number per household was 1.6 and ranged from 1 to 8. Farmers usually buy young cattle or goats at low price and then sell them at a higher price after 1 or 2 years, usually at the time when Muslims slaughter animals in religious rituals. The key informants mentioned that cattle number decreased from 7-15 per households in 1990-2000 to 1-4 per household in 2014. This was in part due to of lack of grazing land for cattle due to increase cropping intensity and in part because of commenced rearing cross breed/hybrid variety beef cattle which gave higher return but required intensive care instead of local breed milking cow. In addition, large and medium farmers would rear livestock during 1990-2000, while, currently small farmers and even landless labourers also rear livestock.

Farmers grew vegetables in their household yards for both home consumption and for the market. They also grew stress tolerant root crops, such as turmeric and ginger, in their backyard. The mean home garden size of respondents was 0.04 ha, but ranges from 0.01 to 0.41 ha. About 62% of farmers have small mango orchards, along with some timber trees (teak and mahogany) and bamboo, to provide building materials and savings.

3.4.2 Non-farm adaptation strategies

Table 4 summarises the non-farm adaptation strategies relating to self-employment activities of respondents in the case study village. Farmer ascertained drivers for non-farm adaptation strategies included the following: (i) farm income was inadequate for family and farm expenses; (ii) paying weekly instalments of NGO sourced loans (most farmers borrow from NGOs); and (iii) uncertainty of returns from farm enterprises. Thus, most farmers (tenants and owner-cum tenants) worked as off-farm wage labourers in the village, with between 10 and 15% were temporarily migrating to other areas, including urban areas, for additional income. The men generally engage in off-farm work in the morning (6-6.5 hours/day), but in the afternoon, they engage in on-farm work and/or collect grass for their cattle from crop field bunds, or engage in other non-farm self-employment activities.

About 24% of total farm families engaged in small business to reduce their dependency on agriculture, or to increase their incomes for better livelihoods (Table 4). Large landowners rented out part of their land and commenced small businesses, while growing small areas of crops to meet family subsistence needs. Due to high uncertainty of farm returns and , higher reliance on hired labour, the younger generation preferred business to agriculture as their occupation. Despite the lack of financial resources, most farmers send their children to school/college to provide an education for better life prospects.

Table 4: Adaptation for income generation through non-farm self-employment activities

Self-employment activities	**Farm families (number)**	**% of total farm families**
Labouring work in village	157	69
Making handicrafts	117	51
Petty trading	54	24
Temporary migration for work	38	17
Hired out power pump	23	10
Hired out power tractor	21	9
Drives a motorised van	12	5
Hired out draught power	9	4
Employed in salaried job	9	4
Drives a transport van	4	2

Source: Village census, 2014

The respondents noted that women did not take part in intercultural activities of crops in fields or worked as off-farm wage labourers due to socio-religious norms/customs but extensively contributed in the post-harvest processing activities of the crops. However, village census data revealed that nearly half of the farm family women made embroidered quilts (*Nakshi Kantha*) and earned nearly BDT 1,500-2,500/month for their families, in addition to their contribution to regular domestic work. Some farmers also hired out farm machinery (power pumps, threshers and tractors) to generate a cash income. Small farmers hired out draught power for levelling the crop fields.

3.4.3 Risks, barriers to adaptation and suggested measures to reduce risks

Farmers' perceptions of risks and barriers to farming were based on their responses to questions on: (a) factors contributing significantly to variability of farm productivity and profitability; and (b) constraints to farmers' adaptation strategies. Furthermore, farmers' views on reducing risks and minimising constraints to adaptation were also sought.

Farmers identified weather events (increased incidence and intensity of droughts, untimely excessive rainfall and erratic rainfall patterns, variability in temperatures and foggy weather), as most critical constraints to farming by contributing to seasonal variability of crop yields and increased irrigation costs. The factors also contributed to the deterioration of groundwater aquifers, increased soil moisture stress, pest infestation and soil erosion. Despite applying increased irrigation and pesticide application, farmers were unable to control crop damage because of droughts and insect pest damage during the crop cycle. In addition, excessive rainfall and hailstorms during the reproductive stage of crop development severely affected crop productivity and profitability.

Farmers also regarded uncertain demand for and prices of major cash crops (maize, cucumber and stem amaranth), together with a low demand and price of hybrid rice, to be critically important risks to farming in the case study village. Respondents noted that farmers receive low produce prices, with intermediaries largely influenced farm gate prices of commodities due to the lack of a program for guaranteeing access to farm output prices. Besides, they lacked an ability to store produce (money and storage facilities) and the ability to take marketing risks (transportation costs and transportation losses). Farmers did not have facilities to dry maize before sale, or to monitor the grain moisture content at a level appropriate for wholesale marketing, due to lack of moisture meters. Demand for other important cash crops (e.g. cucumbers) decreases in response to hot weather conditions and rainfall during harvesting.

Key informants emphasised that a combination of a lack of access to adaptation strategies (e.g., seed of stress tolerant inbred crop varieties), extension services and information about appropriate adaptation measures, were key barriers to adaptation. Although farmers received some extension support from informal extension providers, like traders, and formal sources such as NGOs, they often lacked confidence in them due mainly to their concerns about their motives (particularly of traders). It was felt that sometimes traders were not scrupulous in their dealings with farmer producers, particularly in relation to the provision of improved inputs (seed and fertilizer).

Farmers identified high cost of production as a barrier to technology adoption. Hybrid cash crops (e.g., cucumber, maize and stem amaranth) entail high input costs. They are very labour intensive. High price of seed (both imported and indigenous), increasing irrigation costs because of drought/rising temperatures, low soil water holding capacity and high fuel price militate against their cultivation. Farmers also stated their lack of ready access to soft agricultural credit. They mainly borrowed money from NGOs and commercial banks at high interest rates. Very rigid conditionality of weekly instalments for NGOs and a highly bureaucratic nature of the banking operations, make the system less enabling for the farmers.

Farmers asked for policy support for the development and dissemination of abiotic (drought, cold and excessive rainfall) and biotic (insects and pests) stress tolerant rice and non-rice crops, to reduce farming risks. Easier access to guaranteed prices of farm commodities and soft agriculture credit when needed, were also indicated as having the potential to significantly reduce farming risks and enhance adaptation capabilities. Most informants stated that improved access to extension services (farmer training on newly developed technologies, and farmer field visits to provide advice) and information about farming adaptation strategies also have the potential to reduce production barriers.

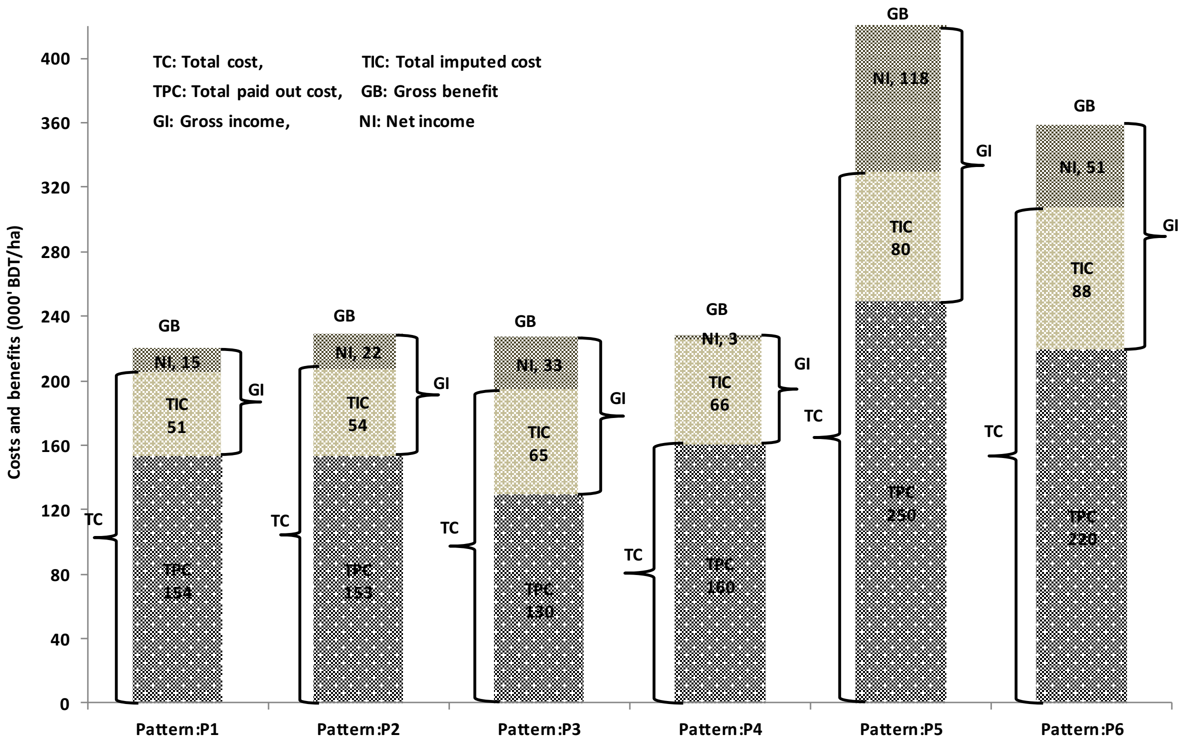
3.5 Economic viability of cropping systems

3.5.1 Profitability analysis

Representative enterprise budgets were developed for the six main currently practised cropping patterns (Table 5) based on typical seasonal crop yields, input use patterns, and current (2013-2014) input and output prices. Figure 3 presents the profitability scenarios of the six major cropping patterns in Durgapur. It appears that rice-rice based cropping patterns (P1) gave a significantly lower per hectare gross income (GI) (1.1-3.0 times) and net income (NI) (1.4-7.7 times) than that of other cropping patterns (P2, P3, P5 and P6), but was practised in the about 40% of NCA of the village (Table 5). Partly because of the need to achieve food self-sufficiency based on rice, and partly due to the lack of availability of cropping options for some the areas of the village and rice culture was an important farming goal in a social context.

Likewise, the maize/EWS rice system (P2) which covers about 25% of the NCA, gave the lowest returns among the maize based cropping system (P2, P3, P5 and P6), due mainly to low price of hybrid paddy rice. Conversely, P5 (Fallow/ maize/cucumber) gave substantially higher returns per unit area of land (GI/ha and NI/ha) but was practiced on a relatively small area. Farmers highlighted that the high production costs and market uncertainties for cucumber as impeding the large-scale adoption of this production system. Another system P6 (maize/stem amaranth/rice) rgenerated second higher returns per hectare (Figure 3) but was not widely adopted due to a lack of suitable land and market uncertainty for stem amaranth.

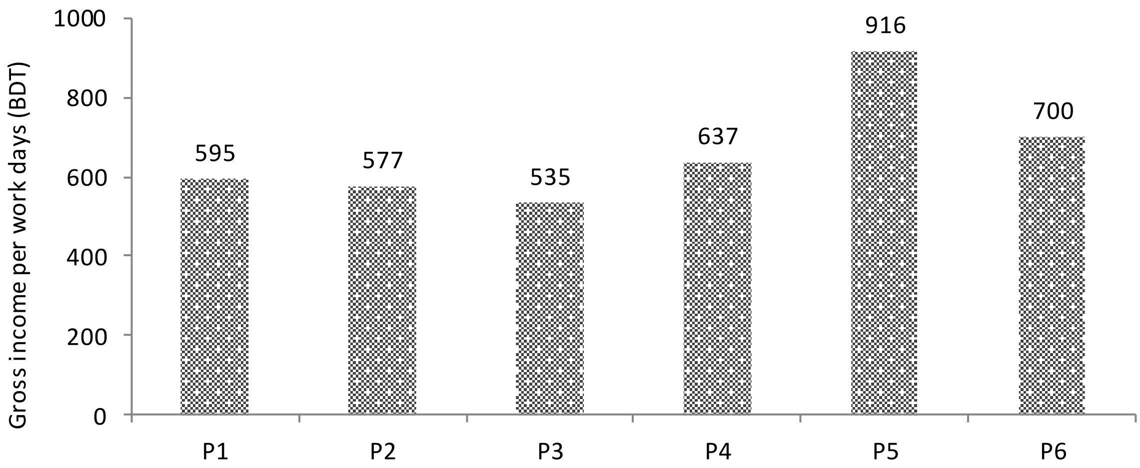
Figure 3 also shows that the cropping systems P5 (fallow/maize/cucumber) and P6 (maize/stem amaranth/rice) incurred much higher per hectare production costs (both TPC and TIC) than the other cropping patterns, but this high cost was offset by the higher gross benefits, particularly from cucumber in P5 and stem amaranth in P6. The 70:30 of TPC to TIC of the cropping systems reflects the farmers' reliance on purchased inputs.



(P1: Rice/rice/fallow, P2: Fallow/maize/rice, P3: Fallow/hybrid rice/fallow, P4: Rice/hybrid rice/fallow, P5: Fallow/maize/cucumber and P6: maize/stem amaranth/rice)

Figure 2: Comparative profitability of cropping patterns in Durgapur

Figure 4 illustrates that the gross income per work-day for family labour for the major cropping patterns was more than double the local off-farm wages (BDT 250/work-day) and significantly higher than the wage rate (BDT 350/work-day) in the nearest urban centres. This finding of the enterprise budget indicates that farming is a better livelihood option than labouring work, which is consistent with socio-demographic features of the village (most smallholder farmers and some landless labourers leased in land for farming activities).



(P1: Rice/rice/fallow, P2: Fallow/maize/rice, P3: Fallow/hybrid rice/fallow, P4: Rice/hybrid rice/fallow, P5: Fallow/maize/cucumber and P6: maize/stem amaranth/rice).

Figure 3: Gross income per workday for family labour within the main cropping patterns

3.5.2 Risk analysis

The results of enterprise budgets presented in Figures 3 and 4 indicate that two minor cropping systems (P5 and P6) generated much higher returns to family resources on per hectare and per-work day basis. However, the key informants highlighted that the financial returns of most cropping systems are highly volatile. In part because of both abiotic stresses (drought and excessive rain) and biotic stresses (pests and disease) affect productivity and in part because of highly uncertain demand of farm produces in particular for cash crops (maize, cucumber, stem amaranth and jute) affect farm gate price highly. Hence, a risk analysis was carried out for the major cropping systems based on farmers' perceptions of variability in crop yields and prices (Table 5).

Table 5: Seasonal variability of yields and prices of major crops

Crop	Yield (t/ha)			Price (BDT/t)		
	High	Typical	Low	High	Typical	Low
WS rice	5.4	4.5	3.1	20,000	18,000	16,250
DS rice (MV)	5.9	5.4	4.5	22,500	20,500	18,000
DS rice (hybrid)	8.1	6.9	5.4	17,500	16,750	14,500
EWS rice	6.5	6	4.1	18,000	17,000	15,500
Maize	10.50	8.9	6.50	16,250	15,000	12,500
Jute	3.59	2.9	2.69	26,250	24,500	21,250
Stem amaranth	33.90	25.9	16.90	8,000	5,000	3,000
Cucumber	45.5	32	25.00	15,000	10,000	6,000

Source: Case study, 2014.

Figure 4 presents the cumulative probability distributions (CDFs) of net income on per hectare basis for the major cropping patterns. Not surprisingly that two cash crop-based system, maize/cucumber system showed first-degree stochastic dominance (FSD) over all other systems, as the CDF of the system lies to the right of all other systems' CDFs., The three crop-based systems (maize/stem amaranth/EWS rice) showed second-degree stochastic dominance (SSD) over the other systems (rice/rice, EWS rice/maize and maize/jute). The CDF of the system lies to the right in more areas of even the CDFs of the maize/jute cropping system. Maize/jute system shows dominance (FSD) over other systems (EWS rice/maize and rice/rice) as the CDF of the system lies fully to the right of other CDFs.

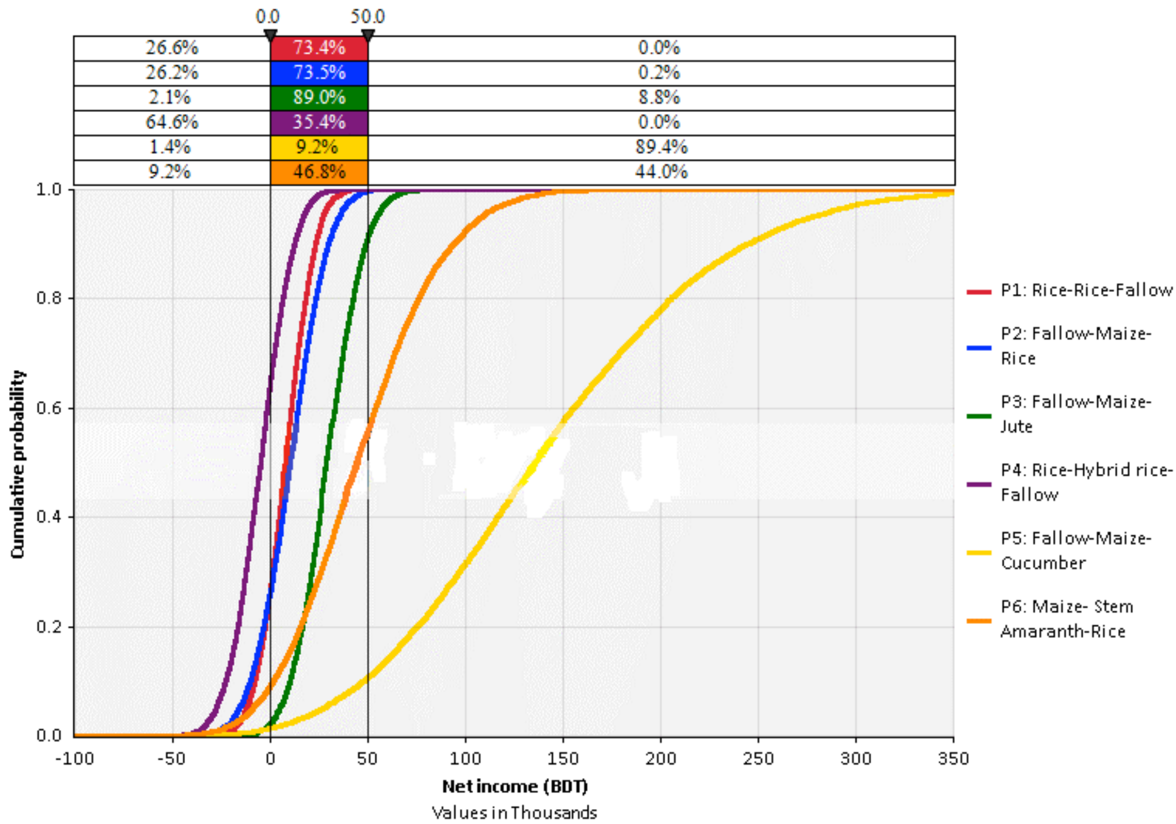


Figure 4: Cumulative probability distribution of net income of major cropping systems in Durgapur

Figure 5 presents the cumulative probability distributions (CDFs) of gross income per workday of family labour for the major cropping systems of Durgapur. The lowest benchmark is the urban wage rate and the upper benchmark is based on daily income from self-employment activities (e.g. power operated van driving). Similarly, the maize/cucumber system showed FSD over other systems and the maize/stem amaranth/EWS rice system showed SSD over other systems. However, the rice/rice based system (P4) reversed its ranking and showed SSD dominance over the maize/jute and other systems. However, the most important finding of the risk analysis is that most cropping systems have at at least 90% chance of GI/work-days being higher than the urban wage rate.

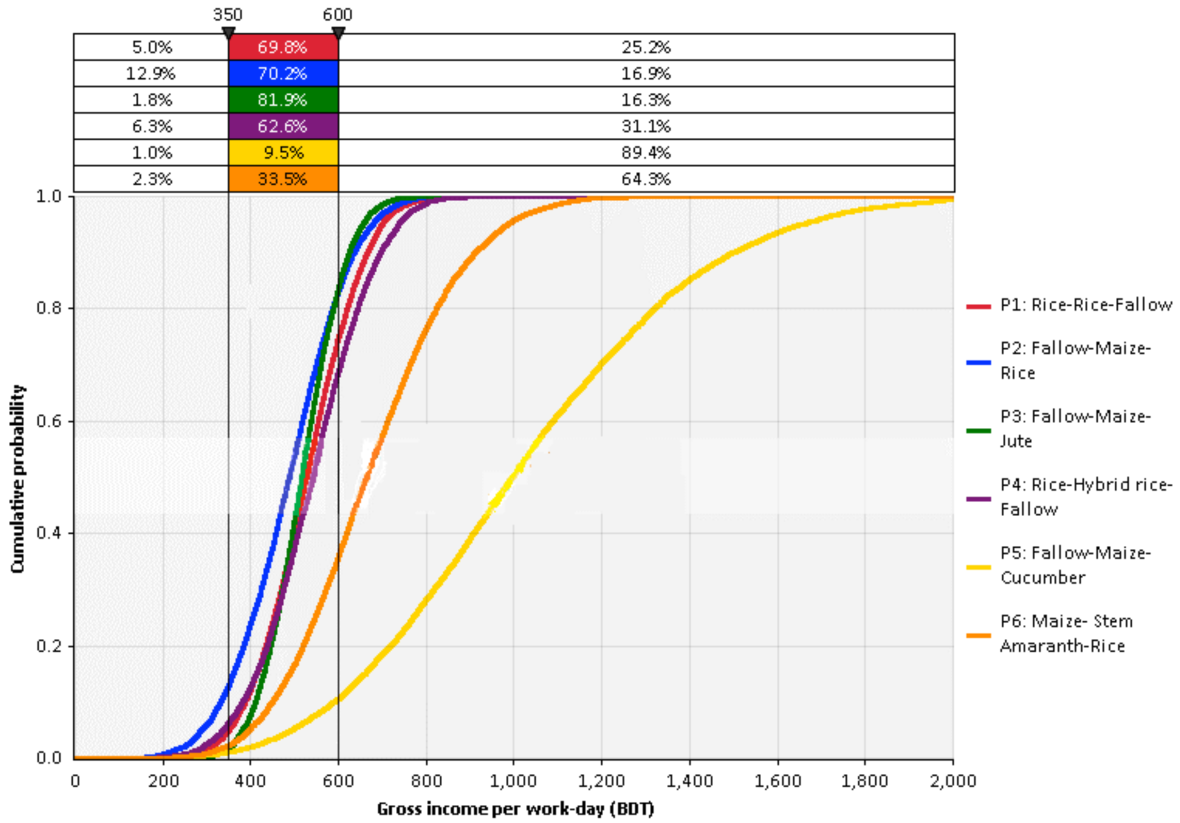


Figure 5: Probability distribution of gross income per workday for family labour of major cropping systems in Durgapur

4. Discussion

The findings of this study appear to be consistent with a number of studies in Bangladesh and elsewhere. However, in some cases dissimilarities can also be observed. Farmers in the study village perceived climate change which was consistent with trend of district climate record, and increase in environmental stress in a somewhat similar way to the scenario portrayed in earlier studies in north-western Bangladesh (Habiba et al., 2012; Thomas et al., 2013; Alauddin and Sarker, 2014). The mean maximum temperatures have increased by 1°C during the pre-wet (MAM), and post-wet (SON) seasons, but have increased by almost 2°C during the wet (JJA) period for the district. Nishat and Mukherjee (2013) reported increasing surface air temperatures in the range 0.4–0.65 °C over the past 40-years in the western part of Bangladesh, making this region vulnerable to soil moisture stress.

Farmers in the study area perceived climate uncertainty as most critical risk to farming, potentially affecting both the productivity and profitability of farm enterprises. This was similar to the findings of Shahid and Behrawan (2008) for north-western Bangladesh as well as to those reported by Shackleton et al. (2015) for sub-Saharan Africa. Farmers stated market uncertainty (demand and prices) as second most critical risk for farming in the case-study village. Ali and Kapoor (2008) reported a similar finding in the context of the Indian state of Uttar Pradesh. However, this is somewhat different from the Mexican scenario where low commodity prices were of greater concern to farmers than extreme weather events (Tucker et al., 2010).

Farming adaptation strategies in the village included changes in cropping systems and land use patterns. Among the changes the use of more stress tolerant and less irrigation intensive crops, the adoption of new crop cultivars (high yielding, short duration and stress tolerant) and crop diversification (growing high value cash crops), subject to the suitability of the land (physiography and soil texture), weather and availability of resources (technologies) were the major. Lowland areas were used for rice crops (WS and DS), while elevated areas were used for less irrigation intensive rice (EWS) and diversified non-rice crops (maize, jute, cucumber and various seasonal vegetables), and highland areas were used for mixed agroforestry systems. Changes in crop varieties (short duration/drought tolerant cultivars), types of crops (non-rice crops), alternate uses of land (mango orchards instead of rice) and crops diversification, were common adaptive strategies reported in other drought-prone areas of Bangladesh (Ahmed and Chowdhury, 2006; FAO, 2006; Habiba et al., 2012; Alauddin and Sarker, 2014).

Changes in the cropping calendar (advanced and delayed planting dates) in order to avoid the potential impacts of extreme weather events (drought and heavy rainfall) on farming and reduce irrigation costs through reaping the benefits of natural rainfall underpinned motivation for the farming adaptation options in Durgapur. Moreover, changes in crop management, including increased use of fertilizers, pesticides and irrigation, and supplementary irrigation of rained crops, were among the key agronomic adaptation strategies to reduce seasonal variability of crop yields in the village. These strategies have been supported by earlier research (Thomas et al., 2013; Alauddin and Sarker, 2014) that identified changes crop planting dates, increased irrigation/supplementary irrigation and fertilizer application, as key farming adaptation strategies in the drought-prone and groundwater-depleted areas of Bangladesh.

In addition, small-scale farm mechanization (owned/hired SWT, DTW, powered tractors and trolleys) was also an important adaptation measure in the case village that also contributed to reduce the effects of climatic and environmental stress. Similarly, harvesting water in ponds, canals and mini-ponds for irrigation use, and exploitation of other water resources (deep tube-wells, STW and rivers) were common adaptive options in the drought prone areas in northwest Bangladesh (Ahmed and Chowdhury, 2006; FAO, 2006; Habiba et al., 2012). Improved home yard cropping, mainly for family subsistence and rearing beef cattle (cattle and goats) to increase cash income were very common adaptive options in Durgapur. Other studies (Ahmed and Chowdhury, 2006; FAO, 2006; Habiba et al., 2012; Kabir et al., 2016) have also reported that homestead gardens and fish cultivation in mini-ponds were common adaptive strategies in other drought prone areas of Bangladesh. It was also the case that some farmers (large landowners) reduced their farm size by leasing part of their land, and commenced small business as farming remains highly uncertain in stress prone (drought and flood affected areas) village.

Most farmers also adopted non-farm adaptive strategies, including undertaking labouring work in the village, temporary migration in the lean season of cropping, various non-farm self-employment activities (making handicrafts, petty trading, hiring out of powered farm machinery, draught animals and driving engine/push vans) to improve their incomes and household livelihoods as farm income is often inadequate to sustain livelihoods for many farm families. Most farmers received NGO credit mainly for farming related activities (rental of land to increase farm size and purchase of calves for rearing).These were similar to those in the drought prone areas of north-west Bangladesh (Ahmed and Chowdhury, 2006).

Lack of adequate access to stress tolerant (drought, pest and disease) crop varieties, uncertainty of the price of farm commodities, inadequate extension services and the related lack of information about appropriate adaptation measures, and inadequate access to soft credit were the commonly reported barriers to adaptation in Durgapur. High production costs due to the high price of seed, fuel and fertilizer, and increased irrigation costs because of change climate, and limited access to ensured quality inputs (seed and fertilizer) also impeded adoption. Similar, constraints have also been reported as adaptation barriers in drought prone regions of Africa (Bryan et al., 2009; Deressa et al., 2009). Low literacy and underdeveloped markets, high opportunity costs of infrastructural development and poor governance have generally militated against farm-level adaptation to climate change (Wright et al., 2014).

Both the rice/rice and rice/maize systems were practised on about 65% of the total arable land in Durgapur, as achieving self-sufficiency in the staple food, rice, was the key goal of semi-subsistence farming. Between the two rice/rice systems (P1 and P4) the inbred modern rice variety based system (P1) was cultivated in nearly 80% of total DS rice cultivated area of Durgapur, as the system provided a somewhat higher return to land due to market for this variety of rice was better as they tasted better and shorter maturity time (thereby reducing irrigation costs and having less chance of being affected by EWS rain). Incorporation of the variability in yield and price in the risk analysis revealed that maize/cucumber system was not only the most profitable but was also less risky than other systems due to a recent adjustment in the crop management (switching the planting date of maize early, and cucumber when its demand in the market is very high). The early planting of maize also facilitates its avoidance of potential adverse impact of drought/rising temperature and heavy rain/storms in the EWS (harvesting of the corn takes place before the start of the EWS rain). In relation to cucumber, in addition to the demand, it also commands a high price if harvested during Ramadan.

Farmers in the study village preferred strong public policy support for ensuring access to appropriate technologies (variety/management), extension services (training/information), guaranteed prices, quality inputs and soft credit. Government investment in agricultural research and development were critically important to enable farmers to adapt to climate change (Burke and Lobell, 2010; Alauddin and Sarker, 2014; Kabir et al., 2016).

5. Concluding Remarks

Over the past two decades, farmers have been experiencing increasingly negative adverse effects on agricultural production and livelihoods due to environmental stress and market uncertainty. Many farmers have taken various farm and non-farm adaptation initiatives in an attempt to reduce the potential effects of adverse weather events and environmental stresses, to improve their food security, increase profitability and farm incomes as a basis for improving their wellbeing. Under current practices, emerging maize/cucumber and maize/stem amaranth/rice systems were economically more viable (higher returns and less risky) than traditional rice/rice and even rice/maize cropping systems. However, the profitability of cash crops (maize, cucumber and stem amaranth) was sensitive to both markets and climatic/environmental stresses, while the traditional rice/rice system was less prone to market impact. Despite the uncertainty, farming was the preferred adaptation option to non-farm labouring work, as the potential return to labour of the cropping systems was much higher than even the urban wage rates. A lack of stress tolerant crop varieties and a lack of access to modern technologies and extension services, were the key barriers to agricultural adaptation. High production costs, volatility of prices of farm outputs and a lack of soft credit, were also the adoption constraints. Increased investment is needed on research for the development of improved production technologies (including improved crop varieties) and extension services for the dissemination of the technologies to smallholder farmers as well, together with appropriate policy measures for improving price stability of agricultural products, quality of inputs and access to credit.

References

Ahmed, A. K., & Chowdhury, E. H. (2006). Study on Livelihood Systems Assessment, Vulnerable Groups Profiling and Livelihood Adaptation to Climate Hazard and Long-term Climate Change in Drought-prone Areas of NW Bangladesh, Final Report. Food and Agriculture Organization of the United Nations (FAO), Rome and Department of Agricultural Extension, Dhaka, Bangladesh.

Alam, K. (2015). Farmers' adaptation to water scarcity in drought-prone environments: A case study of Rajshahi District, Bangladesh. *Agricultural Water Management, 148*, 196-206.

Alamgir, M., Shahid, S., Hazarika, M. K., Nashrrullah, S., Harun, S. B., & Shamsudin, S. (2015). Analysis of meteorological drought pattern during different climatic and cropping seasons in Bangladesh. JAWRA Journal of the American Water Resources Association, *51*(3), 794–806.

Alauddin, M., & Hossain, M. (2001). Environment and Agriculture in a Developing Economy: Problems and Prospects for Bangladesh. Edward Elgar, Aldershot, UK.

Alauddin, M., Mujeri, M. K., & Tisdell, C. A. (1995). Technology- environment- employment linkages and the rural poor of Bangladesh: Insights from farm-level data. In: I. Ahmed, & J. A. Doeleman (Eds.), *Beyond Rio: The Environmental Crisis and Sustainable Livelihoods in the Third World*. London: Macmillan, pp.221-255.

Alauddin, M & Sharma, B.R. (2013). Inter-district rice water productivity differences in Bangladesh: An empirical exploration and implications. *Ecological Economics, 93*, 210-218.

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

Ali, J., & Kapoor, S. (2008). Farmers' perception on risks in fruits and vegetables production: an empirical study of Uttar Pradesh. *Agricultural Economics Research Review, 21*, 317-326.

Anderson, J. R., & Dillion, J. L. (1992). *Risk Analysis in Dryland Farming Systems*. Food and Agriculture Organization of the United Nations (FAO), Rome.

Anderson, J. R., Dillon, J. L., & Hardaker, J. B. (1988). *Agricultural Decision Analysis* (Third ed.) Ames: Iowa State University Press.

Anderson, S., Sharma, V., Hesse, C., Pattison, J., & Orindi, V. (2014). Supporting local climate adaptation planning and implementation through local governance and decentralised finance provision. *Development in Practice, 24*(4), 579-590.

Atwell, B. J., Kriedemann, P. E., & Turnbull, C. G. N. (1999). *Plants in Action: Adaptation in Nature, Performance in Cultivation*. South Yarra, Vic: Macmillan Education Australia.

Baas, S., & Ramasamy, S. (2008). *Community Based Adaptation in Action: A case study from Bangladesh* (Project Summary Report (Phase I) Improved Adaptive Capacity to Climate Change for Sustainable Livelihoods in the Agriculture Sector). FAO, Rome: Environment and Natural Resources Service Series, Food and Agriculture Organization of the United Nations (FAO), Rome and Department of Agricultural Extension, Dhaka, Bangladesh.

BBS (2014a). *Statistical Yearbook of Bangladesh 2012*: Bangladesh Bureau of Statistics, Dhaka.

BBS (2014b). *Yearbook of Agricultural Statistics of Bangladesh 2012*: Bangladesh Bureau of Statistics, Dhaka.

Bradshaw, B., Dolan, H., & Smit, B. (2004). Farm-level adaptation to climatic variability and change: Crop diversification in the Canadian prairies. *Climatic Change, 67*(1), 119-14.

BRRI (2016). *Adhunik Dhaner Chash* (Modern Rice Cultivation), Bangladesh Rice Research Institute, Gazipur, Bangladesh.

Bryan, E, Deressa, TT, Gbetibouo, GA & Ringler, C. (2009). Adaptation to climate change in Ethiopia and South Africa: options and constraints. *Environmental Science and Policy*, *12*(4), 413-26.

Burke, M., & Lobell, D. (2010). Food security and adaptation to climate change: What do we know? *In:* Lobell, D. & Burke, M. (eds.) *Climate Change and Food Security: Adapting Agriculture to A Warmer World,* Advances in Global Change Research No. 37*.* New York: Springer Verlag.

Chavas, J.-P., Chambers, R. G. & Pope, R. D. (2010). Production economics and farm management: A century of contributions. *American Journal of Agricultural Economics, 92*(2), 356-375.

Deressa, T. T., Hassan, R. M., & Ringler, C. (2011). Perception of and adaptation to climate change by farmers in the Nile basin of Ethiopia. *Journal of Agricultural Science, 149*(1), 23-31.

Deressa, TT, Hassan, RM, Ringler, C, Alemu, T & Yesuf, M. (2009). Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global Environmental Change*, *19*(2), 248-255.

Dillon, C. R. (2003). A framework for economic analysis of cropping systems: Profitability, risk management, and resource allocation. *Journal of Crop Production, 9*(1-2), 409-432.

Dillon, J. L., & Hardaker, J. B. (1993). *Farm Management Research for Small Farmer Development*. Food and Agriculture Organization of the United Nations (FAO), Rome.

FAO (2006). *Livelihood Adaptation to Climate Variability and Change In Drought-Prone Areas of Bangladesh.* Improved Adaptive Capacity to Climate Change for Sustainable Livelihoods in the Agriculture Sector. Food and Agriculture Organization of the United Nations (FAO), Rome.

Fosu-Mensah, B. Y., Vlek, P. L. G., & MacCarthy, D. S. (2012). Farmers' perception and adaptation to climate change: A case study of Sekyedumase district in Ghana. *Environment, Development and Sustainability, 14*(4), 495-505.

Gandure, S., Walker, S., & Botha, J. J. (2013). Farmers' perceptions of adaptation to climate change and water stress in a South African rural community. *Environmental Development, 5*(1), 39-53.

Habiba, U., Shaw, R., & Takeuchi, Y. (2012). Farmer's perception and adaptation practices to cope with drought: Perspectives from Northwestern Bangladesh. *International Journal of Disaster Risk Reduction, 1*, 72-84.

Habiba, U., Takeuchi, Y., & Shaw, R. (2010). Overview of drought risk reduction approaches in Bangladesh. In *Climate Change Adaptation and Disaster Risk Reduction: Issues and Challenges* (Vol. 5, pp. 37-58).

Hardaker, J. B., Lien, G., & Huirne, R. B. M. (2004). *Coping with Risk in Agriculture*, Oxford CABI Publishing.

Hassan, A., Wahid, S., Shrestha, M. L., Rashid, M. A., Ahmed, T., Mazumder, A., et al. (2014). Climate change and water availability in the Ganges-Brahmaputra-Meghna basin: impact on local crop production and policy directives. In: *Research Insights on Climate and Water in the Hindu Kush Himalayas*, International Centre for Integrated Mountain Development, Nepal, pp. 97-108.

Haylock, M. R., & Goodess, C. M. (2004). Interannual variability of European extreme winter rainfall and links with mean large-scale circulation. *International Journal of Climatology, 24*, 759-779.

Herdt, R. W. (1978). Costs and returns for rice production. In: *Economic Consequences of The New Rice Technology*. Los Banos: International Rice Research Institute (IRRI), pp. 63-80

Huq, S., Reid, H., Konate, M., Rahman, A., Sokona, Y., & Crick, F. (2004). Mainstreaming adaptation to climate change in Least Developed Countries (LDCs). *Climate Policy, 4*(1), 25-43.

IPCC, 2014: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Kabir, MJ, Cramb, R, Alauddin, M & Roth, C. (2016). Farming adaptation to environmental change in coastal Bangladesh: shrimp culture versus crop diversification. *Environment, Development and Sustainability*, *18*(4), 1195-1216.

Khan, M. M. H., Bryceson, I., Kolivras, K. N., Faruque, F., Rahman, M. M., & Haque, U. (2014). Natural disasters and land-use/land-cover change in the southwest coastal areas of Bangladesh. *Regional Environmental Change, 15*(2), 241-250.

Lien, G. (2003). Assisting whole-farm decision-making through stochastic budgeting. *Agricultural Systems, 76*(2), 399-413.

Mertz, O., Mbow, C., Reenberg, A., & Diouf, A. (2009). Farmers' perceptions of climate change and agricultural adaptation strategies in rural Sahel. *Environmental Management, 43*(5), 804-816.

Nishat, A., & Mukherjee, N. (2013). Climate change impacts, scenario and vulnerability of Bangladesh. In: R. Shaw, F. Mallick, & A. Islam (Eds.), *Climate Change Adaptation Actions in Bangladesh,* Springer, Tokyo, Japan, pp. 15-41

Ruane, A. C., Major, D. C., Yu, W. H., Alam, M., Hussain, S. G., Khan, A. S., et al. (2013). Multi-factor impact analysis of agricultural production in Bangladesh with climate change. *Global Environmental Change, 23*(1), 338-350.

Shackleton, S., Ziervogel, G., Sallu, S., Gill, T., & Tschakert, P. (2015). Why is socially-just climate change adaptation in sub-Saharan Africa so challenging? A review of barriers identified from empirical cases. *Climate Change, 6*(3), 321-344.

Shahid, S., & Behrawan, H. (2008). Drought risk assessment in the western part of Bangladesh. *Natural Hazards, 46*(3), 391-413.

Stringer, L. C., Dyer, J. C., Reed, M. S., Dougill, A. J., Twyman, C., & Mkwambisi, D. (2009). Adaptations to climate change, drought and desertification: local insights to enhance policy in southern Africa. *Environmental Science and Policy, 12*(7), 748-765.

Thomas, T. S., Mainuddin, K., Chiang, C., Rahman, A., Haque, A., Islam, N., et al. (2013). *Agriculture And Adaptation in Bangladesh: Current and Projected Impacts af Climate Change.*International Food Policy Research Institute (IFPRI), Washington, DC, USA.

Tucker, C. M., Eakin, H., & Castellanos, E. J. (2010). Perceptions of risk and adaptation: Coffee producers, market shocks, and extreme weather in Central America and Mexico. *Global Environmental Change, 20*(1), 23-32.

Vaidya, R. A., Sharma, E., Karky, B. S., Kotru, R., Mool, P., Mukherji, A., Pradhan, N. A., Shrestha, A. B., Wahid, S., & Molden, D., (2014). Research insights on climate change and water resources management in the Hindukush Himalayas. In: *Research Insights on Climate and Water in the Hindu Kush Himalayas*, International Centre for Integrated Mountain Development, Kathmundu, Nepal, pp. 3-40

Vivekananda, J., Schilling, J., Mitra, S., & Pandey, N. (2014). On shrimp, salt and security: livelihood risks and responses in South Bangladesh and East India. *Environment, Development and Sustainability, 16*(6), 1141-1161.

WB (2011). Population Projection Tables by Country and Group. Health, Nutrition and Population (HNP) statistics, The World Bank Group, http://go.worldbank.org/KZHE1CQFA0.

WB (2013). *Turn Down the Heat: Climate Extremes, Regional Impacts, and the Case for Resilience*. Postdam Institute for Climate Imapcts Research and Climate Analysis*,* World Bank, Washington DC, USA.

Wheeler, S., Zuo, A., & Bjornlund, H. (2013). Farmers' climate change beliefs and adaptation strategies for a water scarce future in Australia. *Global Environmental Change, 23*(2), 537-547.

Wright, H., Vermeulen, S., Laganda, G., Olupot, M., Ampaire, E., & Jat, M. L. (2014). Farmers, food and climate change: ensuring community-based adaptation is mainstreamed into agricultural programmes. *Climate and Development, 6*(4), 318-328.

Yin, R. K. (2009). *Case Study Research: Design and Methods* (Vol. 5.). Thousand Oaks, California: Sage Publications.

Yu, W., Alam, M., Hassan, A., Khan, A.S., Ruane, A.C., Rosenzweig, C., Major, D.C., Thurlow, J. (2010). Climate Change Risk and Food Security in Bangladesh. Earthscan, London.