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Sustaining groundwater irrigation for food security in the northwest region of Bangladesh: socioeconomics, livelihood and gender aspect

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Important disclaimer

SDIP's goal is increased water, food and energy security in South Asia to support climate resilient livelihoods and economic growth, benefiting the poor and vulnerable, particularly women and girls

Considerations of gender and social inclusion are embedded in all CSIRO SDIP projects. While this report considers gender explicitly, we have assumed that improved understanding of groundwater irrigation is of benefit to all, regardless of gender and other social factors. This assumption should be borne in mind when interpreting this report.

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EXECUTIVE SUMMARY

Bangladesh is one of the most densely populated countries in the world. Land is scarce to produce crops. Farmers use irrigation to grow crops year-round to meet increasing food demand. In the Northwest Region (NWR) of Bangladesh, known as the food bowl of the country, farmers depend on groundwater for dry season irrigation since both rainfall and surface water are scarce, particularly in the Barind areas. Key questions have been raised on how much groundwater is used and where, how rainfall recharges groundwater after irrigation, what are the costs of groundwater irrigation, what are the prevailing livelihood assets to pay for the irrigation, when women influence farming decisions in the rural household, how and when farmers adapt to climate change and what are the most beneficial cropping patterns.

A forward-looking research project titled 'Sustaining Groundwater Irrigation for Food Security in the Northwest Region of Bangladesh: Socioeconomics, Livelihood and Gender Aspects'' was initiated by CSIRO within its Sustainable Development Investment Portfolio research program to answer some of these questions crucial for sustaining groundwater use for growing crops and improving local livelihoods. As such it has 6 specific **objectives** to:

- identify optimal cropping patterns under prevailing water availability
- conduct cost-benefit analysis of dry season crops
- assess gender involvement in decision-making process in farm practices
- analyse livelihood conditions
- determine the dynamic behaviours of the aquifers
- enhance research capacity of the graduate students of Bangladesh Agricultural University.

To fulfil these objectives, primary and secondary data were collected from five major agricultural crop producing northwest districts: Rajshahi, Chapainawabganj, Bogura, Dinajpur and Nilphamari. Primary data were collected by 20 post-graduate students of Bangladesh Agriculture University (BAU) through survey administration. A total of 643 samples were collected from the selected five districts. Furthermore, a total of 120 samples were collected from the spouses to identify those perceptions that may be gender-related. Secondary data were collected from various governmental sources (BBS, BMDA, WARPO etc.). Statistical and econometric methods were used to analyse the data. Among different econometric models, non-linear optimization, logit regression, profitability analysis, Cobb-Douglas production function were used.

Key findings

Results of the study show that the production of non-rice crops is less profitable than production of all variety of rice crops. This finding partially explains the slow diversification of crop production observed over time in the study region.

The cropping choice optimization investigation illustrates that choice based on nutrition diversification could increase farm incomes and may help in poverty reduction.

According to the study women's growing involvement in farming is not adequately recognized by husbands. Men were uncomfortable to admit wives' influence on on-farm decisions due to prevailing social norms.

Another interesting finding is the impact of groundwater depletion on rural household's livelihood capitals. Remarkable inequality was found in five forms of livelihood assets directly related to groundwater availability, access, and institutions.

And finally, there is a significant difference in husbands' and spouses' perceptions about the severity of climatic change in high water scarcity and low water scarcity areas.

Findings generated through this comprehensive research can inform planners and policymakers to evaluate the different management options for crop choice and agricultural development in the region. They can help in preparing zone-specific customized rationing of more water consuming crops cultivation in the northwest region of Bangladesh. Study evidence might help with policy interventions to integrate gender into farming decision making in Bangladesh. To strengthen farmers' ability and resilience, the government might provide more incentives in severe water scarcity regions to make a balance of their livelihood status with other regions. Sound financial policy and supports will help farmers to adapt better to the changing world, in particular climate change.

CSIRO and BAU collaboration greatly helped post-graduate students to enhance their research capacity. Therefore, research collaboration is suggested for development of human capacity in Bangladesh.

ACRONYMS AND ABBREVIATIONS

TERM	DESCRIPTION
ADB	Asian Development Bank
ADF	Augmented Dickey–Fuller (test)
ADF	Augmented Dickey–Fuller test
AIC	Akaike information criterion
BADC	Bangladesh Agricultural Development Corporation
BARI	Bangladesh Agriculture Research Institute
BBS	Bangladesh Bureau of Statistics
BMDA	Barind Multipurpose Development Authority
BMDP	Barind Multipurpose Development Project
BRRI	Bangladesh Rice Research Institute
BWDB	Bangladesh Water Development Board
DAE	Department of Agriculture Extension
DAP	Di-ammonium Phosphate
DTW	Deep tubewell
FAO	Food and Agriculture Organization of the United Nations
FGD	Focus Group Discussion
GDP	Gross Domestic Product
HIES	Household Income and Expenditure Survey
HYV	High Yielding Variety
IFAD	International Fund for Agricultural Development
LDC	Least Developed Countries
MNL	Multinomial logit model
MP	Muriate of Potash
NWR	Northwest region
OLS	Ordinary least squares
OLS	Ordinary least square (regression)
PSU	Primary Sampling Unit
QR	Quantile regression
QR	Quantile regression
RDA	Rural Development Academy
RRR	Relative risk ratio
STW	Shallow tubewell
Tk.	Bangladeshi currency
TSP	Triple Super Phosphate

Chapter 1 INTRODUCTION

The CSIRO project 'Sustainable Development Investment Portfolio, Bangladesh' aims to define the sustainable level of water (particularly groundwater) use for irrigation and its impacts on the socio-economy and livelihood of the farmers (both men and women) in the northwest region of Bangladesh. A key element of the project is to examine the impact of future water availability on the irrigated agriculture, food security, regional socio-economy, livelihoods, and women and girls. This report is one of a series of reports from the project. The other works include groundwater trend analysis (Hodgson et al., 2021; Mojid et al., 2019), surface water and groundwater modelling (Janardhanan et al., 2021; Karim et al., 2021; Mojid et al., 2021a), water balance analysis (Mainuddin et al., 2021; Karim et al., 2021), and historical trends in land-use change and crop water requirements (Mojid et al., 2021b; Pena-Arancibia et al., 2020; 2021a,b).

Over the recent decades, Bangladesh made considerable achievements in agricultural development in terms of the overall production of agricultural products and intensification of the agricultural system. Agriculture has been growing tremendously with 2.6% annually in the last 50 years (World Development Indicators, 2019). While the contribution of the agricultural sector to the country's GDP has been steadily declining since the late 1970s, its value in absolute terms is rising. As such, albeit 4.2 times drop in contribution to the country's wealth, its dollar value jumped 3.2 times in the last half of the century (World Development Indicators, 2019). That remarkable development in agriculture let the country gain self-sufficiency in rice production (Mainuddin et al. 2015; Mainuddin et al. 2019). In addition, it is the main source of food supply for the ever-increasing urban population and plays a significant role in addressing the nation's poverty and food security challenges as a large part of the Bangladeshi population derives their livelihood income from agricultural activities.

The growth of agricultural production has resulted from a substantial intensification of agriculture rather than from increases in the land area available for cultivation. The overall cropping intensity for the country has increased from 149% in 1977 to 190% in 2012 with an increasing proportion of land being double- or triple- cropped (BBS, 2018). This growth in intensity was driven by increased cultivation during the dry season, made possible by the growing availability of irrigation (Mainuddin et al. 2019). Groundwater irrigation has been the most dramatic development in Bangladesh agriculture since the 1980s. Groundwater irrigation has contributed significantly to cereal production, mainly Boro rice and wheat, by supplementing soil moisture in the dry months of November/December to April/May (Haque et al. 2013).

Having a small land-person ratio (0.09 ha per person; SYB, 2018), a major focus was given to increase the coverage of cereal production area. Rice crop is the most important and hence dominant crop in Bangladesh. An astonishing 74% of the entire cropping area is under rice production (Beal et al. 2015). Three rice varieties are differentiated: Aman, Aus, and Boro. In addition to rice, non-rice crops as wheat, maize, potato, tomato, mustard, jute, and lentil are also grown in the dry season with irrigation. Because of this significant increase in production, agriculture has become a leading contributor to poverty reduction in Bangladesh since 2000 (World Bank, 2016; BBS, 2018).

The northwest region (NWR) of the country is considered as the food basket of Bangladesh as it provides more than one-third of the total country's rice production, more than half of its wheat production and more than two-thirds of its maize and potato production. Dry-season crops, such as Boro rice, wheat, maize, potato, pulses, and winter vegetables, are the main contributors to ensuring food security at household, regional, and national levels (Rahman, 2020). As a result, the region has the largest cultivable area and the most intensive groundwater use system.

In recent years, serious concerns have been raised about the sustainability of groundwater use especially in the Barind area of NWR (Shamsudduha *et al.* 2009, Shahid and Hazarika 2010, Kirby et al. 2016; Mojid et al. 2019; Peña-Arancibia et al. 2020). The groundwater level is gradually going down due to excessive use in irrigation, a declining trend in rainfall, less availability of water in the rivers in the dry season, change in land use characteristics and other reasons (Sumiya et al. 2016; Peña-Arancibia et al. 2020). Changes in a spatial-time series (1985–2016) of pre-monsoon and post-monsoon groundwater depths in NWR suggest that if the current level of groundwater use continues, groundwater level will continue to decline, posing a potential long-term threat to the sustainability of irrigated agriculture (Ahmad et al. 2014). This causes serious concerns to the policymakers as the country must increase food production for the growing population, requiring further intensification of crop production from a land area that is decreasing continuously due to urbanization and industrial development (Mainuddin et al. 2020). So, the sustainable management of groundwater resources is one of the essential objectives for the future food security of the country (Mende et al. 2007; Mainuddin and Kirby, 2015; Dey et al. 2017). As groundwater irrigation and food production are strongly linked, efficient groundwater management could bring multiple benefits for the farming community and improve farmers' livelihoods. To identify various levels of groundwater level decline during the dry season, three types of water stress in the study area have been identified. They are – 1) a high water scarcity area where groundwater level goes 10 m below the surface, 2) a medium water scarcity area with groundwater remaining within 7–10 m below the ground, and a low water scarcity area where groundwater stays at 5–6 m depth in the dry season (Mojid et al. 2019).

Water availability also influences the livelihood assets of the rural households in northwest Bangladesh. Economic progress particularly agricultural development brings changes in rural livelihoods. Hence, documentation of livelihood strategies under current condition in northwest Bangladesh is crucial for sustainable livelihoods. Like livelihoods, gender-based perception on adaptation strategies under water stress situation is equally important. Farm households require access to clean water for their livelihoods not only for domestic uses (drinking, washing, cooking and sanitation) but also for productive needs (crop farming, vegetable gardening, livestock, etc). Adequate availability of groundwater for these different needs can contribute to poverty alleviation (Smit, 2005).

In Bangladesh, there is a growing participation of women in farming. Female share in employment by major occupations shows that the highest contribution is from agriculture-related businesses, estimated at 49% in 2016–17 (LFS, 2018). Gender roles and norms in agriculture are changing (ADB, 2010) and enhancing women's involvement in agriculture is an important strategy for reducing poverty and improving food security. The National Agricultural Policy (2018) and National Strategy for Accelerated Poverty Reduction (2011) outline commitments to ensure women access to agricultural extension, productive resources, inputs, and services. It is argued that in absence of a spouse, women often provide all the farm labour, feed farm labourers, and frequently provide managerial input and advice. However, statistics do not tend to record the full range of farm work undertaken by women, and for this reason, women's involvement in farming is systematically under-reported. Since both women and men are involved in farming, there is a need to assess their respective participation and decision-making processes.

All these raise questions about the current and future state of the social and economic environment, provision of food security in face of declining availability of groundwater and ongoing climate change in Bangladesh, all of which could significantly impact and might already be impacting the sustainability of local livelihoods and gender role in the local society.

Chapter 2 STUDY AREA AND DATA MANAGEMENT

2.1 STUDY DESIGN

The study was taken in four steps (Figure 2-1):

1. The research proposal and specific objectives were finalized.
2. Evidence was gathered through survey and literature review. Both primary and secondary information was gathered through the surveys. Qualitative and quantitative tools were employed for primary data collection. The survey instrument was prepared, pre-tested and finalised. Then data were collected from different sources.
3. Collected data were edited, coded, categorized, sub-categorized and analysed to address the specific objectives. Data management details are described in section 2.3. Descriptive and inferential statistics were used to explain the research findings.
4. Finally, the inception report, annual report and final report are prepared. Twenty postgraduate students of Bangladesh Agriculture University (BAU) participated in this research. Fifteen theses have been published already while five are being finalised. Six journal articles have also been published as a significant output of this research work.

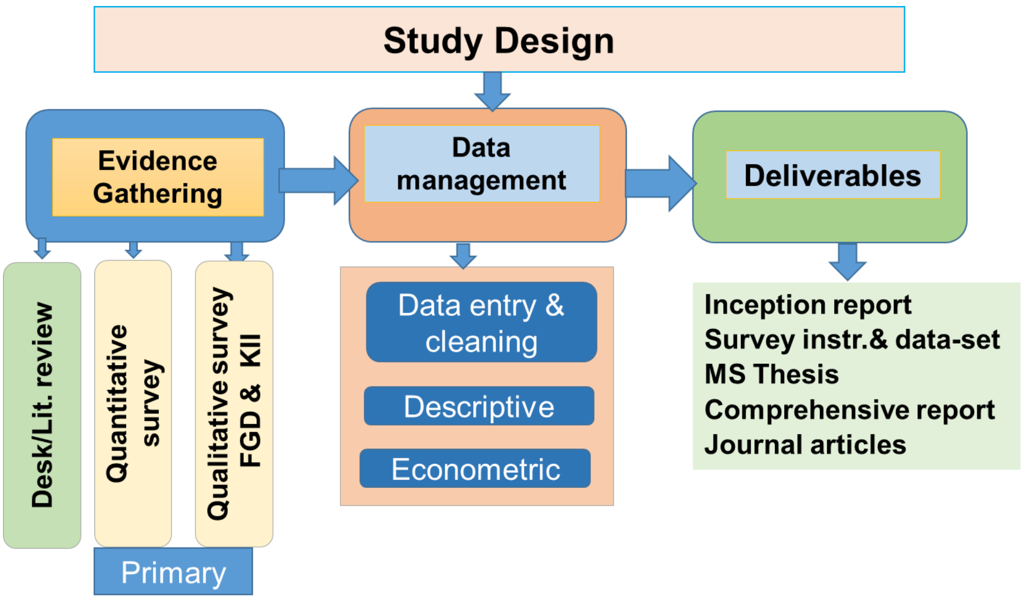


Figure 2-1 Study design

2.2 STUDY AREA

Five districts namely Rajshahi, Chapainawabganj, Bogura, Dinajpur and Nilphamari were chosen in this study (Figure 2-2). They represent different levels of water scarcity based on groundwater level declination during the dry season. Rajshahi and Chapainawabganj are high water scarcity area (groundwater level goes 10 m below the surface in the dry season). Bogura district is categorised as a medium water scarcity area (groundwater remain 7–10 m below the ground during the dry season). Dinajpur and Nilphamari districts are in low water scarcity area (groundwater is at 5–6 m depth in the dry season) (Mojid et al. 2019). The large decline in groundwater levels in the high water scarcity area characterises unsustainable groundwater use (Kirby et al. 2015). Conversely, other areas (such as Bogura, Dinajpur, Nilphamari) have only experienced moderate to low groundwater level declines (Dey et al. 2017). The major crops grown in these areas include rice, maize, wheat, potato, lentil crops and tomato.

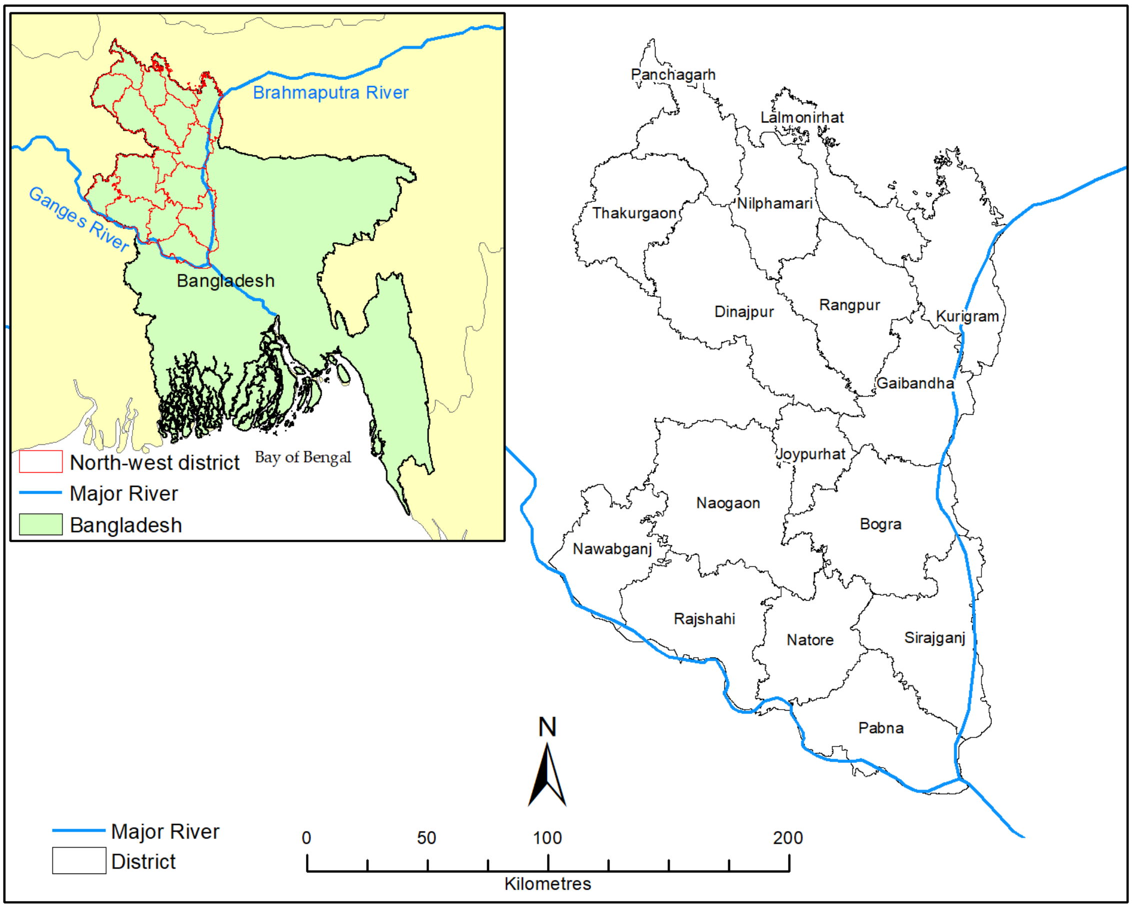


Figure 2-2 Map of study area showing districts and major rivers

2.3 SAMPLING TECHNIQUES

There is a greater homogeneity within the three water scarcity areas. Thus, clustered villages from each district were selected with the help of Department of Agriculture Extension personnel. One clustered village from each district were selected except Bogura district where two clustered villages were selected. Thus, a total of 6 clustered villages were selected from six sub-districts under five districts (Figure 2-3). These clustered villages are known as Primary Sampling Unit (PSU). At first, a list of eligible households for inclusion in the survey was prepared based on predefined selection criteria (farm size). There are two clustered villages in each region. Accordingly, the target population was listed in each PSU from where representative samples were chosen proportionately.

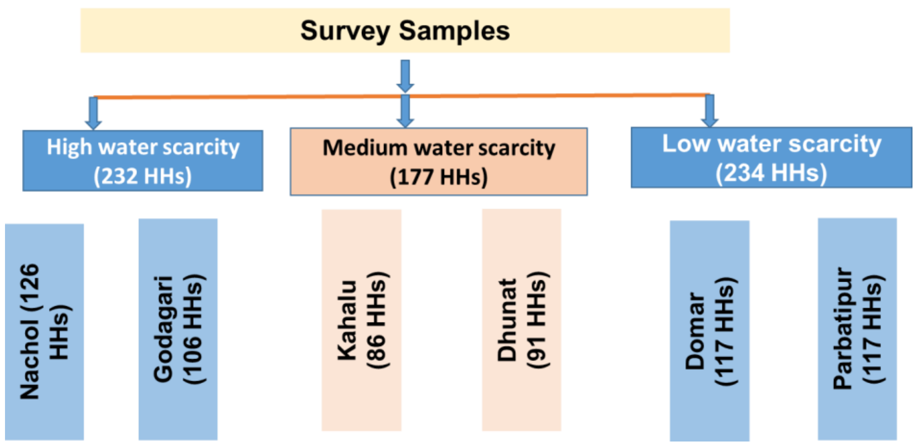


Figure 2-3 Sample size determination for household survey

DATA COLLECTION

Two sources of data - primary and secondary, were collected. The main source of primary data was field survey, Focus Group Discussion (FGD) and Key Informant Interview (KII). The secondary data were collected from BMDA, Bangladesh Agricultural Research Institute (BARI), Bangladesh Rice Research Institute (BRRI), Department of Agricultural Extension (DAE), Bangladesh Bureau of Statistics (BBS), and other agencies that deal with groundwater research.

To collect the required data, an interview schedule was developed in accordance with the objectives of the study. A questionnaire was drafted, pre-tested and updated, modified and finalized incorporating feedback from field tests. A FGD guide and a KII checklist were prepared for collecting general data and information. For collecting survey data, eight BAU post-graduate students were recruited as data enumerators. The minimum qualification of the enumerator was bachelor's degree in agricultural science having relevant field experiences. After recruitment, supervisors and enumerators were trained to undertake the survey and how to build rapport with the respondents, fill-in the questionnaires and other tools. A comprehensive three-day long training workshop on 'Data Collection Procedure' was performed (Figure 2-4).

Figure 2-4 Photos of enumerators' training and field survey

Attempts were made to ensure a uniform pattern in administering the survey. The training plan would put more emphasis on skill training on the real situation rather than classroom training. The steps in the training strategy are shown in Figure 2-5.

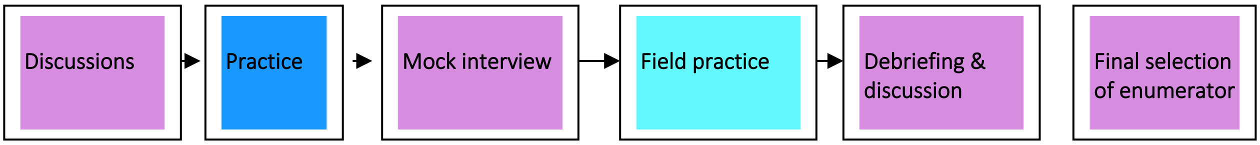


Figure 2-5 Schematic of the steps in the training strategy

Data were collected by the enumerators through face-to-face interview under direct supervision of the research team. A total 643 samples were collected from the five selected districts: 117 from each of Nilphamari and Dinajpur, 106 from Rajshahi, 126 from Chapainawabganj and 177 from Bogura. To select/identify the study areas, basic information on the groundwater irrigation was collected through a Transect Walk and FGDs with participation of different stakeholders and representatives of the local upazila (sub-district, several sub-districts constitutes a district) agriculture office. In addition to irrigation data, data on land area, yield, outputs, production cost of agricultural inputs (tillage, seeds, labour, fertilizers, pesticides, lease value) and crop prices were collected. Furthermore, a total of 120 samples were collected from the survey participants' spouses to differentiate gendered perceptions. In addition, 20 post-graduate students involved in this project collected data separately for their thesis, which they received support and advice from the project team members. Among these 20 MS students, one student's work is presented in chapter 7.

As soon as the filled-out interview schedules returned from the field, they were sorted based on identification criteria. The sorted and identified schedules were stored and handled during data processing stage with direct supervision of the research team. Despite extensive supervision, it is obvious to have some errors in various forms such as inaccuracy, incompleteness, inconsistencies, local unit, etc. Each schedule, therefore, was edited and coded before final data entry procedure. Data were scrutinized and carefully edited to eliminate errors and inconsistencies. The first step was to investigate the data of each interview schedule to ensure consistency and reliability with the aims and objectives of the study. After completing the pre-tabulation task, it was transferred to an Excel spreadsheet from the interview schedules. After cleaning the entire data set, it was transferred to relevant software for further analysis. The final dataset was used to conduct the analysis described in the following chapters.

Chapter 3 WATER STRESS AND LIVELIHOOD

Rice production can be segmented as pre-plantation (input materials collection and preparation), cultivation (sowing, planting, irrigating, inter-culture activities) and post-harvesting stage (harvesting, threshing, winnowing, etc.). Although Bangladesh is a land surrounded by rivers and most of the agricultural land is lowland, irrigation is needed for dry season rice cultivation. However, water is now scarce in Bangladesh. This is a recent phenomenon resulting from its geographic condition, climate change, and socio-domestic status of the region (Habiba et al. 2011). This chapter describes the water stress effect on different factors of production as well as yield and return of irrigated rice (Boro) in the northwest regions of Bangladesh. Along with this, livelihood indexing of the Boro farmers considering five capitals of livelihood for three different water scarcity regions were calculated and then different parameters of these capitals were compared within these water scarcity regions.

3.1 ANALYSIS OF WATER STRESS

The data were analysed using Tukey-Kramer test for comparing pair wise differences of means. For unequal sample size, Tukey-Kramer test indicates if there exists a significant mean difference in comparable groups or not. The idea behind the Tukey HSD (Honestly Significant Difference) test is to focus on the largest value of the difference between two group means. The relevant statistic is

$$q = \frac{\bar{x}_{max} - \bar{x}_{min}}{s.e.} \quad where\ s.e. = \sqrt{MS_w/n} \qquad \text{Equation 3-1}$$

where MS_w is the Mean Square Within and n = the size of each of the group samples. The statistic q has a distribution called the studentized range q. The statistic q is related to the usual t statistic by q = $\sqrt{2}$t. Thus, we can use the following t statistic (Zaiontz, 2019b)

$$t = \frac{\bar{x}_{max} - \bar{x}_{min}}{\sqrt{2MS_w/n}} \qquad \text{Equation 3-2}$$

When sample sizes are unequal, the Tukey HSD test can be modified by replacing $\frac{2}{n}$ with $\frac{1}{n_i} + \frac{1}{n_j}$ in the above formulas. In particular, the standard error for the q statistic becomes

$$s.e. = \sqrt{\frac{MS_w}{2}\left(\frac{1}{n_i} + \frac{1}{n_j}\right)} \qquad \text{Equation 3-3}$$

The Real Statistics Tukey HSD data analysis tool actually performs the Tukey-Kramer Test when the sample sizes are unequal (Zaiontz, 2019a).

The economic productivity of water was calculated using the income (I, Tk.) from crop yield and volume of water applied (measures in monetary value) (Materu *et al.* 2018) as

$$\text{Economic productivity of water} = \frac{\text{I}(BDT)}{\text{Water applied (Tk.)}} \qquad \text{Equation 3-4}$$

3.2 LIVELIHOOD ANALYSIS

The livelihood asset framework has five components including many variables (DFID, 2017). One of the technical challenges of using the livelihood asset framework is to identify the relevant variables from the large number of variables involved. We applied the FGD method to reduce the number of dimensions or variables under review. The variables which are related to the benefits of easy extraction of groundwater in the dry seasons were considered for the regression analysis. Multinomial logistic regression analysis was used to see the effect on livelihood assets in the groundwater scarcity region. When there are more categories in a nominal dependent variable, the correlation between the explanatory and the explained variable is explained by multinomial logistic regression (Washington *et al.* 2003; Hosmer *et al.* 2013). The dependent variable of the multinomial logistic regression is the logarithm of the odds ratio, the probability that the event occurs to the probability that the event does not occur (Zhang *et al.* 2019). There must have 'J-1' logistic regression models for a single categorical dependent variable in a multinomial logistic regression (Liao 1994; Long and Freese 2006). In a multinomial logistic regression model, the probability of a dependent variable to be in the n^{th} category is expressed as (Liao, 1994):

$$\boldsymbol{\pi_j = \frac{\exp(\sum_{k=1}^{K}\beta_{jk}x_k)}{1+\sum_{j=1}^{J-1}(\sum_{k=1}^{K}\beta_{jk}x_k)} \qquad j = 1, 2, \dots, J-1}$$ Equation 3-5

We can rewrite Equation 3–5 as:

$$\boldsymbol{\pi_j = \frac{1}{1+\sum_{j=1}^{J-1} exp-(\sum_{k=1}^{K}\beta_{jk}x_k)}}$$ Equation 3-6

Here, K in coefficient in equation 2 denotes the dependent variable and J denotes the category of the dependent variable.

The sum of probabilities of categories belonging to the dependent variable should be '1' as in binary. For instance, in a multinomial logistic regression in which the number of dependent variable categories (D) has 3 levels, the sum of probabilities of each category is equal to '1'.

$$\boldsymbol{P\ (D=0|x) + P(D=1|x) + P(D=2|x) = 1}$$ Equation 3-7

In multinomial logistic regression, we need to determine a base category for the dependent variable for making comparisons or analyses. Hence, for a model, the dependent variable has three categories, two odds ratios are calculated, each category compared with these ratios, and the model is linearized by taking the natural logarithms of these odds ratios to obtain logistic models (Liao, 1994). If J is marked as the baseline category, the probability of the dependent variable to lie within the baseline category is defined as given in Equation 3-8.

$$\boldsymbol{\pi_J = P(y=J) = \frac{1}{1+\sum_{j=1}^{J-1} exp[(\sum_{k=1}^{K}\beta_{jk}x_k)]}\ j = 1, 2, \dots, J-1}$$ Equation 3-8

Furthermore, if the other probabilities are known, we can compute the probability to lie in the baseline category with the help of these probabilities as given in the equation (Liao, 1994). In our study, groundwater stressed area (Y) is the only categorical dependent variable.

There are 3 categories of Y. Y= 0 for low water scarcity area (Baseline category); Y= 1 for medium water scarcity area; Y= 2 for high water scarcity area; X= independent variables.

3.3 GROUNDWATER LEVELS IN NORTHWEST REGION

To see the picture of groundwater stress in the northwest region of Bangladesh, monthly groundwater depletion level data from 1985 to 2016 were analysed during the water scarcity period (November to May). A total of 132 active groundwater wells were considered for getting the actual picture of water level in the specified water scarcity areas. Of these, 48 are in high water scarcity areas (Chapainawabganj and Rajshahi districts), 27 in medium (Bogura) and 57 (Dinajpur and Nilphamari) in low water scarcity areas.

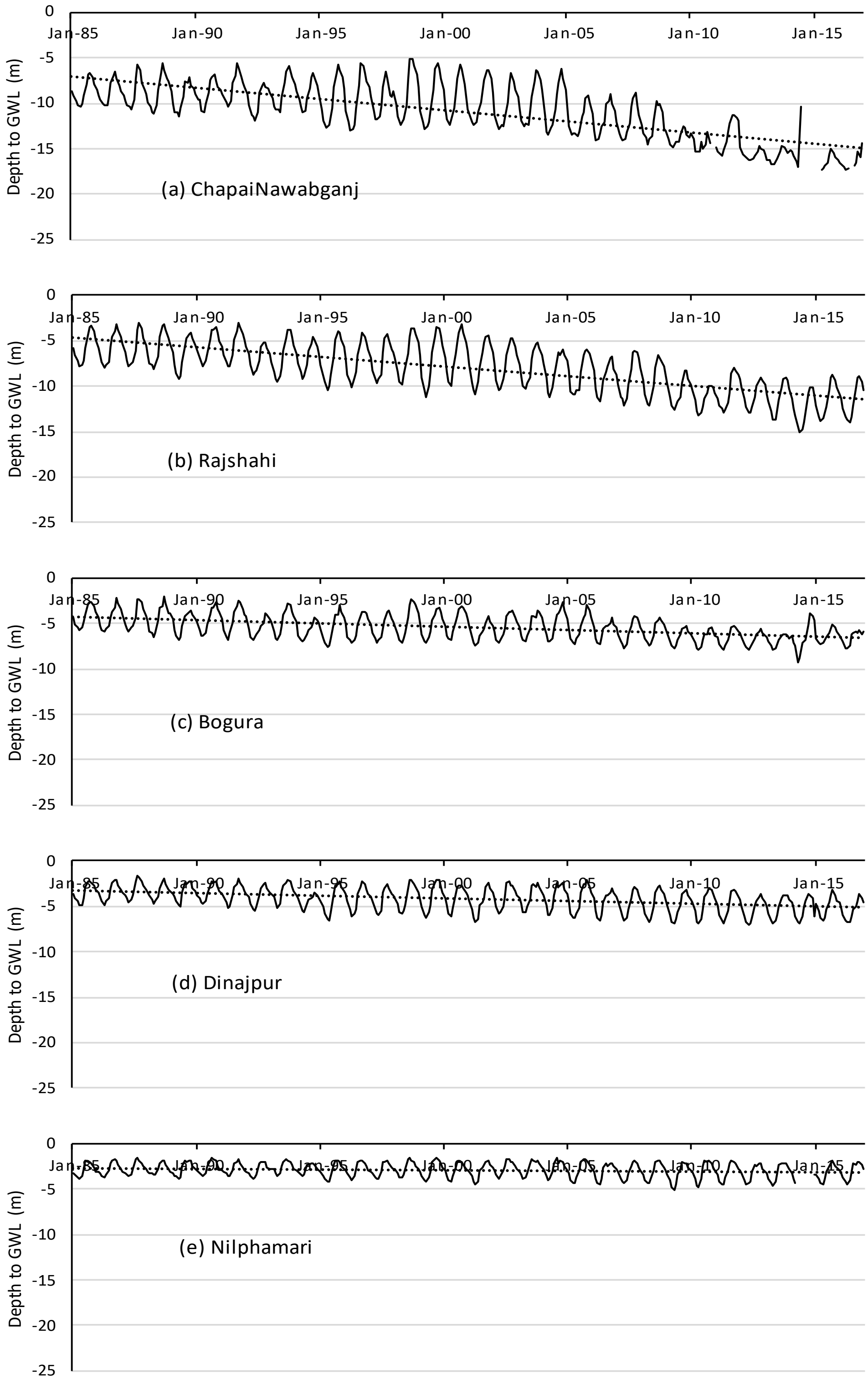


Figure 3-1 Groundwater level (solid line) and declining trends (dotted line) in the 5 districts of the region

Figure 3-1 shows the groundwater depletion rate in high, medium, and low water scarcity regions from the year 1985 to 2016. Over the last 31 years, the minimum groundwater level declined from 10.4 m to 17.4 m in Chapainawabganj, 7.8 m to 15.1 m in Rajshahi, 5.8 m to 9.3 m in Bogura, 4.9 m to 7.0 m in Dinajpur, and 3.8 m to 5.1 m in Nilphamari. The overall decline over this period was 7.0 m, 7.3 m, 3.55 m, 2.06 m and 1.28 m for Chapainawabganj, Rajshahi, Bogura, Dinajpur and Nilphamari respectively. As shown in Figure 3.1 by the trend line, the rate of decline was higher in the high scarcity region (Chapainawabganj, Rajshahi), followed by the medium scarcity region (Bogura), and low scarcity region (Dinajpur and Nilphamari). The groundwater level falls deeper in the peak dry months of March to May.

3.4 Informal water markets

In Bangladesh, informal water markets for irrigation have developed quickly with the rapid expansion of shallow tubewell (STW) irrigation over the last few decades. There is no single rate or uniform method for the payment of irrigation water. Water rates vary not only from one area to another but also depend on the type of tubewell within a particular area (Mandal and Dutta 1993; Mainuddin et al. 2019). Different institutional bodies exist in the water market to serve farmers.

In the study area, three government organisations supply irrigation water in the Boro season. Two of them – the Barind Multipurpose Development Authority (BMDA) and Bangladesh Agricultural Development Corporation (BADC) – are government organizations under the Ministry of Agriculture while the Rural Development Academy (RDA) is a community service provision organisation under the Ministry of Local Government and Rural Development. These three government organisations work in different geographical locations and farmers purchase from an irrigation provider nearest to their farmlands. Pricing mechanisms vary between the irrigation providers and are mostly area-based, time-based, crop sharing based, and mixed charging system dependent (Mainuddin et al. 2019).

The Rural Development Academy (RDA) which operates in the Bogura district supplies the cheapest irrigation water to the Boro rice fields. The Bangladesh Agriculture Development Corporation (BADC) irrigation water is more expensive than RDA. Barind Multipurpose Development Authority (BMDA) supply the costliest irrigation water amongst the government agencies. Nevertheless, BMDA operates in the most water stressed area of the region. Apart from the government organisations, individual tubewell owners supply water to farmers in the water scarcity areas and are usually more expensive than RDA, BADC and BMDA (Figure 3-2).

RDA has great water pricing to support farmers, but they do not have sufficient technical support to provide water supply to all the Boro farmers during the season and farmers turn to costlier individual suppliers for reliable supply. The same is true for BADC. They are providing the service only in limited areas. Individual tubewell (STW) owners, mostly farmers, provide service to the largest area in the northwest region followed by BMDA. BMDA provides services only through electricity operated deep tubewells (DTWs) and follows time-based water pricing throughout the year (Mainuddin et al. 2019). BADC and RDA also provide services only by DTW and they cover a relatively small area where there are no services by BMDA.

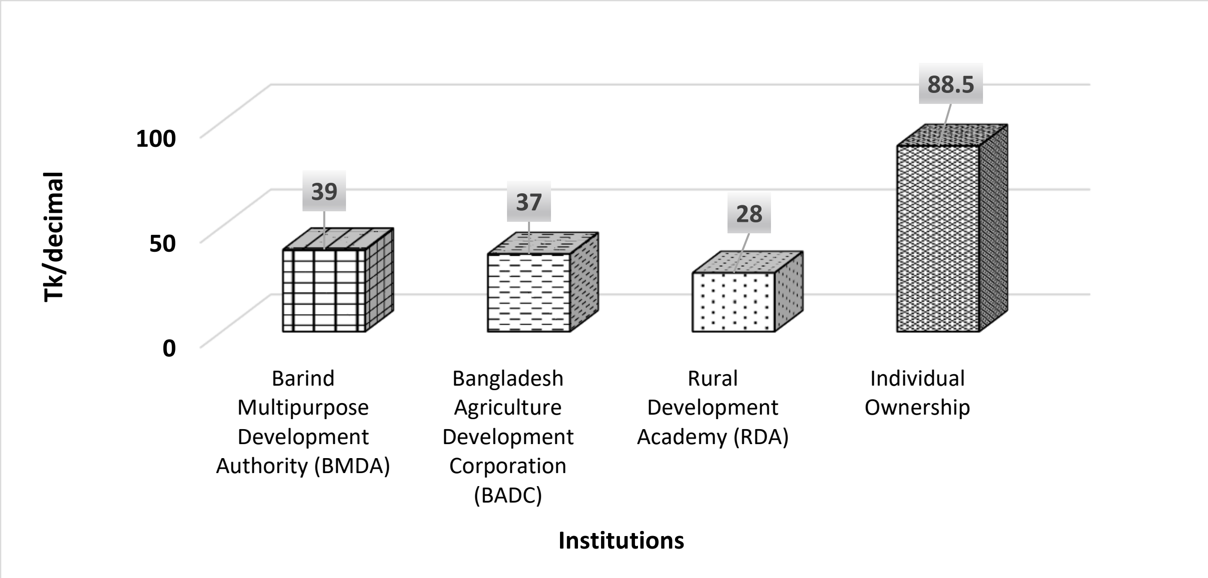


Figure 3-2 Irrigation cost of different institutions

The same average pricing of water supply (per decimal) is found in both high and low water scarcity areas. In the low water scarcity area, the community service providing institution is not present while they are active in medium and high water scarcity areas. BADC and RDA receive operational support from the government to function while BMDA does not. However, BMDA is trying to fix their cost of irrigation to a lower level. BADC sets their water pricing through committee meeting arranged before the Boro season. BMDA always fixes price the same (an average of Tk. 100/hour while the range is 80–120 Tk./hour based on the capacity of the pump) irrespective of the season. It is slightly higher, and maintenance and technical operations are slower than other institutions. Different institutions follow different water pricing mechanisms: BADC and RDA follow area-based water pricing; BMDA follows time-based water pricing; and the individual owner follows a crop sharing based and mix charging system to sell the water.

3.5 WATER STRESS EFFECT ON THE FACTORS OF IRRIGATED RICE PRODUCTION

The groundwater availability has a significant influence over the production costs and benefits of Boro rice. The costs incurred for rice production include the cost of leasing land for production, tillage of the land, purchasing seed of Boro rice, labour use, pesticide and fertilizer purchase and application, providing irrigation. Figure 3-3 shows the water stress effect on the factors of irrigated rice (Boro) production. In areas where water scarcity is high (districts like Chapainawabganj and Rajshahi), the irrigation cost is very high since the groundwater level is lower than in low and medium water scarcity areas. In every other cost unit (leasing cultivable land, land tillage, purchasing seed of Boro rice, pesticide and fertilizer purchase and application, etc.) high scarce water areas farmers have higher or equal costs compared to other areas (medium and low water scarcity areas farmers).

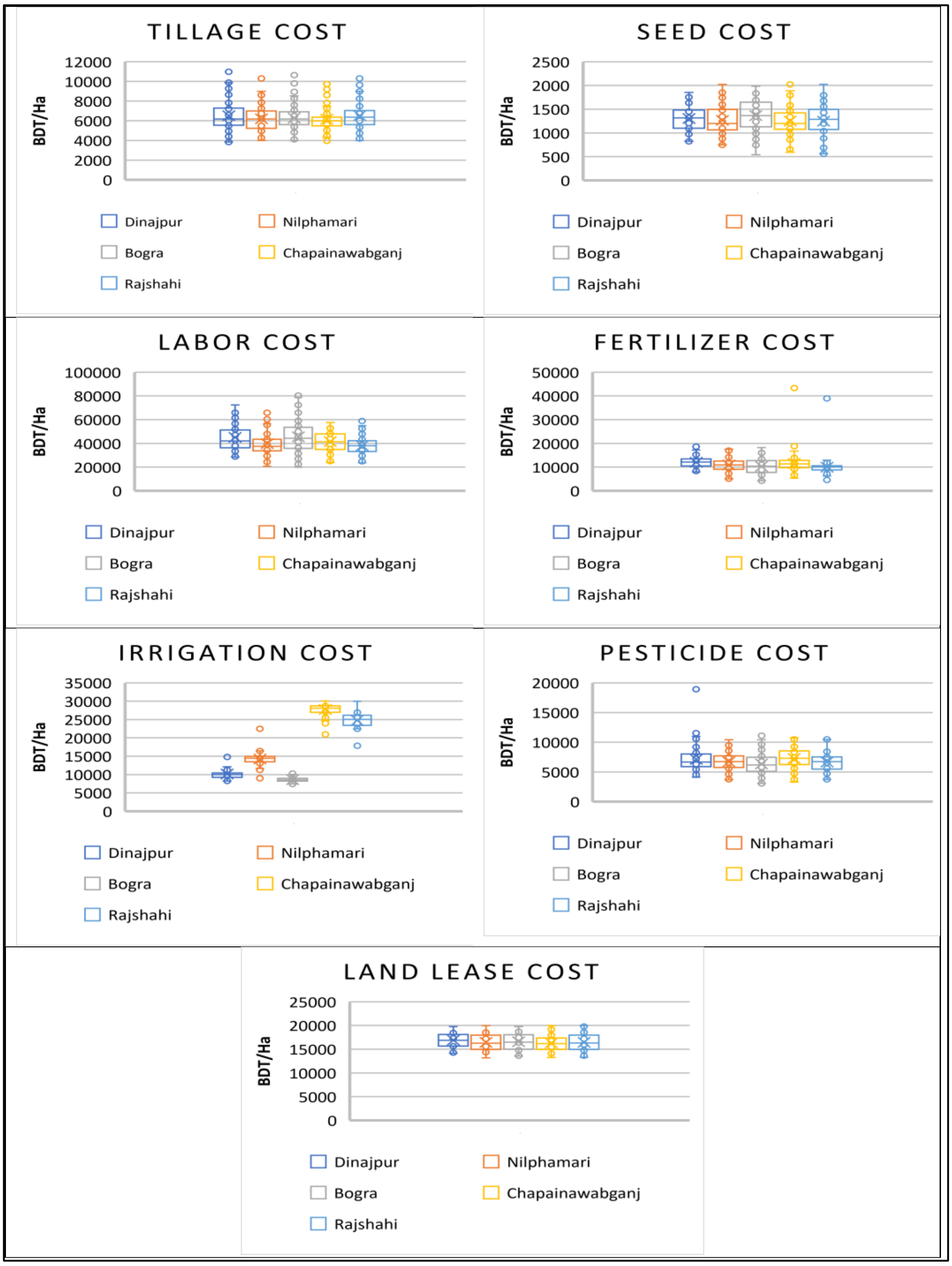


Figure 3-3 Cost variation in Boro rice production in different water stressed areas

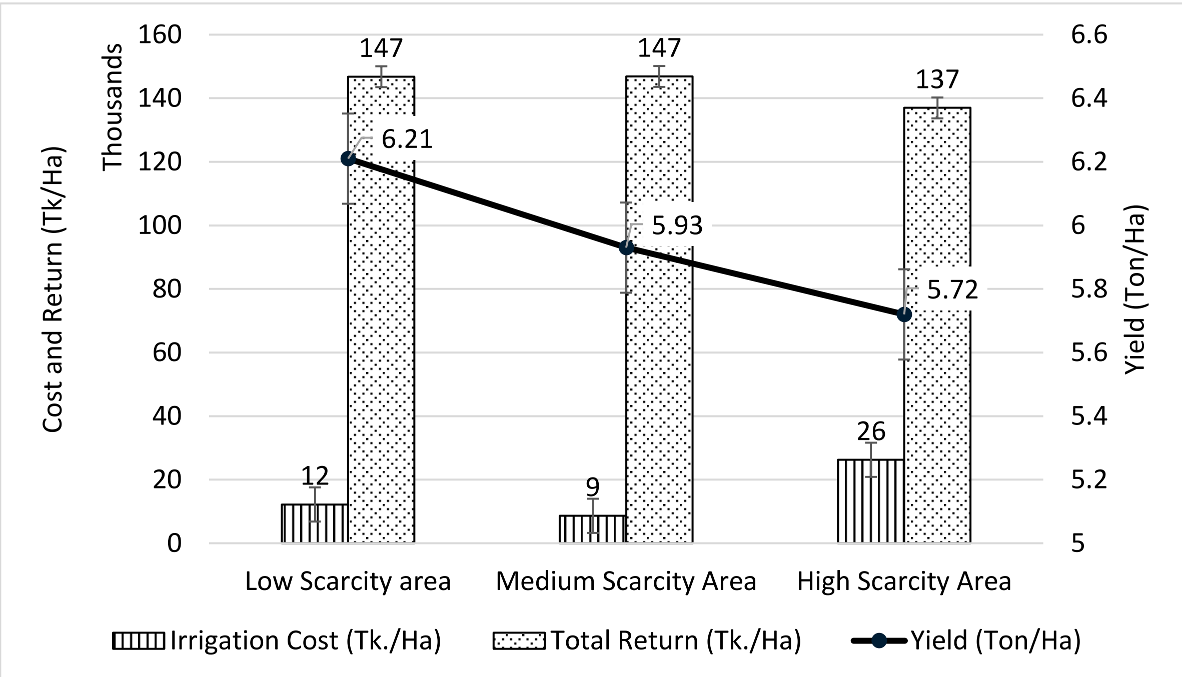
The labour cost for irrigated rice (Boro*)* includes the cost of family and hired labour required throughout the season. Although farmers do not estimate the cost of their labour in calculating the production cost of any agricultural crop, we included them as an opportunity cost in our economic analysis to account for the actual cost of farming. The involvement of labour includes land preparation, seedling growing, weeding, fertilizer and manure use, irrigation, harvesting, threshing, winnowing, storing and ends at selling the harvested rice. The cost of family labour was calculated considering the ongoing cost of hired labour. In the medium water scarcity areas, the labour cost is maximum, and it is less for high water scarcity area while low water scarcity area indicates the in-between cost of labour for Boro rice production.

Figure 3-3 shows that irrigation costs differ among the water stressed areas. As expected, it is high in high water stressed regions where major command areas are operated by BMDA. Between medium and high water stressed region, the irrigation cost is higher for low water stressed regions. It is not likely that fewer water stress regions should have low irrigation cost it depends on the availability of water institutions. In the earlier section mentioned that the cost of the individual water service provider is high that leads the higher irrigation cost in the low water stressed areas where the majority of the irrigated area is covered by the individual water service providers. The level of water stressed condition induces some other production costs of Boro rice cultivation especially the labour cost. Labour is required in every step of rice production and it varies across the water stressed areas. The other input costs of Boro rice production show hardly difference since the farmers are efficient in rice production and the input markets are highly competitive.

3.6 RELATIONSHIP AMONG IRRIGATION COST, TOTAL RETURN, AND YIELD OF BORO RICE

The relationship among irrigation cost, total return and yield is illustrated in Figure 3-4. The total return is the multiplication of yield and market price of rice. The market price is volatile not only across the region but also in the same region between the early harvesting season and later. Therefore, yield is a good indicator to see the irrigation effect on the production of rice. When the scenario is compared to **irrigation cost and yield per hectare** in different water scarcity areas, we see a downward trend from low water scarcity area to high water scarcity area with the per hectare yield of 6.21, 5.93 and 5.72 tonnes respectively for low, medium and high water scarcity area. This result indicates that water stress has a significant effect on Boro rice production.

In relationship between **irrigation cost and total return per hectare** in different water scarcity areas, the return is the same for the low and medium water stressed area and it is decreased by 6.7% in a high water scarcity area. This reduction is not significant in number because of the high market price of rice in the high water stressed regions during the period of study. Considering all costs of production, the net return from high water scarcity areas is 43.5% lower compared to the medium and low water scarcity area. It is worth mentioning that water scarcity not only increases the cost but also reduces the yield which leads to narrowing the net return from irrigated rice production.



Figure

Figure 3-4 Irrigation cost, return and yield variation in different water stressed areas

As the sample sizes are unequal, the Tukey Kramer test was used to determine which pairwise comparisons are significant. Table 3-1, Table 3-2 and Table 3-3 show the statistical relationship among irrigation cost, yield and return of irrigated rice (Boro). Table 3-1 and Table 3-2 show that there is a significant difference between the groups of irrigation cost (Tk./ha) and yield (ton/ha) of different water scarcity regions (low, medium and high). The *p* values for irrigation and yield are less than alpha ($p<0.05$). Also, the standardized *q* value for group 1 and group 2 ($q>q_{crit}$) shows in the above-mentioned group a significant mean difference exists. Table 3-3 shows the mean differences of total return (Tk./ha) among different water scarcity areas (low, medium and high). The Tukey Kramer test identifies which groups have significant mean differences. Likewise, the results of irrigation cost and yield, Tukey-Kramer test' shows a similar result such as standardized $q>q_{crit}$ and *p*<alpha (0.05) except the return from low and medium scarcity area (*p* is not less than 0.1). This means a significant mean difference exists between irrigation and total return too.

Table 3-1 Tukey Kramer test for irrigation

GROUP 1 (IRRIGATION)	GROUP 2 (IRRIGATION)	MEAN DIFFERENCES	STANDARD ERROR	Q-STAT	P-VALUE
Low	Medium	3530	155.41	22.71	7.7E-14
Low	High	14426	158.70	90.90	7.7E-14
Medium	Low	17956	121.65	147.60	7.7E-14
F- test statistic		F= 5724.22, P value = 0, F critical = 3.02			

Table 3-2 Tukey Kramer test for yield

GROUP 1 (IRRIGATION)	GROUP 2 (IRRIGATION)	MEAN DIFFERENCES	STANDARD ERROR	Q-STAT	P-VALUE
Low	Medium	0.233	0.07	3.01	0.084
Low	High	0.541	0.07	6.78	7E-06
Medium	Low	0.308	0.07	4.03	0.012
F- test statistic		F= 11.60, P value = 0, F critical = 3.02			

Table 3-3 Tukey Kramer test for total return

GROUP 1 (RETURN)	GROUP 2 (RETURN)	MEAN	STANDARD ERROR	Q-STAT	P-VALUE
Low	Medium	1138	1827.16	0.62	0.898
Low	High	9992	2003..85	4.98	0.001
Medium	Low	8853	1827.16	4.84	0.001
F- test statistic		F= 7.80, P value = 0, F critical = 3.01			

In summary, groundwater unavailability makes a considerable difference in irrigation cost among the low, medium and high water scarcity areas as the groundwater level decreased and more effort, resource, and cost are incurred for the same irrigation. The higher production cost in high water scarcity areas offsets the benefit of the high market price of rice. Yield The yield rate is low in the greater stressed areas, but the net return is not shrinking substantially because of the higher market price.

3.7 LIVELIHOOD ASSETS

Farm households require water for their livelihoods not only for domestic uses (drinking, washing, cooking and sanitation) but also for productive needs (crop farming, vegetable gardening, livestock, etc). Adequate availability of groundwater for these different needs can contribute to poverty alleviation (Smit 2005). Water covers major aspects of livelihood capitals such as water is a natural capital (i.e. agricultural input, domestic needs); physical capital (i.e. irrigation infrastructure); social capital (i.e. water organizations, institutional, collective action); as well as political capital (Mwakalila 2011). During the peak demand for irrigation (March to May), the groundwater level falls below the suction limit of hand tubewells, predominantly used for household water supply, severely limiting the availability of water to farm households in some areas of the northern region of Bangladesh. This limits access of households to water. When households suffer, they have limited options and therefore impact negatively on their livelihoods (HDR 2006). **Five capitals of livelihood** for 3 water scarcity regions have been calculated and different parameters of these capitals compared within these water scarcity regions. These results are reported in this section.

3.7.1 HUMAN CAPITAL

Human capital is the skills, knowledge, ability to labour and good health and physical capability necessary for the successful adoption of different livelihood strategies (Fang 2014). The status of human capital influences the ability of a farming household to control other types of capital (Babulo et al. 2008; Alemu 2012; Bhandar 2013; Diniz et al. 2013). Four parameters – **age group, years of farming experience, education, household size** – were used to determine the present status of human capital within these three water scarcity regions.

Age is an important component of livelihood. The survey found that the mean age of household's respondents in the low water scarcity region was 45.76 years while the mean ages of household's respondents in medium and high-water scarcity region were 45.64 years and 45.71 years respectively (Table 3-4). The mean age of respondents in these three different water scarcity regions is effectively the same, i.e. 45–46 years.

Years of farming experience reflect the respondents' skills and abilities running farm activities more efficiently. The survey revealed that the average years of farm experience for the respondents living in low water scarcity area is 26.76 years while the average year of farm experiences for the respondents living in medium and high-water scarcity region was 25.76 and 26.71 years respectively (Table 3-4). The years of farm experience for these three different water scarcity regions is effectively the same, i.e. 25–27 years.

Table 3-4 Descriptive statistics of age and years of farm experience

VARIABLE	LEVEL OF WATER SCARCITY					
	LOW		MEDIUM		HIGH	
	MEAN	SD	MEAN	SD	MEAN	SD
Age (years)	45.7	12.9	45.6	13.8	45.7	12.5
Farm experience (years)	26.7	13.3	25.7	13.9	26.7	12.9

Household size is an important determinant of livelihood strategies of a farm household. Table 3-5 shows that the majority of respondents in the hig-water scarcity region have 2 to 4 family members (52.54%). Family size in low and medium water scarcity region ranges between 5 and 7 persons (Table 3-5). This implies that the respondents residing in low and medium water scarcity area might have an advantage of larger family size than high water scarcity region. The larger family size can be a source of unpaid farm labour. This availability of unpaid labour reduces the total farm labour cost (Bwala and John 2018). However, Ogundele and Okoruwa (2004) asserted that large family size doesn't always turn into high usage of family labour. This is because some of the family members may choose other jobs as the main occupation rather than farming which also improves the livelihood conditions of the family.

Education is another human capital that influences the livelihood levels of the farm household. Most of the respondents had primary and secondary level educations (Table 3-5). Liu et al. (2013) and Stiglbauer et al. (2000) had already shown in their separate studies that educated households have greater access to labour markets and short-term non-agricultural work that have a positive impact on the livelihood status of the household.

Table 3-5 **Family size and educational status of the respondents (%)**

VARIABLES	LEVEL OF WATER SCARCITY		
	LOW	MEDIUM	HIGH
Family size			
2–4	42.6%	39.3%	52.5%
5–7	49.1%	50.0%	40.6%
8–10	6.8%	7.2%	5.6%
≥11	3.0%	3.4%	1.1%
Years of education			
No education	23.2%	17.5%	26.5%
Only signature	0.8%	0.8%	2.8%
Up to primary	32.3%	30.3%	27.6%
S.S.C	30.1%	38.8%	32.7%
H.S.C	6.0%	7.6%	6.2%
Bachelor	7.3%	4.7%	3.9%

3.7.2 Physical capital

Physical capital includes all the basic infrastructures and goods needed to support livelihoods such as housing condition, health facility, electricity facility, sanitation, access to information and so on. The **housing condition** represents the strength of the physical capital of a farm household (Table 3-6). A mentionable aspect of this result is that almost one-quarter of the respondents in the low water scarcity region have a building type house. The housing condition of the larger part of the households in medium water scarcity area is tin shed (45.7%). The majority (70.3%) of the households in high water scarcity area has *kacha* type house. High water scarcity region might have a greater cost of farming activities. The financial condition may not support them to make a building type house more frequently than households living in the low and medium water scarcity areas.

Electricity facility is another component of physical capital. Medium and high scarcity regions have 94% and 92% access to electricity respectively; 82.5% of respondents living in the low water scarcity region have access to electricity (Table 3-6). Farm households need electricity during water crisis period for irrigating their cropping field. Reduced electric facility in the low water scarcity region encourages farmers to adopt diesel operated irrigation facility. The government provides some subsidy for diesel which is used for irrigation in the water crisis period (Tanvir et al. 2012).

Most of the respondents have **tubewell** in low (98.30%) and medium (97.86%) water scarcity regions whereas only 53.44% respondents in high water scarcity region have tubewell. This is due to the geological condition of the high water scarcity area as STW cannot be used there. That is the reason government has installed DTWs to provide irrigation to the farmers. The level of groundwater goes below the suction level in the later part of water crisis period (March to May) causes having less STW dependency in the high water scarcity region.

Toilet and sanitation facility are a parameter of physical capital. Bangladesh has great achievement in toilet and sanitation facility; thus, all regions' farm households have 100 % sanitation and toilet facility. All respondents have 100% access to cooking fuel also.

Table 3-6 Physical capital status of the respondents (%)

VARIABLES	LEVEL OF WATER SCARCITY		
	LOW	MEDIUM	HIGH
Housing type			
Kacha	29.9%	8.1%	70.2%
Tin shed	26.5%	45.7%	5.1%
Half building	18.6%	23.9%	9.4%
Building	24.8%	22.2%	15.0%
Electricity	82.4%	94.0%	91.8%
Tube well	98.3%	97.9%	53.4%
Toilet	100.0%	100.0%	100.0%
Cooking fuel	100.0%	100.0%	100.0%

3.7.3 NATURAL CAPITAL

Natural capital consists of natural resources (land, air, water, forest, etc.) that are useful for household livelihood. Table 3-7 reveals that most of the respondents in low, medium and high water-scarcity regions have a **cultivable land size** ranging between 5–249 decimals and they are small farmers (BBS 2018). The highest number of small farmers (76.3%) are in the low water scarcity region, with 67.1% and 64.2% in the medium and high scarcity regions respectively (Table 3-7). There are more medium (250–749 decimal of land) and large (equal or above 750 decimal of land) farmers in high water scarcity region (than the other two regions) because inheritably the farmers of Rajshahi and Chapainawabganj have more farming land; more specifically, 26.7% and 1.3% of the respondents in high water scarcity region are medium and large farmers respectively. Ghosh et al. (2019) found that 77.5% and 7.5% of farmers belong to medium and large-scale farmers in Chapainawabganj district, respectively.

Table 3-7 Natural capital status of the farm household

VARIABLES	LEVEL OF WATER SCARCITY		
	LOW	MEDIUM	HIGH
	Cultivable land size (%)		
0-49 decimal	16.4%	9.4%	7.8%
50-249 decimal	76.3%	67.1%	64.2%
250-749 decimal	7.3%	23.1%	26.7%
≥750 decimal	0.0%	0.4%	1.3%
House (Decimal)	10.2%	9.3%	9.1%
Homestead garden (Decimal)	2.9%	3.4%	6.3%
Tree (Decimal)	14.3%	12.1%	14.7%
Pond (Decimal)	6.9%	6.5%	5.3%

Though the average area for the houses in three different water scarcity regions did not differ so much, the low water scarcity region had a larger average **house area** (10.26 decimal) than other regions. The average areas for homestead garden differed much among these three different regions. The high water scarcity region had a larger average area for homestead garden (6.31 decimal) while the low water scarcity region had the lowest average area for homestead garden (2.97 decimal). Low water scarcity area might have the advantage to utilize their lands for crop cultivation purpose as they had cost-effective irrigation facility during a water crisis period.

3.7.4 FINANCIAL CAPITAL

Financial capitals are those financial resources that are essential to fulfil a household's livelihood objectives. The strength of financial capital shows the bargaining and purchasing power of a farm household. Crop production was the main income earning source for almost all farm households (Table 3-8). The average **income from crop production** is highest in the high water scarcity region (Tk. 148,928/household/year) and lowest in the low water scarcity region (Tk. 113,964/household/year). The households living in the low water scarcity region have comparatively smaller farming area than the other two types of farm households (Table 3-7) and this is reflected in their yearly income from crop farming. **Livestock earnings** are almost parallel for all three regions. On the other hand, average earning from **fisheries** for households is higher in the low water scarcity region (Tk. 9,696/household/year) than in the other regions. The low water scarcity region does not face as severe water scarcity as the other regions and this might motivate them to fish farming.

Table 3-8 Financial capital (Tk./household/year) status of respondents

VARIABLES	LEVEL OF WATER SCARCITY		
	LOW	MEDIUM	HIGH
Crop production	113,964	144,411	148,928
Livestock & poultry	25,251	24,097	27,732
Fisheries/Ponds	9,696	5,397	4,258
Wages & salaries	16,512	45,902	32,392
Remittance	2,359	1,200	2,573
Household expenditure	65,716	78,716	76,661
Farm expenses	56,051	42,593	47,684
Education	20,424	22,944	21,518
Health care	14,106	16,639	17,623

Wages and salaries are another important financial capital item. The average earnings from wage and salary for respondents living in low water scarcity region were the lowest (Tk. 16,512/household/year), mainly due to less outmigration from these areas to urban areas resulting in lower levels of **remittance**. The respondents living in the low water scarcity region have the lowest **household expenses** (Tk. 65,716/household/year). This is a result of less aggregate yearly income from all income-generating activities. This also has an effect on yearly **education and health expense** of the low water scarcity farm household. **Farm expense** is higher in the low water scarcity region (Tk. 56,051 /farm household /year), indicating that the small-scale farmers are less efficient in resource (Rahman et al. 2014).

3.7.5 SOCIAL CAPITAL

Social capital includes social networks used by respondents to adopt a better livelihood. Communication with social networks and access to extension services are the important components of social capital. **Agricultural extension service** is an essential source for learning about different farming systems. In the case of agricultural extension services and getting **formal credit** from NGOs, farm households living in the low scarcity region receive the highest priority in the study regions (Table 3-9).

Table 3-9 Social capital status of the respondents

Variable	LEVEL OF WATER SCARCITY		
	Low	Medium	High
Agricultural extension services	29.9	28.2	25.8
Formal credit	36.1	4.7	11.6

3.8 Effect of groundwater stress on livelihood capitals

Multinomial logistic regression was used to see the effect of groundwater stress on several livelihood capitals for farm household where **groundwater stress area** is the dependent variable and low water scarcity area is the baseline category. The likelihood ratio of *chi*^{2} (*chi*^{2} = 181.01 with a p<0.00) testifies that the fits are significantly better than an empty model (i.e. a model with no predictors). For each category of the models, the odds ratios of the variables vary with different values of β coefficients. Therefore, parameters with significant positive coefficients increase the likelihood of that response category for the base category and vice versa.

Table 3-10 Multinomial logistic regression model for medium and high water scarcity region (baseline category: low water scarcity region)

ASSETS GROUP	VARIABLES	MEDIUM WATER SCARCITY			HIGH WATER SCARCITY		
		COEFFICIENT	STAND.ERROR	P>Z	COEFFICIENT	STAND.ERROR	P>Z
Natural	Farm size	0.011611	0.001969	**0.000**	0.012031	0.001961	**0.000**
Physical	Electricity	1.231794	0.382111	**0.001**	0.819614	0.345220	**0.018**
	Toilet	0 (omitted)			0 (omitted)		
Human	Gender	1.064727	0.871976	0.222	-14.65271	960.9301	0.988
	Age	0.000866	0.008952	0.923	-0.003601	0.008725	0.680
	Education	0.025273	0.027318	0.355	-0.006973	0.027124	0.797
Financial	**Occupation**						
	Labour selling	2.828816	1.789573	0.114	-13.20851	1267.695	0.992
	Business	1.650946	0.811037	**0.042**	1.878706	0.799924	**0.019**
	Job	-1.644823	0.864430	**0.057**	-1.863658	0.933464	**0.046**
	Housewife	-0.249386	1.324371	0.851	0.136151	1469.937	1.000
	Student	0.276330	1.062607	0.795	-0.003574	1.118612	0.997
	Others	17.11166	3260.762	0.996	0.562928	4310.963	1.000
	Farm income	-0.000002	0.000001	0.109	-0.000003	0.000001	**0.057**
	Livestock income	-0.000006	0.000003	0.106	-0.000003	0.000003	0.407
	Fish income	-.0000123	0.000005	**0.035**	-0.000016	0.000006	**0.014**
	Wage and salary	0.000009	0.000002	**0.000**	0.000008	0.000002	**0.002**
	Remittance	-0.000004	0.000007	0.607	0.000001	0.000004	0.756
	Household expend.	0.000007	0.000003	**0.023**	0.000005	0.000003	**0.068**
	Farm expenditure	-0.000017	0.00003	**0.000**	-0.000016	0.000003	**0.000**
Social	Extension service	-0.219777	0.255498	0.390	-0.389869	0.254782	0.126
	Constant	-2.143952	0.632249	0.001	-1.247749	0.592830	0.035

Note: *p<.1* significance at .1 level, *p<.05* significance at .05 level, *p<.01* significance at .01 level

The coefficients of the explanatory variables measure the influence of the variables on the likelihood in a groundwater stress region of improving the livelihood status of a farm household, in comparison with choosing the base groundwater region (low water scarcity area) (Table 3-10). The estimated model shows that an increase in the households' engagement in the main occupation as 'business' increases the likelihood of livelihood status of a farm household in the 'medium and high water scarcity region'. The variables of main occupation 'job' mean involving in monthly paid work and getting more than 50% yearly household income from that source rather from agriculture or other income-earning activities. The medium and high-water scarcity regions have a comparatively higher farming land area, therefore the estimated model shows that the higher the engagement in the main occupation as 'job', the lower the likelihood of livelihood status of a farm household in 'medium and high water scarcity region', relative to the baseline water stress region. As mentioned earlier, farm households with a larger farming area ensure a higher likelihood of livelihood status than the base of the model.

Income from crop farming is decreasing over the year in Bangladesh (Alamgir et al. 2018). Farm households that rely on only farm income (high water scarcity region) are associated with a lower likelihood of increasing livelihood status than other categories. Fish income completely depends on the availability of water; therefore, livelihood status is less likely to increase by choosing the option of 'medium and high water scarcity region' than the base category. An additional income-generating activity such as 'wage salary' is also helpful to increase all capitals of livelihood. Thus, engagement in income from 'wage salary' is likely to improve the livelihood status for 'medium and high water scarcity region' farm households compared to the low scarcity region's household.

Household and farm expenditure are mutually exclusive that means if one farm household increases the farm expenditure then that household must reduce the household expenditure and vice versa which has effects on different capitals of livelihood. The estimated model shows that the higher the 'household expenditure', the higher the livelihood status for 'medium and high water scarcity region' farm household. In contrast, the higher the 'farm expenditure', the lower the livelihood status in the 'medium and high water scarcity region' relative to the base category. Availability of electricity has a positive impact on livelihood status in both (medium and high) water scarcity region.

For livelihood indexing, it may be concluded that the choice of groundwater stress region made by farm households examined in this study is likely to be influenced by factors such as business, job, farm size, farm income fish income, wage and salary, household expenditure, farm expenditure and availability of electricity. In addition, the results show the farm size, wage and salary, farm expenditure and electricity have a strong influence on the farm livelihood status. Finally, household main occupation (business, job), fish income and household expenditure also support farm households in changing their livelihood status.

3.8 FINDINGS

Though Bangladesh is surrounded by rivers and average sea level alleviation is not more than 10 m, irrigation is necessary to cultivate the major staple food grain (rice) of the country. Irrigated rice (Boro) plays a major role in the rice bank of Bangladesh, the contribution is more than 60% of total rice production. Any natural calamities such as excessive or lower rainfall and extreme/lesser temperature harm rice production. Therefore, an in-depth analysis is performed to see the impacts of water availability on functional factors of irrigated rice (Boro) production and productivity. Results show the availability of groundwater for irrigation has a multi-dimensional effect on different factors of rice production which affect the rice production and return from rice farming in the north-western region of Bangladesh.

The livelihood asset framework approach was used to see how the declining groundwater level affects the livelihood assets and how rural livelihood assets are interlinked with the declining groundwater level. All household capitals are linked with the productive usages of groundwater. The majority of the respondents of these three types of water scarcity regions have primary and secondary level educations (human capitals). Physical capitals (energy and sanitation) situation is different; farm households of all regions have 100% sanitation and toilet facility, but in the low water scarcity region, the electricity facility is less. The study further revealed that most of the respondents in low, medium and high water scarcity regions are mainly under the small-scale farm category (financial capital). The households living in low water scarcity region have a comparatively smaller farming area that reflects in their yearly income from crop farming. In the case of agricultural extension services (social capital), farm household living in the low scarcity area receive the highest priority in the study areas. Multinomial logistic regression identifies **business, job, farm size, farm income, fish income, wage and salary, household expenditure, farm expenditure and availability of electricity** as the main determinants influencing the level of livelihood status. The study did not identify superior or preferred livelihood capitals but showed that livelihoods are influenced by specific household characteristics.

Chapter 4 COST AND BENEFIT ANALYSIS OF MAJOR CROPS IN NORTHWEST BANGLADESH

4.1 PROFITABILITY ANALYSIS

The profitability of a farm is an expression of economic efficiency. It indicates how decisions are made (Burja and Burja 2008). The profitability can be measured by the expenses during farm production and the earned income (Burja 2011). Profitability is the main part of the economic and financial mechanism, reflecting the leverage of available resources. Profitability level and its dynamics can be further considered as the key factors of economic sustainability (Baležentis et al. 2019). Cost-benefit analysis is the most common method of determining and comparing the profitability of different crops grown by farm households. The estimates of yield and input coefficients of various crops used in this chapter are based on the information collected in the farm survey (see Sections 2.2 and 2.3 for details). The net financial returns and production cost of different crops have been estimated using financial prices. The financial prices are market prices received by farmers for outputs and paid for purchased inputs during the period under consideration in this study. The returns from the crops have been estimated based on the value of the main products and by-products. The cost items identified for the study were:

- cost of human labour
- cost of draft/mechanical power
- cost of machinery inputs
- cost of material inputs
- land use cost.

The profitability of selected crops is calculated by the following measurements:

Calculation of Gross Return (GR)

Per hectare gross return was calculated by summing up the value of product and by-products. The value of product and by-product has been obtained by multiplying the total amount of product and by-product by their respective per-unit prices.

Gross return = (Quantity of the product × Average price of the product) + Value of by-product Equation 4-1

Calculation of Net Return

Net return or profit was calculated by deducting the total costs of production from the total return or GR, that is,

Net return = Total return – Total costs of production Equation 4-2

Calculation of Net profit

The following conventional profit equation was applied to estimate farmer's profitability of producing the selected crops in the study areas:

Net profit, $\boldsymbol{\pi = \sum P_m Q_m + \sum P_f Q_f - \sum P_{xi} X_i - TFC}$ Equation 4-3

where,

π = Net profit/Net return from selected crop farming (Tk./ha)

P_m = Per unit price of the selected crop (Tk./kg)

Q_m = Total quantity of the production (kg/ha)

P_f = Per unit price of by-product (Tk./kg)

Q_f = Total quantity of by-products (kg/ha)

P_{xi} = Per unit price of ith inputs (Tk.)

X_i = Quantity of the ith inputs (kg/ha)

TFC = Total fixed cost (Tk.)

i = 1, 2, 3, … , n (number of inputs).

Calculation of Undiscounted Benefit Cost Ratio (BCR)

The average return to each Taka spent on production is an important criterion for measuring profitability. Undiscounted benefit-cost ratio (BCR) was calculated as the ratio of total return to total costs on a per hectare basis.

BCR = Total return/Total cost Equation 4-4

4.2 FUNCTIONAL ANALYSIS

The input-output relationships of selected crops were analysed with the help of Cobb–Douglas production function approach. To determine the contribution of the most important inputs in the production process of selected crops farming, the following specification has been used:

$$\boldsymbol{Y = aX_1^{b1}X_2^{b2}X_3^{b3}X_4^{b4}X_5^{b5}X_6^{b6}X_7^{b7}X_8^{b8}X_9^{b9}X_{10}^{b10}X_{11}^{b11}e^{ui}}$$ Equation 4-5

The Cobb–Douglas production function was transformed into the following logarithmic form so that it could be solved by the ordinary least squares (OLS) method:

$$\boldsymbol{lnY = lna + b_1lnX_1 + b_2lnX_2 + b_3lnX_3 + b_4lnX_4 + b_5lnX_5 + b_6lnX_6 + b_7lnX_7 + b_8lnX_8 + b_9lnX_9 + b_{10}lnX_{10} + b_{11}lnX_{11} + U_i}$$ Equation 4-6

where,

Y = Gross income from selected crop production (Tk./ha)

X_1 = Cost of tillage (Tk./ha)

X_2 = Cost of seed (Tk./ha)

X_3= Cost of labour (Tk./ha)

X_4 = Cost of urea (Tk./ha)

X_5 = Cost of Triple Super Phosphate (TSP) (Tk./ha)

X_6 = Cost of Diammonium phosphate (DAP) (Tk./ha)

X_7= Cost of Muriate of Potash (MOP) (Tk./ha)

X_8 = Cost of compost (Tk./ha)

X_9 = Cost of irrigation (Tk./ha)

X_{10} = Cost of pesticides (Tk./ha)

X_{11} = Cost of herbicides (Tk./ha)

a = Intercept

b_1, … , b_{11} = Coefficient of the respective variable

U_i = Error term

i = 1, 2, … , 11.

4.2.1 FINANCIAL PROFITABILITY OF AMAN RICE

The crop production in Bangladesh is dominated by intensive rice cropping. There are three types of rice depending on the season of the year: (1) Aus, (2) Aman, and (3) Boro. Aman rice is the predominant crop (72% of the net cultivable area) in the wet season (Jalilov et al. 2019) and the most dominated cropping pattern is Boro-T. aman rice. The Aman crop includes broadcast Aman (B. Aman) and transplanted Aman (T. Aman). Broadcast Aman is sown in the month of mid-March to mid-April in the lowlands; and transplanted Aman which is planted during late June to August. The Aman paddy is harvested in November and December. Traditionally, T. Aman occupied the largest rice harvested area. The T. Aman crops are grown mostly under rainfed conditions. However, recently supplemental irrigation, especially during reproductive phases, has become increasingly popular. All types of land except lowlands are brought under T. Aman cultivation where planting of seedlings is possible. The transplanted Aman (T. Aman) crop is dominated by a variety of Swarna followed by other high yielding varieties (HYVs) such BRRI dhan49, BRRI dhan51 and BRRI dhan52 (Kabir *et al.* 2019). The B. Aman is mostly planted in deeply flooded lowland areas. This type of Aman has been cultivating in Bangladesh from time immemorial. Since this local variety paddy gives a lower yield, the area under B. Aman has been increasingly converted for growing Boro crop, which is mostly a transplanted crop under irrigated conditions (FAO 2006).

A total of 643 samples were chosen randomly from the selected five districts: 117 from each of Nilphamari and Dinajpur, 106 from Rajshahi, 126 from Chapainawabganj and 177 from Bogura for the present study. Total Aman farmers in the sample were 291. The financial profitability analysis of Aman has been presented in Table 4-1. It can be inferred from Table 4-1 that labour cost is the highest cost item in producing Aman followed by lease or land use cost. The production of Aman requires less fertilizer and irrigation than other Rabi season crops and farmers usually do not use compost in producing Aman as it is a rainfed crop. The average yield of Aman was estimated at 4.02 tonnes/hectare and the price of Aman during the data collection period was Tk. 835 per mound or Tk. 20,862 per tonne. The total revenue from Aman production was calculated at Tk. 105,675 per hectare which includes the revenue from paddy (product) and straw (by-product). The net return (net profit) was derived from the difference of total revenue (TR) and total cost (TC) and was found to be positive (28,058 Tk./ha). The undiscounted BCR is the ratio of TR and TC which was found to be greater than 1 (1.36) for the present study. BCR plays an important role in deciding the production of a crop because it indicates whether producers should continue the production of the crop. If it is greater than one, it means that the producer becomes benefited and farmers will be interested in continuing the production of the crop; and if it is less than one, the rational farmer will not produce the crop. So, it can be concluded that the production of Aman paddy can be encouraged from the viewpoint of benefit for the farmers.

Table 4-1 Per hectare profitability of Aman, Boro, potato, wheat and mustard, 2017

COST/REVENUE	AMAN	SD[1]	BORO	SD	POTATO	SD	WHEAT	SD	MUSTARD	SD
Tillage	6,475	937	6,318	1,269	6,715	1,789	4,523	1,000	4,920	1,266
Seed	1,232	336	1,297	290	45,376	13,099	2,410	598	1,100	420
Family supplied labour (male)	6,834	4,210	20,083	11,258	22,575	15,642	10,048	5,932	18,592	11,385
Family supplied labour (female)	2,733	2,934	2,838	3,730	7,769	6,452	3,721	2,465	4,308	4,804
Hired labour (male)	28,659	8,911	18,283	11,022	30,705	14,635	25,642	7,940	15,396	8,149
Hired labour (female)	4,016	3,932	2,060	3,758	8,443	5,059	3,480	2,062	1,468	2,761
Total labour cost	42,242	6,020	43,264	10,805	69,492	14,997	42,891	2,480	39,764	12,172
Urea	1,721	264	2,737	383	3,601	1,001	2,047	399	2,318	1,108
TSP	1,951	755	2,497	577	5,868	2,585	2,220	671	2,021	2,097
DAP	1,461	848	2,640	1,621	4,455	3,322	2,363	488	3,037	2,515
MoP	571	617	1,435	304	2,875	1,537	1,197	349	2,059	1,352
Total chemical fertiliser cost	5,704	1,267	9,309	3,204	16,799	7,292	7,827	3,060	9,435	4,754
Compost	0	0	3,811	1,510	4,734	5,068	2,923	1,770	2,468	2,567
Irrigation	1,921	2,663	11,426	2,616	8,382	2,832	3,712	889	3,632	2,562
Pesticides	2,526	758	5,490	1,383	1,138	2,347	1,483	513	1,388	1,357
Herbicides	1,518	633	1,867	904	490	1,267	282	410	277	687
Lease (land use)	15,999	964	16,488	1,668	9,941	3,055	6,610	998	8,182	1,701
Total cost (TC)	77,617	7,393	99,270	22382	163,067	22,185	72,661	7,118	71,166	16,935
Product	83,830	9,773	120,723	21,273	172,634	28,593	69,011	11,557	75,500	17,922
By-product	21,845	2,550	22,646	8,434	106	452	4,966	1,453	3,811	1,464
Total revenue (TR)	105,675	9,995	143,369	23,287	172,740	28,623	73,977	12,413	79,311	18,496
Net profit	28,058		44,099		9,673		1,316		8,145	
BCR (undiscounted)	1.36		1.44		1.06		1.02		1.11	
BCR without family labour cost	1.55		1.88		1.30		1.26		1.64	

Figure 4.1 shows the share of major cost items of Boro, Aman, potato, and wheat. It can be seen from Figure 4-1 that labour cost occupies the major share (40–55%) of total cost in producing all the selected crops. The calculation of labour cost includes both family labour and hired labour. Family supplied labour, although it does not receive any explicit monetary reward, should not be ignored in the analysis on the ground that there is an opportunity cost of the time spent by the family labourers on their farm. The inclusion of family labour in the analysis is also required for the sake of achieving an estimate of profitability to an acceptable precision. For instance, in the dataset it has been noted that several farm households did not use any hired labour at all and all farming activities were performed by the home supplied labours. In such cases, if family labourers are not accounted for in the analysis then it would imply the farm household did not use any labour at all, which is erroneous. To avoid any potential bias in the calculation and to be consistent with farm management principles, the costs of family labours have been accounted for in this analysis. However, it is obvious that without counting family labour cost, the BCR will be higher (see Table 4-1) and since it is an opportunity cost, farmers usually do not realize it directly. Therefore, their farm business decision might be superficial without counting family labour cost as it is not counting the opportunity cost.

[1] A standard deviation (SD) is a statistic that measures the dispersion of a dataset relative to its mean.

The seed cost is not a very significant cost item except potato where it occupies 26% of the total cost. Land use cost is another important cost item but often it is overlooked by the farmers who cultivate crops on their land. It is intuitively easy to understand that if we exclude lease costs like family labour costs, the profit margin will be high. However, it is unjustifiable because there is no ground for which we can ignore lease value when several farmers incur rental costs. Moreover, if the farmer rented out the land, he would have earned some money. Therefore, from the perspective of opportunity costs, we need to consider lease value in the analysis. It is not surprising that irrigation cost has come out as a significant cost item in the case of Boro rice production compared to other crops. Fertilizer cost is another material cost item that farmers care about. While comparing all these four crops, it can be said that Aman production requires fewer material inputs than Boro, potato and wheat production while potato production requires the material inputs most.

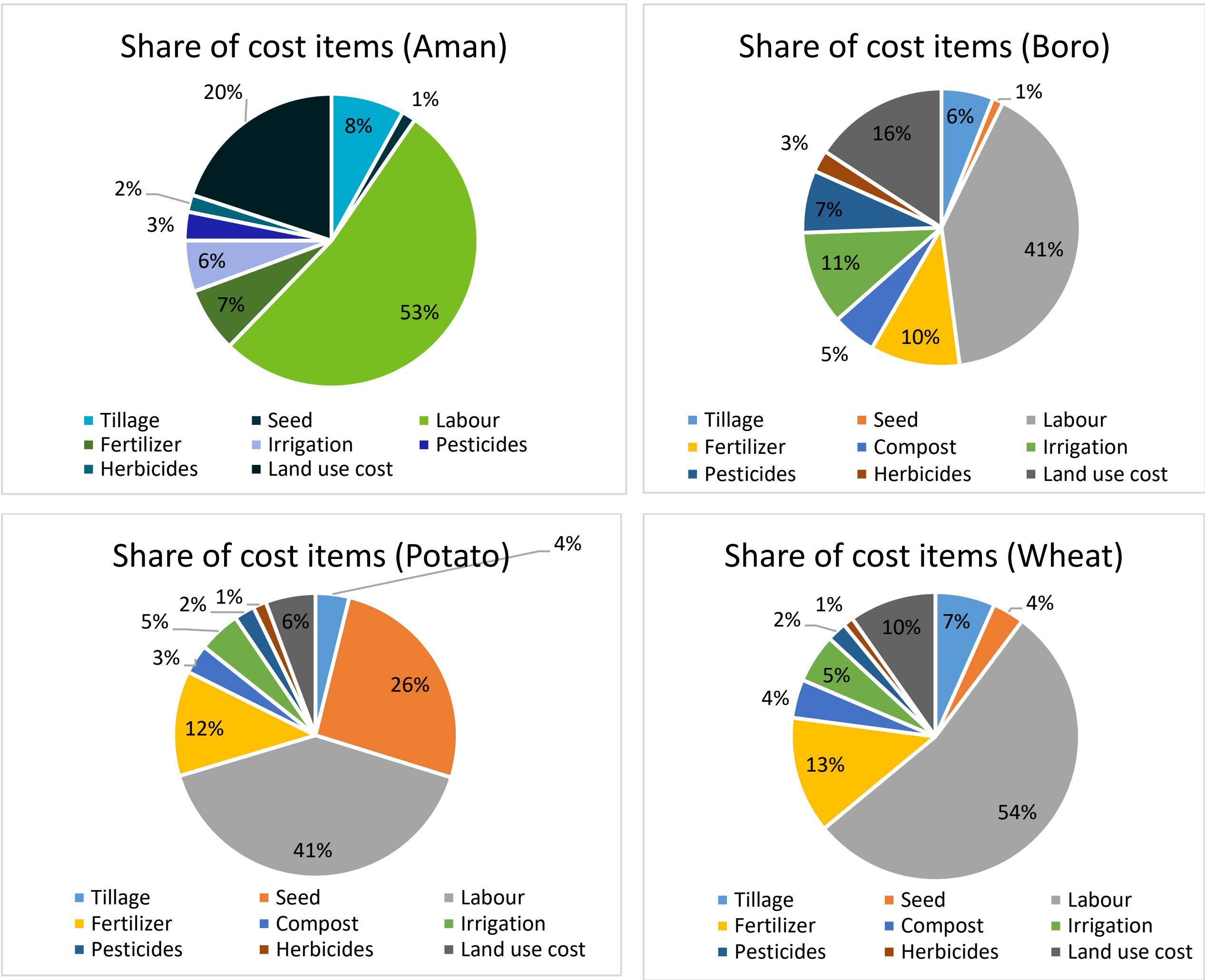


Figure 4-1 Share of different cost items of Aman, Boro, potato and wheat

The financial profitability of Aman has also been estimated based on farm categories such as small, medium and large[2]. Among the 291 Aman farmers, 244 were small, 46 were medium and only one was a large farmer. Since, there was only one large farmer in the sample, SD is not applicable to this case. The results of the financial profitability of Aman by farm category are presented in Table **4-2**. It was found that the costs and returns did not vary significantly considering the farm size. BCRs were positive (greater than 1) for all farm categories. Therefore, it can be concluded that if yield and price are satisfactory, Aman production is

[2] According to agricultural census of Bangladesh, a farm household was classified into three categories such as: small (up to 2.4 acres); medium (2.5 to 7.4 acres); and large (7.5 acres or more) (BBS 2016).

profitable irrespective of farm size. Since we have found that Aman production requires fewer material inputs, the small and medium farmers are also capable of attaining the expected yield. This might be the main reason behind the similarity of cost and benefits across the three types of farms.

Table 4-2 Financial profitability of Aman by farm categories, 2017

COST/REVENUE	SMALL	SD	MEDIUM	SD	LARGE
Tillage	6,528	975	6,198	653	6,351
Seed	1,247	344	1,155	281	1,101
Family supplied labour (male)	7,282	4,311	4,481	2,660	5,646
Family supplied labour (female)	2,896	3,068	1,880	1,934	2,117
Hired labour (male)	28,134	9,001	31,453	8,048	28,228
Hired labour (female)	4,082	3,900	3,617	4,142	6,351
Total labour cost	42,394	6,194	41,431	5,057	42,342
Urea	1,734	274	1,650	197	1,694
TSP	1,950	771	1,950	678	2,205
DAP	1,451	860	1,543	765	-
MoP	628	627	259	448	1,129
Total chemical fertiliser cost	5,763	1,320	5,402	906	5,028
Irrigation	2,033	2,762	1,368	2,008	-
Pesticides	2,630	746	1,981	577	2,117
Herbicides	1,611	622	1,044	454	706
Lease (Land use)	15,968	959	16,144	993	16,937
Total cost	78,174	7,819	74,723	5,152	74,582
Product	84,236	10,213	81,672	6,831	83,980
By-product	22,045	2,510	20,880	2,515	17,643
Total revenue	106,281	10,408	102,552	6,818	101,623
Net profit	28,106		27,829		27,041
BCR (undiscounted)	1.36		1.37		1.36

4.2.2 FINANCIAL PROFITABILITY OF BORO RICE

Boro is more important than all other rice in Bangladesh as it is considered one of the main drivers of food security of the country. Due to flood and other natural disasters, the dry season is the most productive in Bangladesh, hence Boro rice is the major crop in the dry season that currently contributes 55–60 % of the country's total rice production (Mainuddin et al. 2019). Production of Boro is an input-intensive crop that depends on the use of fertilizers, irrigation, pesticides, etc. The northwest region has the most intensive use of groundwater, with 97% of the irrigated area irrigated only from groundwater, while irrigated Boro rice covers around 65% of the total irrigated area (Mainuddin et al. 2015). Due to higher irrigation requirements, 91% of the total irrigation water is used for Boro rice cultivation (Mainuddin et al. 2014, 2015). The DTWs and STWs installed by the Barind Multipurpose Development Authority (BMDA), Bangladesh Agricultural Development Corporation, and Rural Development Academy (RDA) supply the groundwater for irrigation to the farmers. Besides these, private pump owners also sell water to the farmers on a small scale. The government spends a huge amount of money for giving subsidy to the farmers on different inputs such as fertilizer, irrigation etc. to achieve self-sufficiency in rice production. Boro farmers especially get the benefit of these subsidy programmes as the production of Boro requires more fertilizer and irrigation than other rice varieties. The planting and harvesting time of Boro are December to February and April to June, respectively. There are three types of Boro namely local Boro, High Yielding Variety (HYV) Boro and hybrid Boro. Presently

HYV Boro ranks top in the list of paddy production all over the country. Farmers produce different varieties of HYV Boro all over the country. The most two popular varieties are BRRI dhan28 (BR-28) and BRRI dhan29 (BR-29) (Tiongco and Hossain 2015).

Most of the sampled farmers in the present study produce Boro and, after data cleaning, 557 farmers were counted for analysis. The results of the profitability analysis of Boro production are presented in Table 4-3. The average yield and price of Boro paddy were 6 ton/ha and Tk. 800 per mound or Tk. 20,067 per ton, respectively during the data collection period. The estimated results show that the per hectare net financial return of Boro was positive (44,099 Tk./ha). The BCR is also greater than 1 (1.44) which proves that farmers made sufficient profit from the Boro production in that particular year (2017). The main reason behind this high profit was the high price of Boro in the market. It is a common phenomenon that if in a particular year, farmers get a high price for their product, then in the next year, more farmers enter into the market. The market faces a huge supply of that product in the harvesting period and the product price drops down rapidly. The farmers faced this situation for Boro production in the year 2018. The results also show that producing Boro is more profitable than producing Aman and among the Rabi crops considered in this study, Boro is the most profitable crop. The financial profitability of Boro was also estimated according to farm categories and the results are presented in Table 4-3. The results show that large farms are more efficient than small and medium farmers in producing Boro rice on the basis of BCR. One of the reasons behind this result might be, large farmers use labour and material inputs more efficiently than small and medium farmers which decrease their per hectare production cost.

Table 4-3 Financial profitability of Boro by farm categories, 2017

COST/REVENUE	SMALL	SD	MEDIUM	SD	LARGE	SD
Tillage	6,196	1,172	6,784	1,511	7,037	1,427
Seed	1,315	302	1,228	227	1,179	83
Family supplied labour (male)	19,821	11,160	21,048	11,766	22,182	1,307
Family supplied labour (female)	3,178	3,975	1,516	2,143	1,926	2,270
Hired labour (male)	18,282	11,111	18,362	10,900	16,051	5,094
Hired labour (female)	2,051	3,915	2,070	3,134	2,782	2,163
Total labour cost	43,332	10,539	42,996	11,924	42,941	7,418
Urea	2,743	382	2,720	386	2,610	537
TSP	2,514	583	2,442	550	2,055	512
DAP	2,559	534	2,923	3,310	3,253	-
MoP	1,437	299	1,429	324	1,483	377
Total chemical fertiliser cost	9,253	2,775	9,514	3,761	9,401	14,593
Compost	3,861	1,566	3,645	1,290	3,317	1,195
Irrigation	11,337	2,689	11,778	2,307	11,474	1,867
Pesticides	5,504	1,441	5,462	1,141	4,660	828
Herbicides	1,844	687	1,942	1,436	1,958	600
Lease (Land use)	16,524	1,673	16,350	1,660	14,970	-
Total cost	99,166	22,431	99,699	21,916	96,937	34,409
Product	120,897	22,053	120,441	17,867	108,573	22,296
By-product	21,944	4,090	24,136	11,062	60,933	67,133
Total revenue	142,841	22,649	144,577	22,840	169,506	72,948
Net profit	43,675		44,878		72,569	
BCR (undiscounted)	1.44		1.45		1.75	

4.2.3 FINANCIAL PROFITABILITY OF POTATO

Potato (Solanum tuberosum) is the third-largest food crop in Bangladesh and has recently occupied an important place in the list of major food and cash crops of Bangladesh (Ali and Haque 2011). Potato is widely cultivated in all the districts of Bangladesh during winter (Rabi season). Well-fertilized, sunny land with sufficient moisture in the soil is appropriate for potato plantation. The first fortnight of November is the right time to plant. In certain northwestern areas, farmers even plant potato in October to harvest the crop early. Virtually all potatoes in this country are planted manually. Potato varieties that are cultivated in Bangladesh are broadly categorised into two groups, local and high yielding. There are about 27 local varieties of potatoes cultivated in different parts of the country. Some of the popular local varieties are: (a) Sheel Bilatee – mostly cultivated in Rangpur with oblong and reddish tubers; (b) Lal Sheel – primarily cultivated in Bogura with round tubers reddish in colour; (c) Lal Pakri – cultivated widely in Dinajpur, Bogura and Sirajganj districts with reddish and round tubers; (d) Du Hajari – mostly cultivated in Chittagong area Tubers appear with round and pale tubers (Ali and Haque 2011). The so-called local varieties are in fact, not native. In the distant past those were brought to this part of the subcontinent but in the absence of varietal improvement efforts, gradually degenerated, showing poor yield performance. Despite poor yields, some of the local varieties are still being cultivated because of their taste and cooking qualities. Among the high-yielding popular varieties, the following are notable: (a) Cardinal – most popular among the foreign varieties with oblong, reddish tubers, shallow eyes, and smooth skin. The variety has been introduced from Holland and has a yield potential of 20 to 25 tonnes/ha. (b) Diamant – another Holland variety with oval to oblong, pale yellow tubers, skin smooth, and eyes shallow. It is quite a disease resistant. Per hectare, yield ranges from 18 to 24 tonnes. (c) Kufri Shindhury – tubers reddish, round, and eyes deep with rough skin. This variety was introduced from India and is comparatively less susceptible to pests and diseases. It has a yield potential of 18 to 22 tonnes/ha. Other notable exotic varieties are Patronis, Alpha, Archa, Multa, Ukama, Hira, Maurin, Origo, Alisa, etc. (Khalil *et al.* 2013).

In total 118 sample farmers were counted for the analysis of potato production. The cost and return analysis of potato production is presented in Table 4-4. Labour cost is the highest cost item for potato production similar to other crops. But seed cost is high for potato than any other crops as the potato seed is a bulky item. The average yield and price of potato during the data collection period was 18 ton/ha and Tk. 335 per mound, respectively. The price of potato was very low in the year of the data collection period (2017) which eventually affected the profitability of potato production. That year was an unusual year for potato price. The net return was estimated at Tk. 9,673 per ha and the BCR was 1.06. The BCR shows that the farmers survived marginally by producing potato. Usually, potato is more profitable than other alternative crops but due to price drop of potato in the data collection year (2017), potato cultivation was found less profitable than other crops of the region. This kind of risk is a great concern for farmers and affects their crop choice decision significantly. The price volatility especially affects the small farmers who run their agricultural business with a small amount of cash in hand.

The financial profitability of potato was also estimated by farm categories. Only small and medium farmers were considered for the analysis as there were not many large farmers in the selected sample. It has been depicted that there are not many significant variations between the profitability of small and medium farmers though small framers are more efficient than medium farmers (Table 4-4). It can be concluded from the comparison that farm size is not a significant factor that affects profitability. It is mostly the price which determines the profitability of a particular crop.

Table 4-4 Financial profitability of potato by farm categories, 2017

COST/REVENUE	SMALL	SD	MEDIUM	SD
Tillage	6,634	1,749	7,117	1,975
Seed	44,827	12,943	48,070	13,862
Family supplied labour (male)	22,895	15,361	20,926	17,370
Family supplied labour (female)	7,758	6,243	7,860	8,296
Hired labour (male)	30,443	13,619	31,908	19,001
Hired labour (female)	7,681	4,236	11,711	6,936
Total labour cost	68,777	14,732	72,405	16,555
Urea	3,657	1,033	3,327	788
TSP	5,735	2,641	6,478	2,277
DAP	4,513	3,395	4,171	3,003
MoP	2,841	1,568	3,041	1,401
Total chemical fertiliser cost	16,746	7,495	17,017	6,373
Compost	4,865	5,099	4,097	4,996
Irrigation	8,511	2,876	7,746	2,577
Pesticides	1,243	2,440	623	1,786
Herbicides	588	1,370	9	42
Lease (Land use)	10,298	2,948	8,196	3,038
Total cost	162,489	22,585	165,280	20,582
Product	173,029	28,563	170,695	29,401
By-product	98	406	144	644
Total revenue	173,127	28,598	170,839	29,415
Net profit	10,638		5,559	-
BCR (undiscounted)	1.07		1.03	

4.2.4 FINANCIAL PROFITABILITY OF WHEAT

Wheat is one of the most important winter crops and is a temperature-sensitive grain crop of Bangladesh. The cereal, considered as the second staple after rice, grows in Rangpur, Rajshahi, Khulna and some parts of the Dhaka division on a large scale where the winter season lasts for a long time. Wheat is grown under a wide range of climatic and soil conditions. It, however, grows well in clayey loam soils. In Bangladesh it is a crop of Rabi season, requires dry weather and bright sunlight. Depending on variety and weather conditions, 100-120 days are required from sowing to harvest. Wheat seeds are sown from November to mid-December while the harvesting time of the crop is March to April (BBS 2020). The commonly cultivated varieties are locally known as Shatabdi (BARI Gom21), Prodip (BARI Gom 24), Bijoy (BARI Gom 23), Sonalika, Kanchan, Balaka, Ananda, Akbar, Barkat, and Aghrani (Hossain and Silva 2013; Rashid and Hossain 2016). The northwest region is especially suitable for wheat production due to its dry weather. The Bangladesh Bureau of Statistics (BBS) data showed that both wheat planted area and its production saw a gradual drop in the last couple of years. Wheat acreage was 0.444 million hectares with an output of nearly 1.35 million tonnes in FY'16 which declined to 0.328 hectares with an output of 1.06 million tonnes in FY'19. Farmers' interest in the cultivation of more profitable contemporary crops is considered the main reason for the decrease in wheat cultivation in the country (BBS 2020). Wheat acreage has continued to shrink in the country as many farmers switch to maize and vegetables farming for higher profits. The attack of wheat blast in recent years is another factor that has discouraged farmers from wheat cultivation.

The profitability analysis of wheat is shown in Table 4-5 where the sample of wheat farmers were only 33. The average yield and price of wheat were 3.19 tonnes/ha and Tk. 866 per mound, respectively during the survey period. The gross return and net return were estimated at Tk. 73,977 and Tk. 1,316 per hectare, respectively. The net return was marginally positive and consequently, benefit-cost ratios came out as greater than 1 (1.02) for wheat production. Thus, the findings indicate that the production of wheat is narrowly feasible in terms of net return and BCR. In addition, recently the outbreak of wheat blast disease is a major concern for wheat production and farmers found it as a significant threat for cultivating wheat. More research initiatives and motivational programmes are needed to encourage wheat farmers in continuing their production.

Table 4-5 shows the profitability of wheat by farm categories and it was found that small farmers are more efficient than medium farmers in wheat production in terms of BCR. There were not sufficient large farmers for analysis.

Table 4-5 Financial profitability of wheat by farm categories, 2017

COST/REVENUE	SMALL	SD	MEDIUM	SD
Tillage	4,588	1,035	4,374	947
Seed	2,522	612	2,154	501
Family supplied labour (male)	11,000	6,170	7,858	4,941
Family supplied labour (female)	4,025	2,552	2,729	2,153
Hired labour (male)	24,743	7,887	27,711	8,080
Hired labour (female)	3,283	1,806	3,743	2,773
Total labour cost	43,051	2,410	42,041	2,729
Urea	2,091	318	1,945	549
TSP	2,217	700	2,228	634
DAP	2,465	482	2,159	482
MoP	1,254	313	1,091	412
Total chemical fertiliser cost	8,027	3,174	7,423	2,689
Compost	3,274	1,883	2,117	1,197
Irrigation	3,798	1,010	3,513	505
Pesticides	1,594	534	1,227	364
Herbicides	278	433	289	375
Lease (Land use)	6,731	899	6,331	1,202
Total cost	73,863	7,498	69,469	5,954
Product	70,822	9,505	64,845	15,046
By-product	5,071	1,511	4,723	1,353
Total revenue	75,893	10,414	69,568	15,866
Net profit	2,030		99	
BCR (undiscounted)	1.03		1.00	

4.2.5 Financial profitability of mustard

Mustard is a leading oilseed crop, covering about 61% of the total oilseed area in Bangladesh. It is a cold-loving crop that is grown during the Rabi season. The total cultivated area under mustard cultivation is 0.270 million hectares which produce 0.312 m. tonnes of mustard in the 2018–19 financial year. Mustard seed is sown in the month of mid-October to November and harvesting time is late January to late February (BBS 2020). Domestic production of edible oil in Bangladesh comes from mustard and sesame. Cultivation of mustard could be possible if residual moisture remains in the field after the harvest of T. Aman rice. The popular mustard varieties include Tori-7 which is a local low-yielding and pest-susceptible variety. Recently some improved short-duration high-yielding varieties viz. Improved Tori, BARI Sarisha-14, BARI Sarisha-15 and Binasarisha-4 etc. were developed by different research organizations and being practised by the farmers (Helal *et al.* 2016). Bangladesh has been facing an acute shortage of edible oil for the last several decades. Our internal production can meet only about 21% of our consumption. The remaining 79% is met from import (Begum *et al.* 2012). There has been a big gap between the supply and demand of edible oils, which has been fulfilled through imports incurring a huge amount of foreign exchange every year. The values of imported edible oils and oilseeds were US$1,718 million and US$653, respectively in 2018–19 (Bangladesh Bank, 2019). Increased oilseed production is needed not only to meet the demand of the increased population but also to reduce the import of edible oil to save foreign currencies.

The profitability of mustard production is presented in Table 4-6 where 75 sample observations were counted. The average yield and price of mustard were 1.19 ton/ha and Tk. 2,545 per mound, respectively. It is observed from the Table that the net return for mustard cultivation is positive (8,145 Tk./ha) and BCR is greater than 1 (1.11). The findings suggest that mustard production is profitable for the farmers. Table 4-6 shows the profitability analysis for mustard production by farm categories. It reveals that medium farmers are more efficient in mustard production compared to small farmers.

Table 4-6 Financial profitability of mustard by farm categories, 2017

COST/REVENUE	SMALL	SD	MEDIUM	SD
Tillage	5,041	1,203	4,286	1,454
Seed	1,146	440	861	143
Family supplied labour (male)	19,392	11,614	14,392	9,420
Family supplied labour (female)	4,917	4,957	1,112	1,854
Hired labour (male)	15,533	8,471	14,676	6,448
Hired (female)	1,118	2,101	3,305	4,694
Total labour cost	40,960	12,707	33,485	8,420
Urea	2,371	1,134	2,042	950
TSP	2,243	2,119	860	1,581
DAP	3,229	2,634	2,030	1,459
MoP	2,289	1,320	851	758
Total chemical fertiliser cost	10,132	4,528	5,783	3,011
Compost	2,647	2,664	1,527	1,786
Irrigation	3,821	2,712	2,771	1,584
Pesticides	1,465	1,374	986	1,242
Herbicides	320	741	50	120
Lease (Land use)	8,268	1,687	7,732	1,777
Total cost	73,800	17,077	57,481	11,383
Product	77,358	16,976	65,749	20,319
By-product	4,091	1,427	2,341	374
Total revenue	81,448	17,483	68,090	20,375
Net profit	7,648		10,609	
BCR (undiscounted)	1.10		1.18	

4.2.6 FINANCIAL PROFITABILITY OF LENTIL[3]

For many decades, small-holder farmers have planted lentils in dry areas of Bangladesh. Lentils are protein-rich legumes that provide important micronutrients in a rice-based diet. Production of lentil has long lagged domestic demand in Bangladesh, where it is the preferred pulse crop for human consumption. Indeed, lentil is grown so extensively – both as a sole crop and as an intercrop with sugarcane, cereals, and mustard – that Bangladesh is the world's fourth-largest producer (ICARDA 2018). Farming of lentil is increasing gradually across the Rajshahi region including its vast Barind tract as it requires less cultivation and irrigation cost compared to many other crops especially paddy. Since the early 1990s, several improved lentil varieties have been released which include Uthfala (Barimashur-1), Barimashur-2, Barimashur-3, and Barimasur-4 (APAARI 2004; ICARDA 2017). According to the Department of Agriculture Extension (DAE), farmers are showing more interest in lentil cultivation since they reaped a lucrative market price of the crop in the last couple of years and there has been a bright scope of bringing the huge land under the pulse farming. The increasing of area under pulse farming, along with increasing crop intensity, would reduce the current water stress condition.

A master's research (Rahman, 2018) under this project has estimated the cost and return of lentil in Rajshahi and Chapainawabganj districts. The cost and return of lentil are presented in Table 4-7.

Table 4-7 Financial profitability of lentil, 2018

COST/REVENUE	Unit	Quantity	Price per unit (BDT)	Total cost/return (BDT)
Tillage		-	-	5,066
Seed	Kg	44.16	85	3,754
Family supplied labour (male)	Man-days	25.61	300	7,683
Family supplied labour (female)	Man-days	0.71	250	178
Hired labour (male)	Man-days	6.77	300	2,032
Hired (female)	Man-days	2.50	250	624
Total labour cost	-	35.59	-	10,517
Urea	Kg	19.50	16	312
TSP	Kg	47.68	22	1,049
DAP	Kg	113	26	2,945
MoP	Kg	47	15	706
Total chemical fertiliser cost		227	-	5,012
Pesticides	-	-	-	2,715
Herbicides	-	-	-	232
Lease (Land use)	-		-	7,984
Irrigation				2,610
Total cost	-	-	-	37,890
Product	Kg	1025	62	63,550
By-product	Kg	-	-	3,464
Total revenue				67,014
Net profit				29,124
BCR(undiscounted)				1.77

[3] Under the Sustainable Development Investment Portfolio (SDIP2) project, a MS thesis included a cost and return analysis of different Rabi crops in the Chapainawabgonj district. The selected crops for the study were Boro rice, wheat and lentil. As the profitability of Boro rice and wheat are described in the previous sections, a brief discussion of lentil is given here, based on the MS research work.

For calculating the costs and returns of lentil production, all variable and fixed costs were included in the cost head involved in producing lentil. These include seed, human labour, tillage, fertilizer and manure, irrigation, insecticides and pesticides, and land use cost. Human labour cost was the major cost item for producing lentil. The total cost of human labour was estimated at Tk. 10,517 covering 28% of the total cost. The tillage cost was Tk. 5,066 that occupies 13% of the total cost. Per hectare use of lentil seed was 44 kg and the average cost of lentil seed per hectare was estimated at Tk. 3,754. Seed cost occupies 10% of the total cost. Total fertilizer cost was estimated around Tk. 5,000 per hectare where most of the expense was done for DAP purchasing. Irrigation cost was not significant for lentil cultivation (Tk. 2,610) which occupies only 7% of the total cost. Per hectare cost of pesticides and herbicides use was estimated at Tk. 2,947. Land-use cost per hectare was estimated at Tk. 7,984. Per hectare lentil production was 1,025 Kg and the price was 62 Tk./kg during the study period. Moreover, Tk. 3,464 was estimated for return from by-product. Thus, the gross return of lentil was estimated at Tk. 67,014 per hectare and net return estimated at Tk. 29,124. The undiscounted BCR was 1.77 indicating that lentil is a highly profitable crop for the farmers.

4.3 Factors affecting the gross return of Aman, Boro, potato, wheat and mustard

To assess the contribution of major inputs such as human labour, land preparation, seed, manure, chemical fertilizers, insecticide and irrigation for selected crops' production, the Cobb-Douglas production function model was used. It is the most used and appropriate production function concerning agricultural production. It reveals how the quantity of output behaves as a function of the inputs used in production.

The estimated values of coefficient and related statistics of Cobb-Douglas production function are presented in Table 4-8. Eleven input coefficients were used for the analysis for Boro, wheat, potato and mustard and 10 for Aman. Most of the coefficients for the used inputs were positive for all crops, indicating a positive relationship between application of inputs and production rate. A positive relationship indicates that 1% increase of the application of any input will increase the production of the crop by the percentage of its coefficient. The coefficients are also statistically significant at 1% or 5% level.

For Aman, urea shows the highest co-efficient (0.371) which indicates that urea application can significantly increase the Aman rice production, followed by tillage cost.

A similar result was found for Boro rice. The coefficient of 0.295 for urea indicates that 1% increase in urea application will increase the production of Boro by 0.295%. For Aman and Boro all the coefficients were positive which indicates that quantity of inputs plays a vital role in case of rice production. Although the irrigation coefficient for Aman appeared to be negative; it is statistically insignificant.

In the case of mustard production, tillage is the most significant factor, followed by seed cost. TSP, irrigation and herbicides coefficients were negative which supports the fact that these variables are not so important for mustard production.

In the case of potato, coefficient of labour cost shows the highest value followed by seed cost. This result complies with the potato cultivation behaviour, i.e. potato production is a labour-intensive crop and seed is a vital input for potato production.

In the case of wheat, though most of the coefficients were positive, they are not statistically significant. The small sample size might be a reason for that.

The values of multiple determination (R^2) of the model for all the five crops were found very high (above 90%). For example, in case of Aman*,* the value of the co-efficient of multiple determination (R^2) of the Cobb-Douglas model was 0.971 indicating about 97 % of the variation in gross return of Aman production is explained by the explanatory variables included in the model. Similar results were found for other selected crops. Therefore, it can be concluded that the Cobb-Douglas production function applied here, sufficiently captured the production behaviour of the selected crops of the present study.

Table 4-8 Estimated coefficients and their related statistics of production function for selected crops

VARIABLES	AMAN	BORO	MUSTARD	POTATO	WHEAT
Tillage cost	0.220***	0.164***	0.578***	0.209**	0.016
	(0.044)	(0.035)	(0.075)	(0.077)	(0.198)
seed cost	0.065**	0.080***	0.160***	0.238***	0.182
	(0.027)	(0.030)	(0.059)	(0.065)	(0.218)
labour cost	0.148***	0.120***	0.148**	0.336***	0.381
	(0.042)	(0.029)	(0.060)	(0.072)	(0.269)
Urea cost	0.371***	0.295***	0.017	0.077	0.206
	(0.047)	(0.046)	(0.042)	(0.076)	(0.162)
TSP cost	0.022	0.032	-0.025	-0.017	0.133
	(0.034)	(0.020)	(0.034)	(0.045)	(0.097)
DAP cost	0.050**	0.049***	0.077*	-0.062*	-0.202
	(0.025)	(0.019)	(0.041)	(0.031)	(0.175)
MoP cost	0.031*	0.016	0.086**	0.073***	0.127
	(0.017)	(0.029)	(0.036)	(0.024)	(0.126)
Compost	-	0.008	0.060	0.000***	-0.019
		(0.016)	(0.040)	(0.000)	(0.072)
Irrigation	-0.013	0.098***	-0.066	0.137*	0.019
	(0.012)	(0.029)	(0.046)	(0.070)	(0.204)
Pesticides	0.229***	0.067***	0.020	0.024	0.004
	(0.034)	(0.025)	(0.047)	(0.038)	(0.147)
Herbicides	0.055*	0.054***	-0.013	-0.039	0.024
	(0.028)	(0.017)	(0.032)	(0.038)	(0.063)
Constant	2.298***	3.493***	2.515***	2.117***	3.352***
	(0.182)	(0.139)	(0.423)	(0.324)	(0.791)
N	291	598	75	118	33
R-square	0.971	0.926	0.955	0.943	0.944

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Chapter 5 OPTIMAL CROPPING CHOICE PLANNING

This chapter presents the approach of optimal cropping choice planning while minimizing costs of measures to protect food grain and nutrition security through increasing the profitability of domestic food production. Evidence discovered through development and use of a farm income optimization framework offers insights on the least cost set of policy measures to elevate farm profitability sufficiently to assure domestic production of a minimum acceptable level of food grain and nutrition security.

5.1 CROPPING SYSTEM

A crop calendar year represents three major growing seasons namely summer seasons (locally named Kharif-1 from mid-March to mid-July and Kharif-2 from mid-July to mid-November) and winter season (locally named Rabi from mid-November to mid-March) (Figure 5-1). The summer seasons are mostly rainfed and the winter season is mostly irrigated in Bangladesh. The major portion of the cereal food supply comes from winter crops. Rice is the staple food in Bangladesh. Therefore, every farmer produces rice in both seasons along with other crops and vegetables.

To discover an affordable set of measures to protect food grain and nutrition security as well as assure profitability of domestic food production, an empirical model that understand and predict farm economic optimization behaviour and can provide guidance in the search for affordable policies, has been developed. Thus, the model has been constrained to grow: 1) Kharif-1 – Aus rice and other crops (no Boro and Aus rice); 2) Kharif-2 – Aman rice only; 3) Rabi – Boro rice and other crops (no Aman and Aus rice). The model is built with a one-year planning horizon (extendable) with monthly time steps.

Figure 5-1 Cropping season and the standard crop calendars major crops (Mainuddin *et al.* 2019)

5.2 POLICIES AND SCENARIOS

The investigation examines policies that could bring more agricultural benefits to the five districts of Northwest Bangladesh. Thus, we examined the optimization of crop allocation on the available land area. Four policies, one baseline and 3 optimized, are assessed under 3 risk levels (Table 5-1):

- baseline policy (BSL) option or business-as-usual. Under this policy, the model reproduces the current situation with current crop allocation/acreage in each of the districts
- Grain food security (GFS) sets a priority on five-grain crops, namely rice (boro, aman, aus), wheat and maize. This scenario ensures grain food security as rice is the main staple food in Bangladesh,
- Nutrition food security (NFS) emphasizes the priority of the following crops: tomato, potato, mustard, jute and lentil. This scenario focus on vegetables and high-value crops which have potential to increase benefits to farmers
- Unconstrained (UNC) policy. This policy removes all previous constraints (except land constraint) and lets the model decide which crop choice would get the highest agricultural benefits possible. This policy is unlikely and is modelled for comparison.

Risk levels:

- no risk or normal condition with no shocks to the current situation
- low risk when a farmer is exposed to a risk of slight raise in production costs (all inputs including irrigation water) while crop yield and crop price are moderately falling
- high risk when a farmer experiences a severe increase in production costs and fall in crop yield and crop prices.

Table 5-1 Policies and scenarios developed for the modelling framework

Policy / Scenario	No risk	Low risk	High risk
Grain food security (GFS) Nutrition food security (NFS) Unconstrained (UNC)	Yield - normal Production costs - normal Crop price - normal	Yield – 75% of normal Production costs – 125% of normal Crop price – 75% of normal	Yield – 50% of normal Production costs – 150% of normal Crop price – 50% of normal

5.3 OPTIMIZATION FRAMEWORK

Land use planning is driven by many variables such as land type, crop yield, weather conditions, and availability of the agricultural resources, demand for agricultural products, price of products, availability of capital, and the cost of production (Sarker *et al.* 1997). Thus, such variables as capital availability, crop price, input costs (including land area, crop yield, crop production, cost of tillage, seed sowing/transplanting, labour, fertilizer and pesticides application, irrigation, lease value, where applicable) were used in the modelling framework. As the main objective of the study was to ex-post analysis of how optimally crop choice would be set, factors such as weather conditions and soil conditions were ignored.

The model was formulated to find the optimal cropping pattern by maximizing agricultural benefits in each district respecting constraints, including total land availability in each district and land area restrictions for different crops in the three different cropping seasons of the year. Thus, the objective function is set as:

$$\boldsymbol{Totben}_{v\,(n,p)} = \sum_d \quad \sum_t \boldsymbol{Agben}_{v(d,t,n,p)} \qquad \text{Equation 5-1}$$

where, *Totben_v (n,p)* is the value of all benefits (in this particular case only agricultural benefits are considered) by scenario *n* and policy *p*; *Agben_v (d,t,n,p)* is net agriculture-related benefits in district *d*, period *t*, scenario *n* and policy *p,* and defined as:

$$\boldsymbol{Agben}_{v(d,t,n,p)} = \sum_j \quad \sum_k \left[\boldsymbol{crop}_{\boldsymbol{price}_v(j,t,n,p)} * \boldsymbol{yield}_p(\boldsymbol{d},\boldsymbol{j},\boldsymbol{k}) - \boldsymbol{cost}_{\boldsymbol{prod}_p(d,j,k)}\right] * \boldsymbol{hectares}_{v(d,j,k,t,n,p)} \qquad \text{Equation 5-2}$$

where, crop_price_v (j,t,n,p) is the price of crop j, *yield_p (d,j,k)* crop yield in district *d* and cropping season *k*, and *cost_prod (d,j,k)* is the cost of production in that district per crop and season. The parameters yield_p(d,j,k) and cost_prod_p (d,j,k) are given, however crop_price_v(j,t,n,p) price of a particular crop is a negatively sloping demand function, which means that one price is set for each crop for all districts, so any crop can migrate to any district with the most favourable economic conditions (lesser production costs). This means that:

$$Crop_{price_v(j,t,n,p)} = \gamma_0 + \gamma_1 * \sum_k Tot_{prod_v(j,k,t,n,p)} \quad \text{Equation 5-3}$$

where crop_price_v (j,t,n,p,) is price of crop, *Tot_prod_v (j,k,t,n,p)* total crop production. The empirically estimated coefficients γ_0 and γ_1 above are linearized demand functions based on estimated price elasticities combined with observed historical crop prices and production. To measure total crop production *Tot_prod_v (j,k,t,n,p)* the following function is used:

$$Tot_{prod_v(j,k,t,n,p)} = Land_{v(d,j,k,t,n,p)} * yield_{p(d,j,k)} \quad \text{Equation 5-4}$$

where Land_v(d,j,k,t,n,p) is land in production by district, crop, season, time, scenario and policy.

Economic benefits are produced using agricultural inputs in each district. Thus, the willingness to pay is measured by the contribution of inputs to net agricultural revenue which equals crop price multiplied by yield minus cost of production plus any unpriced consumer surplus. Consumer surplus is an unpriced value, equal to the amount by which power buyers' economic welfare exceeds the actual price charged. It is measured as the area beneath the demand function and above the actual price charged:

$$Cons_{surpl_{v(j,t,n,p)}} = 0.5 * \left[b_{0_{p(j)}} - crop_{price_{v(j,t,n,p)}}\right] * \sum_k Tot\_prod_{v(j,k,t,n,p)} \quad \text{Equation 5-5}$$

Land use patterns affect the water demand. For irrigated agriculture, total land in production is expressed as:

$$\sum_j \sum_k Land_{v(d,j,k,t,n,p)} \leq Land_{p(d,t,n,p)} \quad \text{Equation 5-6}$$

This states that land in production by district, crop, season, and time, summed over crops and seasons cannot exceed available land, *Land_p (d,t,n,p).* In Bangladesh land is the limiting resource therefore we used the maximum current capacity in land for districts as the upper limit on available land.

For each crop, a single demand function across the districts is specified as a declining price that is a function of total production in the region. This reflects a price-dependent linear demand function. Model validation is important for credibility. When the optimization model is constrained to reproduce base crop pattern, crop production, and land area, the model reproduces historical (calculated) farm income by a district.

The baseline policy analysis is constrained to replicate historical land by district and crop. For the alternative policies, those constraints are removed by allowing water trade-offs to occur among districts. Either policy permits crop choice to change to reach higher economic value for farmers where the economics would support such a reallocation. The General Algebraic Modelling System (GAMS) language was used to program the model (Brooke *et al.* 2006).

5.4 FINDINGS

5.4.1 OVERVIEW

In general, we find that the current crop choices might be improved and the cropping pattern could be optimized to reach an economically profitable production level while recognising the imposed constraints (Figure 5-2). Each of the considered policy options could produce additional economic (agricultural) benefits for each district. The key findings are:

- The agricultural benefits for all districts will increase in all three policy scenarios. Under GFS, the combined benefits could increase by 13.7% (averaged over three risk scenarios), by 22.6% under NFS (averaged over three risk scenarios), and under UNC agricultural benefits could jump by 25.4% (averaged over three risk scenarios) compared to the BSL policy (Figure 5-2).
- However, benefits won't rise equally in all districts. For example, Bogura district will have the highest increase by 50.2%, 56.3%, and 59.3% in GFS, NFS and UNC scenarios respectively. The lowest growth is observed in the Rajshahi district in all three policies, GFS (5.7%), NFS (7.7%) and UNC (10.4%).
- If the UNC policy option is not considered, the NFS policy could provide more economic benefits than the GFS policy in each of the risk scenarios: by 12.9% more in No risk, by 9% more in Low risk, and by 8.6% more in High-risk scenarios.

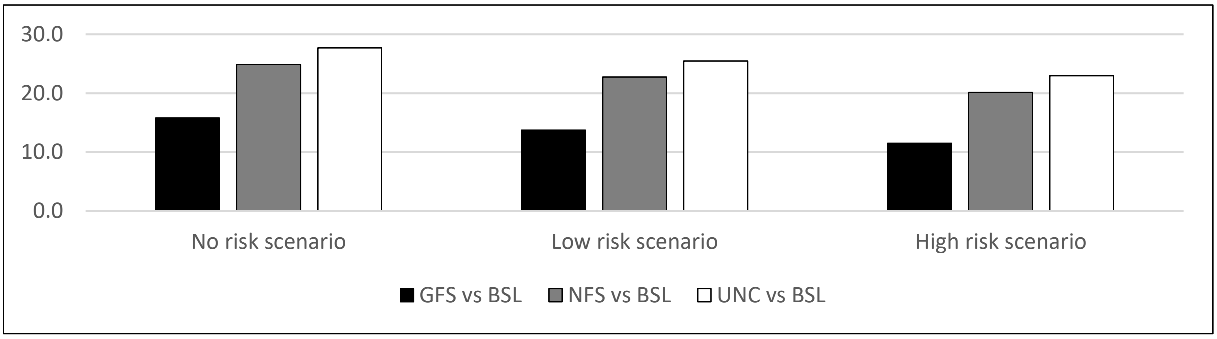


Figure 5-2 Percentage increase in agricultural benefits of each modelled policy on compare with the Baseline policy by scenarios

5.4.2 CROPPING SYSTEM

This subsection examines the main findings against the overarching objective of the study. Table 5-2 to Table 5-6 show land areas under various crops in the districts in each policy and scenario option. While results in the tables are presented by districts, it seems logical to explain them by policy as districts follow similar patterns in most of the policies.

It should be mentioned again that all policies are characterized and constrained as follows: 1) First season - all crops but Boro rice and Aman rice; 2) Second season – Aman rice only; 3) Third season – all crops but Aman rice and Aus rice. This condition lets the optimization run for the first and third cropping seasons.

UNDER BASELINE (BSL) POLICY

The Baseline condition in each district has reproduced the situation according to the collected dataset. Thus, each district produces a range of crops in the first and third seasons, except Bogura that does not grow wheat in any of the cropping seasons (presumably due to the soil, water, and/or weather conditions) and respectively this condition is reflected in the other policies and scenarios as well.

It can be noticed that total land under production in each district in all optimized scenarios is always higher than in the Baseline scenario. This happens due to the fact that the optimization framework has a constraint permitting variation in the total land in each district up to a 10% increase. With the increase in risk level, the model reduced acreage under such crops as mustard, jute and Aus rice.

UNDER GRAIN FOOD SECURITY (GFS) POLICY

As expected, following imposed constraints, districts in this policy distribute land for grain crops at least as the same acreage as in the Baseline policy option. Thus, in the first season – the same area is allocated for Aus, maize and wheat, while the area under tomato (Bogura only) and potato (all districts) increased significantly. This may show that potato growing is more profitable than grain crops growing. The second season is characterized by the allocation of all available land from Aman rice. In the third season, Boro rice is taking the lead while tomato and potato areas decreased. In some cases, the tomato was out of production.

With the rise in risk, factor districts pursue different policies: for instance, Bogura stops tomato growing, Chapainawabganj and Rajshahi reduce the area under wheat and Aus rice, Dinajpur distributes less for wheat and potato, and Nilphamari cuts wheat. When the model cuts area under Aus rice, wheat or any other grain crops it does not violate the imposed constraint as the constraint says – 'land under grain crops in GFS policy must be the same or larger than in the same scenario of the same policy.' As such that acreage could have been cut already in the same scenario of Baseline policy.

UNDER NUTRITION FOOD SECURITY (NFS) POLICY

Under this policy, the model focused on the production of the rest of the crops. This option could happen only in the first and third seasons. As such, the area under grains dropped to zero while the area under potato and tomato (Bogura only) increased many folds. The area of other high-value crops stays the same as in the Baseline policy option. This situation repeated in the third season too.

When the risk factor starts playing a role, Bogura reduces tomato and jute and increases potato area; Chapainawabganj reduces mustard, lentil, potato and increased maize (high risk); Dinajpur also reduces potato, mustard, jute and increases tomato (high risk); Nilphamari reduces mustard and jute, and Rajshahi reduces mustard and lentil increases potato production.

UNDER UNCONSTRAINED (UNC) POLICY

While such a policy is almost impossible to imagine, it is enlightening to consider what would be the choice under a full optimized condition. The distinctive feature of this policy is that two districts (Nilphamari, Rajshahi) in all scenarios choose to grow potato only in the first and the third seasons; Chapainawabganj and Dinajpur do the same, except in High-risk scenario they grow maize (Chapainawabganj) and tomato (Dinajpur); Bogura district grows tomato and potato in No risk and Low-risk scenarios and switches to potato only in High-risk scenario. This kind of behaviour could point to high profitability of such high-value crops like tomato and potato, especially potato. Moreover, these districts might have a comparative advantage in potato and tomato production. As such, the government should promote them but develop policies which would help them to market these products and keep in storages to prevent price fall when obvious excess of production occurs.

Table 5-2 Crop choices in Bogura district by the modelled policies and scenarios (hectares)

Policy	BSL			GFS			NFS			UNC		
Season	First	Second	Third	First	Second	Third	First	Second	Third	First	Second	Third
Crop/Scenario	No risk											
Boro	0	0	197,122	0	0	197,122	0	0	0	0	0	0
Aman	0	188,755	0	0	300,000	0	0	300,000	0	0	300,000	0
Tomato	204	0	204	9,137	0	0	4,593	0	4,593	12,231	0	12,231
Potato	62,890	0	62,890	262,745	0	94,582	267,845	0	267,845	285,900	0	285,900
Mustard	10,043	0	10,043	0	0	0	10,043	0	10,043	0	0	0
Jute	17,276	0	17,276	0	0	0	17,276	0	17,276	0	0	0
Lentil	243	0	243	0	0	0	243	0	243	0	0	0
Wheat	0	0	0	0	0	0	0	0	0	0	0	0
Maize	8,296	0	8,296	8,296	0	8,296	0	0	0	1,869	0	1,869
Aus	19,822	0	0	19,822	0	0	0	0	0	0	0	0
	Low risk											
Boro	0	0	197,122	0	0	197,122	0	0	0	0	0	0
Aman	0	188,755	0	0	300,000	0	0	300,000	0	0	300,000	0
Tomato	204	0	204	10,238	0	5,441	5,741	0	5,741	13,350	0	13,350
Potato	62,890	0	62,890	261,644	0	89,142	267,653	0	267,653	286,650	0	286,650
Mustard	9,087	0	9,087	0	0	0	9,087	0	9,087	0	0	0
Jute	17,276	0	17,276	0	0	0	17,276	0	17,276	0	0	0
Lentil	243	0	243	0	0	0	243	0	243	0	0	0
Wheat	0	0	0	0	0	0	0	0	0	0	0	0
Maize	8,296	0	8,296	8,296	0	8,296	0	0	0	0	0	0
Aus	19,822	0	0	19,822	0	0	0	0	0	0	0	0
	High risk											
Boro	0	0	197,122	0	0	197,122	0	0	0	0	0	0
Aman	0	188,755	0	0	300,000	0	0	300,000	0	0	300,000	0
Tomato	204	0	204	0	0	0	204	0	204	0	0	0
Potato	62,890	0	62,890	273,770	0	94,582	274,836	0	274,836	300,000	0	300,000
Mustard	9,087	0	9,087	0	0	0	9,087	0	9,087	0	0	0
Jute	15,630	0	15,630	0	0	0	15,630	0	15,630	0	0	0
Lentil	243	0	243	0	0	0	243	0	243	0	0	0
Wheat	0	0	0	0	0	0	0	0	0	0	0	0
Maize	8,296	0	8,296	8,296	0	8,296	0	0	0	0	0	0
Aus	17,934	0	0	17,934	0	0	0	0	0	0	0	0

Table 5-3 Crop choices in Chapainawabganj district by the modelled policies and scenarios (hectares)

Policy	BSL			GFS			NFS			UNC		
Season	First	Second	Third	First	Second	Third	First	Second	Third	First	Second	Third
Crop/Scenario	No risk											
Boro	0	0	50,447	0	0	50,447	0	0	0	0	0	0
Aman	0	55,659	0	0	100,000	0	0	100,000	0	0	100,000	0
Tomato	594	0	594	0	0	0	594	0	594	0	0	0
Potato	1,643	0	1,643	12,174	0	10,995	96,127	0	96,127	100,000	0	100,000
Mustard	2,539	0	2,539	0	0	0	2,539	0	2,539	0	0	0
Jute	525	0	525	0	0	0	525	0	525	0	0	0
Lentil	215	0	215	0	0	0	215	0	215	0	0	0
Wheat	32,438	0	32,438	32,438	0	32,438	0	0	0	0	0	0
Maize	6,120	0	6,120	6,120	0	6,120	0	0	0	0	0	0
Aus	49,268	0	0	49,268	0	0	0	0	0	0	0	0
	Low risk											
Boro	0	0	50,447	0	0	50,447	0	0	0	0	0	0
Aman	0	55,659	0	0	100,000	0	0	100,000	0	0	100,000	0
Tomato	594	0	594	0	0	0	594	0	594	0	0	0
Potato	1,643	0	1,643	12,174	0	10,995	96,389	0	96,389	100,000	0	100,000
Mustard	2,297	0	2,297	0	0	0	2,297	0	2,297	0	0	0
Jute	525	0	525	0	0	0	525	0	525	0	0	0
Lentil	195	0	195	0	0	0	195	0	195	0	0	0
Wheat	32,438	0	32,438	32,438	0	32,438	0	0	0	0	0	0
Maize	6,120	0	6,120	6,120	0	6,120	0	0	0	0	0	0
Aus	49,268	0	0	49,268	0	0	0	0	0	0	0	0
	High risk											
Boro	0	0	50,447	0	0	50,447	0	0	0	0	0	0
Aman	0	55,659	0	0	100,000	0	0	100,000	0	0	100,000	0
Tomato	594	0	594	0	0	0	594	0	594	0	0	0
Potato	1,643	0	1,643	19,955	0	14,084	43,788	0	43,788	15,165	0	15,165
Mustard	2,297	0	2,297	0	0	0	2,297	0	2,297	0	0	0
Jute	475	0	475	0	0	0	475	0	475	0	0	0
Lentil	195	0	195	0	0	0	195	0	195	0	0	0
Wheat	29,348	0	29,348	29,348	0	29,348	0	0	0	0	0	0
Maize	6,120	0	6,120	6,120	0	6,120	52,651	0	52,651	84,835	0	84,835
Aus	44,576	0	0	44,576	0	0	0	0	0	0	0	0

Table 5-4 Crop choices in Dinajpur district by the modelled policies and scenarios (hectares)

Policy	BSL			GFS			NFS			UNC		
Season	First	Second	Third	First	Second	Third	First	Second	Third	First	Second	Third
Crop/Scenario						No risk						
Boro	0	0	186,398	0	0	186,398	0	0	0	0	0	0
Aman	0	267,394	0	0	350,000	0	0	350,000	0	0	350,000	0
Tomato	2,790	0	2,790	0	0	0	2,790	0	2,790	0	0	0
Potato	46,712	0	46,712	252,706	0	71,776	332,199	0	332,199	350,000	0	350,000
Mustard	5,563	0	5,563	0	0	0	5,563	0	5,563	0	0	0
Jute	9,211	0	9,211	0	0	0	9,211	0	9,211	0	0	0
Lentil	237	0	237	0	0	0	237	0	237	0	0	0
Wheat	23,739	0	23,739	23,739	0	23,739	0	0	0	0	0	0
Maize	68,086	0	68,086	68,086	0	68,086	0	0	0	0	0	0
Aus	5,468	0	0	5,468	0	0	0	0	0	0	0	0
						Low risk						
Boro	0	0	186,398	0	0	186,398	0	0	0	0	0	0
Aman	0	267,394	0	0	350,000	0	0	350,000	0	0	350,000	0
Tomato	2,790	0	2,790	0	0	0	2,790	0	2,790	0	0	0
Potato	46,712	0	46,712	252,706	0	71,776	332,729	0	332,729	350,000	0	350,000
Mustard	5,033	0	5,033	0	0	0	5,033	0	5,033	0	0	0
Jute	9,211	0	9,211	0	0	0	9,211	0	9,211	0	0	0
Lentil	237	0	237	0	0	0	237	0	237	0	0	0
Wheat	23,739	0	23,739	23,739	0	23,739	0	0	0	0	0	0
Maize	68,086	0	68,086	68,086	0	68,086	0	0	0	0	0	0
Aus	5,468	0	0	5,468	0	0	0	0	0	0	0	0
						High risk						
Boro	0	0	186,398	0	0	186,398	0	0	0	0	0	0
Aman	0	267,394	0	0	267,394	0	0	251,751	0	0	251,751	0
Tomato	2,790	0	2,790	22,112	0	15,944	19,445	0	19,445	24,824	0	24,824
Potato	46,712	0	46,712	233,375	0	58,093	316,951	0	316,951	325,176	0	325,176
Mustard	5,033	0	5,033	0	0	0	5,033	0	5,033	0	0	0
Jute	8,333	0	8,333	0	0	0	8,333	0	8,333	0	0	0
Lentil	237	0	237	0	0	0	237	0	237	0	0	0
Wheat	21,479	0	21,479	21,479	0	21,479	0	0	0	0	0	0
Maize	68,086	0	68,086	68,086	0	68,086	0	0	0	0	0	0
Aus	4,948	0	0	4,948	0	0	0	0	0	0	0	0

Table 5-5 Crop choices in Nilphamari district by the modelled policies and scenarios (hectares)

Policy	BSL			GFS			NFS			UNC		
Season	First	Second	Third	First	Second	Third	First	Second	Third	First	Second	Third
Crop/Scenario	No risk											
Boro	0	0	85,132	0	0	85,132	0	0	0	0	0	0
Aman	0	113,537	0	0	150,000	0	0	150,000	0	0	150,000	0
Tomato	227	0	227	0	0	4,316	227	0	227	0	0	0
Potato	23,029	0	23,029	127,504	0	38,178	140,242	0	140,242	150,000	0	150,000
Mustard	407	0	407	0	0	0	407	0	407	0	0	0
Jute	9,068	0	9,068	0	0	0	9,068	0	9,068	0	0	0
Lentil	56	0	56	0	0	0	56	0	56	0	0	0
Wheat	5,115	0	5,115	5,115	0	5,115	0	0	0	0	0	0
Maize	17,259	0	17,259	17,259	0	17,259	0	0	0	0	0	0
Aus	123	0	0	123	0	0	0	0	0	0	0	0
	Low risk											
Boro	0	0	85,132	0	0	85,132	0	0	0	0	0	0
Aman	0	113,537	0	0	150,000	0	0	150,000	0	0	150,000	0
Tomato	227	0	227	0	0	0	227	0	227	0	0	0
Potato	23,029	0	23,029	127,504	0	42,495	140,281	0	140,281	150,000	0	150,000
Mustard	369	0	369	0	0	0	369	0	369	0	0	0
Jute	9,068	0	9,068	0	0	0	9,068	0	9,068	0	0	0
Lentil	56	0	56	0	0	0	56	0	56	0	0	0
Wheat	5,115	0	5,115	5,115	0	5,115	0	0	0	0	0	0
Maize	17,259	0	17,259	17,259	0	17,259	0	0	0	0	0	0
Aus	123	0	0	123	0	0	0	0	0	0	0	0
	High risk											
Boro	0	0	85,132	0	0	85,132	0	0	0	0	0	0
Aman	0	113,537	0	0	150,000	0	0	150,000	0	0	150,000	0
Tomato	227	0	227	0	0	0	227	0	227	0	0	0
Potato	23,029	0	23,029	127,991	0	42,982	141,145	0	141,145	150,000	0	150,000
Mustard	369	0	369	0	0	0	369	0	369	0	0	0
Jute	8,204	0	8,204	0	0	0	8,204	0	8,204	0	0	0
Lentil	56	0	56	0	0	0	56	0	56	0	0	0
Wheat	4,627	0	4,627	4,627	0	4,627	0	0	0	0	0	0
Maize	17,259	0	17,259	17,259	0	17,259	0	0	0	0	0	0
Aus	123	0	0	123	0	0	0	0	0	0	0	0

Table 5-6 Crop choices in Rajshahi district by the modelled policies and scenarios (hectares)

Policy	BSL			GFS			NFS			UNC		
Season	First	Second	Third	First	Second	Third	First	Second	Third	First	Second	Third
Crop/Scenario	No risk											
Boro	0	0	73,576	0	0	73,576	0	0	0	0	0	0
Aman	0	75,419	0	0	200,000	0	0	200,000	0	0	200,000	0
Tomato	4,291	0	4,291	0	0	0	4,291	0	4,291	0	0	0
Potato	37,982	0	37,982	118,997	0	86,186	152,491	0	152,491	200,000	0	200,000
Mustard	16,465	0	16,465	0	0	0	16,465	0	16,465	0	0	0
Jute	11,575	0	11,575	0	0	0	11,575	0	11,575	0	0	0
Lentil	15,178	0	15,178	0	0	0	15,178	0	15,178	0	0	0
Wheat	25,854	0	25,854	25,854	0	25,854	0	0	0	0	0	0
Maize	14,384	0	14,384	14,384	0	14,384	0	0	0	0	0	0
Aus	40,765	0	0	40,765	0	0	0	0	0	0	0	0
	Low risk											
Boro	0	0	73,576	0	0	73,576	0	0	0	0	0	0
Aman	0	75,419	0	0	200,000	0	0	200,000	0	0	200,000	0
Tomato	4,291	0	4,291	0	0	0	4,291	0	4,291	0	0	0
Potato	37,982	0	37,982	118,997	0	86,186	155,504	0	155,504	200,000	0	200,000
Mustard	14,897	0	14,897	0	0	0	14,897	0	14,897	0	0	0
Jute	11,575	0	11,575	0	0	0	11,575	0	11,575	0	0	0
Lentil	13,732	0	13,732	0	0	0	13,732	0	13,732	0	0	0
Wheat	25,854	0	25,854	25,854	0	25,854	0	0	0	0	0	0
Maize	14,384	0	14,384	14,384	0	14,384	0	0	0	0	0	0
Aus	40,765	0	0	40,765	0	0	0	0	0	0	0	0
	High risk											
Boro	0	0	73,576	0	0	73,576	0	0	0	0	0	0
Aman	0	75,419	0	0	200,000	0	0	200,000	0	0	200,000	0
Tomato	4,291	0	4,291	0	0	0	4,291	0	4,291	0	0	0
Potato	37,982	0	37,982	125,341	0	88,649	155,504	0	155,504	200,000	0	200,000
Mustard	14,897	0	14,897	0	0	0	14,897	0	14,897	0	0	0
Jute	11,575	0	11,575	0	0	0	11,575	0	11,575	0	0	0
Lentil	13,732	0	13,732	0	0	0	13,732	0	13,732	0	0	0
Wheat	23,392	0	23,392	23,392	0	23,392	0	0	0	0	0	0
Maize	14,384	0	14,384	14,384	0	14,384	0	0	0	0	0	0
Aus	36,883	0	0	36,883	0	0	0	0	0	0	0	0

5.4.3 Crop production

Agricultural production follows patterns shown and explained in the earlier subsection. Thus, in the Baseline scenario, each district produces a variety of crops and their total production quantity depends on the costs of production, its yield and available land for the production in the specific district. The rest of the policies repeat the pattern seen in the preceding subsection as well. Rather than repeat the explanation of production patterns, the details are provided in Table 5-7 to Table 5-11 for the interested reader.

Table 5-7 Crop production in Bogura district by the modelled policies and scenarios (tonnes)

Policy	BSL			GFS			NFS			UNC		
Season	**First**	**Second**	**Third**	**First**	**Second**	**Third**	**First**	**Second**	**Third**	**First**	**Second**	**Third**
Crop/Scenario	No risk											
Boro	0	0	1,168,932	0	0	1,168,932	0	0	0	0	0	0
Aman	0	753,134	0	0	1,197,000	0	0	1,197,000	0	0	1,197,000	0
Tomato	4,559	0	4,559	204,484	0	0	102,791	0	102,791	273,721	0	273,721
Potato	1,131,387	0	1,131,387	4,726,785	0	1,701,534	4,818,530	0	4,818,530	5,143,348	0	5,143,348
Mustard	13,056	0	13,056	0	0	0	13,056	0	13,056	0	0	0
Jute	54,246	0	54,246	0	0	0	54,246	0	54,246	0	0	0
Lentil	331	0	331	0	0	0	331	0	331	0	0	0
Wheat	0	0	0	0	0	0	0	0	0	0	0	0
Maize	85,781	0	85,781	85,781	0	85,781	0	0	0	19,325	0	19,325
Aus	65,016	0	0	65,016	0	0	0	0	0	0	0	0
	Low risk											
Boro	0	0	1,168,932	0	0	1,168,932	0	0	0	0	0	0
Aman	0	753,134	0	0	1,197,000	0	0	1,197,000	0	0	1,197,000	0
Tomato	4,559	0	4,559	229,120	0	121,760	128,483	0	128,483	298,764	0	298,764
Potato	1,131,387	0	1,131,387	4,706,981	0	1,603,658	4,815,085	0	4,815,085	5,156,841	0	5,156,841
Mustard	11,813	0	11,813	0	0	0	11,813	0	11,813	0	0	0
Jute	54,246	0	54,246	0	0	0	54,246	0	54,246	0	0	0
Lentil	331	0	331	0	0	0	331	0	331	0	0	0
Wheat	0	0	0	0	0	0	0	0	0	0	0	0
Maize	85,781	0	85,781	85,781	0	85,781	0	0	0	0	0	0
Aus	65,016	0	0	65,016	0	0	0	0	0	0	0	0
	High risk											
Boro	0	0	1,168,932	0	0	1,168,932	0	0	0	0	0	0
Aman	0	753,134	0	0	1,197,000	0	0	1,197,000	0	0	1,197,000	0
Tomato	4,559	0	4,559	0	0	0	4,559	0	4,559	0	0	0
Potato	1,131,387	0	1,131,387	4,925,120	0	1,701,534	4,944,300	0	4,944,300	5,397,000	0	5,397,000
Mustard	11,813	0	11,813	0	0	0	11,813	0	11,813	0	0	0
Jute	49,079	0	49,079	0	0	0	49,079	0	49,079	0	0	0
Lentil	331	0	331	0	0	0	331	0	331	0	0	0
Wheat	0	0	0	0	0	0	0	0	0	0	0	0
Maize	85,781	0	85,781	85,781	0	85,781	0	0	0	0	0	0
Aus	58,824	0	0	58,824	0	0	0	0	0	0	0	0

Table 5-8 Crop production in Chapainawabganj district by the modelled policies and scenarios (tonnes)

Policy	BSL			GFS			NFS			UNC		
Season	First	Second	Third	First	Second	Third	First	Second	Third	First	Second	Third
Crop/Scenario	No risk											
Boro	0	0	283,009	0	0	283,009	0	0	0	0	0	0
Aman	0	228,760	0	0	411,000	0	0	411,000	0	0	411,000	0
Tomato	12,332	0	12,332	0	0	0	12,332	0	12,332	0	0	0
Potato	27,639	0	27,639	204,763	0	184,930	1,616,849	0	1,616,849	1,682,000	0	1,682,000
Mustard	2,844	0	2,844	0	0	0	2,844	0	2,844	0	0	0
Jute	1,260	0	1,260	0	0	0	1,260	0	1,260	0	0	0
Lentil	314	0	314	0	0	0	314	0	314	0	0	0
Wheat	103,152	0	103,152	103,152	0	103,152	0	0	0	0	0	0
Maize	51,289	0	51,289	51,289	0	51,289	0	0	0	0	0	0
Aus	174,902	0	0	174,902	0	0	0	0	0	0	0	0
	Low risk											
Boro	0	0	283,009	0	0	283,009	0	0	0	0	0	0
Aman	0	228,760	0	0	411,000	0	0	411,000	0	0	411,000	0
Tomato	12,332	0	12,332	0	0	0	12,332	0	12,332	0	0	0
Potato	27,639	0	27,639	204,763	0	184,930	1,621,260	0	1,621,260	1,682,000	0	1,682,000
Mustard	2,573	0	2,573	0	0	0	2,573	0	2,573	0	0	0
Jute	1,260	0	1,260	0	0	0	1,260	0	1,260	0	0	0
Lentil	284	0	284	0	0	0	284	0	284	0	0	0
Wheat	103,152	0	103,152	103,152	0	103,152	0	0	0	0	0	0
Maize	51,289	0	51,289	51,289	0	51,289	0	0	0	0	0	0
Aus	174,902	0	0	174,902	0	0	0	0	0	0	0	0
	High risk											
Boro	0	0	283,009	0	0	283,009	0	0	0	0	0	0
Aman	0	228,760	0	0	411,000	0	0	411,000	0	0	411,000	0
Tomato	12,332	0	12,332	0	0	0	12,332	0	12,332	0	0	0
Potato	27,639	0	27,639	335,648	0	236,892	736,520	0	736,520	255,071	0	255,071
Mustard	2,573	0	2,573	0	0	0	2,573	0	2,573	0	0	0
Jute	1,140	0	1,140	0	0	0	1,140	0	1,140	0	0	0
Lentil	284	0	284	0	0	0	284	0	284	0	0	0
Wheat	93,328	0	93,328	93,328	0	93,328	0	0	0	0	0	0
Maize	51,289	0	51,289	51,289	0	51,289	441,211	0	441,211	710,919	0	710,919
Aus	158,244	0	0	158,244	0	0	0	0	0	0	0	0

Table 5-9 Crop production in Dinajpur district by the modelled policies and scenarios (tonnes)

Policy	BSL			GFS			NFS			UNC		
Season	First	Second	Third	First	Second	Third	First	Second	Third	First	Second	Third
Crop/Scenario	No risk											
Boro	0	0	1,183,628	0	0	1,183,628	0	0	0	0	0	0
Aman	0	1,040,163	0	0	1,361,500	0	0	1,361,500	0	0	1,361,500	0
Tomato	57,889	0	57,889	0	0	0	57,889	0	57,889	0	0	0
Potato	912,293	0	912,293	4,935,347	0	1,401,790	6,487,853	0	6,487,853	6,835,500	0	6,835,500
Mustard	5,619	0	5,619	0	0	0	5,619	0	5,619	0	0	0
Jute	30,303	0	30,303	0	0	0	30,303	0	30,303	0	0	0
Lentil	356	0	356	0	0	0	356	0	356	0	0	0
Wheat	93,771	0	93,771	93,771	0	93,771	0	0	0	0	0	0
Maize	537,881	0	537,881	537,881	0	537,881	0	0	0	0	0	0
Aus	21,053	0	0	21,053	0	0	0	0	0	0	0	0
	Low risk											
Boro	0	0	1,183,628	0	0	1,183,628	0	0	0	0	0	0
Aman	0	1,040,163	0	0	1,361,500	0	0	1,361,500	0	0	1,361,500	0
Tomato	57,889	0	57,889	0	0	0	57,889	0	57,889	0	0	0
Potato	912,293	0	912,293	4,935,347	0	1,401,790	6,498,200	0	6,498,200	6,835,500	0	6,835,500
Mustard	5,083	0	5,083	0	0	0	5,083	0	5,083	0	0	0
Jute	30,303	0	30,303	0	0	0	30,303	0	30,303	0	0	0
Lentil	356	0	356	0	0	0	356	0	356	0	0	0
Wheat	93,771	0	93,771	93,771	0	93,771	0	0	0	0	0	0
Maize	537,881	0	537,881	537,881	0	537,881	0	0	0	0	0	0
Aus	21,053	0	0	21,053	0	0	0	0	0	0	0	0
	High risk											
Boro	0	0	1,183,628	0	0	1,183,628	0	0	0	0	0	0
Aman	0	1,040,163	0	0	1,040,163	0	0	979,311	0	0	979,311	0
Tomato	57,889	0	57,889	458,830	0	330,846	403,478	0	403,478	515,104	0	515,104
Potato	912,293	0	912,293	4,557,821	0	1,134,551	6,190,062	0	6,190,062	6,350,682	0	6,350,682
Mustard	5,083	0	5,083	0	0	0	5,083	0	5,083	0	0	0
Jute	27,417	0	27,417	0	0	0	27,417	0	27,417	0	0	0
Lentil	356	0	356	0	0	0	356	0	356	0	0	0
Wheat	84,840	0	84,840	84,840	0	84,840	0	0	0	0	0	0
Maize	537,881	0	537,881	537,881	0	537,881	0	0	0	0	0	0
Aus	19,048	0	0	19,048	0	0	0	0	0	0	0	0

Table 5-10 Crop production in Nilphamari district by the modelled policies and scenarios (tonnes)

Policy	BSL			GFS			NFS			UNC		
Season	First	Second	Third	First	Second	Third	First	Second	Third	First	Second	Third
Crop/Scenario	No risk											
Boro	0	0	544,844	0	0	544,844	0	0	0	0	0	0
Aman	0	448,469	0	0	592,500	0	0	592,500	0	0	592,500	0
Tomato	5,135	0	5,135	0	0	97,723	5,135	0	5,135	0	0	0
Potato	416,587	0	416,587	2,306,543	0	690,645	2,536,984	0	2,536,984	2,713,500	0	2,713,500
Mustard	387	0	387	0	0	0	387	0	387	0	0	0
Jute	21,491	0	21,491	0	0	0	21,491	0	21,491	0	0	0
Lentil	83	0	83	0	0	0	83	0	83	0	0	0
Wheat	17,952	0	17,952	17,952	0	17,952	0	0	0	0	0	0
Maize	134,792	0	134,792	134,792	0	134,792	0	0	0	0	0	0
Aus	447	0	0	447	0	0	0	0	0	0	0	0
	Low risk											
Boro	0	0	544,844	0	0	544,844	0	0	0	0	0	0
Aman	0	448,469	0	0	592,500	0	0	592,500	0	0	592,500	0
Tomato	5,135	0	5,135	0	0	0	5,135	0	5,135	0	0	0
Potato	416,587	0	416,587	2,306,543	0	768,729	2,537,686	0	2,537,686	2,713,500	0	2,713,500
Mustard	350	0	350	0	0	0	350	0	350	0	0	0
Jute	21,491	0	21,491	0	0	0	21,491	0	21,491	0	0	0
Lentil	83	0	83	0	0	0	83	0	83	0	0	0
Wheat	17,952	0	17,952	17,952	0	17,952	0	0	0	0	0	0
Maize	134,792	0	134,792	134,792	0	134,792	0	0	0	0	0	0
Aus	447	0	0	447	0	0	0	0	0	0	0	0
	High risk											
Boro	0	0	544,844	0	0	544,844	0	0	0	0	0	0
Aman	0	448,469	0	0	592,500	0	0	592,500	0	0	592,500	0
Tomato	5,135	0	5,135	0	0	0	5,135	0	5,135	0	0	0
Potato	416,587	0	416,587	2,315,354	0	777,541	2,553,309	0	2,553,309	2,713,500	0	2,713,500
Mustard	350	0	350	0	0	0	350	0	350	0	0	0
Jute	19,444	0	19,444	0	0	0	19,444	0	19,444	0	0	0
Lentil	83	0	83	0	0	0	83	0	83	0	0	0
Wheat	16,242	0	16,242	16,242	0	16,242	0	0	0	0	0	0
Maize	134,792	0	134,792	134,792	0	134,792	0	0	0	0	0	0
Aus	447	0	0	447	0	0	0	0	0	0	0	0

Table 5-11 Crop production in Nilphamari district by the modelled policies and scenarios (tonnes)

Policy	BSL			GFS			NFS			UNC		
Season	First	Second	Third	First	Second	Third	First	Second	Third	First	Second	Third
Crop/Scenario	No risk											
Boro	0	0	429,682	0	0	429,682	0	0	0	0	0	0
Aman	0	310,728	0	0	824,000	0	0	824,000	0	0	824,000	0
Tomato	73,897	0	73,897	0	0	0	73,897	0	73,897	0	0	0
Potato	687,848	0	687,848	2,155,030	0	1,560,834	2,761,606	0	2,761,606	3,622,000	0	3,622,000
Mustard	15,312	0	15,312	0	0	0	15,312	0	15,312	0	0	0
Jute	32,411	0	32,411	0	0	0	32,411	0	32,411	0	0	0
Lentil	25,499	0	25,499	0	0	0	25,499	0	25,499	0	0	0
Wheat	75,494	0	75,494	75,494	0	75,494	0	0	0	0	0	0
Maize	107,592	0	107,592	107,592	0	107,592	0	0	0	0	0	0
Aus	158,169	0	0	158,169	0	0	0	0	0	0	0	0
	Low risk											
Boro	0	0	429,682	0	0	429,682	0	0	0	0	0	0
Aman	0	310,728	0	0	824,000	0	0	824,000	0	0	824,000	0
Tomato	73,897	0	73,897	0	0	0	73,897	0	73,897	0	0	0
Potato	687,848	0	687,848	2,155,030	0	1,560,834	2,816,182	0	2,816,182	3,622,000	0	3,622,000
Mustard	13,854	0	13,854	0	0	0	13,854	0	13,854	0	0	0
Jute	32,411	0	32,411	0	0	0	32,411	0	32,411	0	0	0
Lentil	23,070	0	23,070	0	0	0	23,070	0	23,070	0	0	0
Wheat	75,494	0	75,494	75,494	0	75,494	0	0	0	0	0	0
Maize	107,592	0	107,592	107,592	0	107,592	0	0	0	0	0	0
Aus	158,169	0	0	158,169	0	0	0	0	0	0	0	0
	High risk											
Boro	0	0	429,682	0	0	429,682	0	0	0	0	0	0
Aman	0	310,728	0	0	824,000	0	0	824,000	0	0	824,000	0
Tomato	73,897	0	73,897	0	0	0	73,897	0	73,897	0	0	0
Potato	687,848	0	687,848	2,269,933	0	1,605,426	2,816,182	0	2,816,182	3,622,000	0	3,622,000
Mustard	13,854	0	13,854	0	0	0	13,854	0	13,854	0	0	0
Jute	32,411	0	32,411	0	0	0	32,411	0	32,411	0	0	0
Lentil	23,070	0	23,070	0	0	0	23,070	0	23,070	0	0	0
Wheat	68,304	0	68,304	68,304	0	68,304	0	0	0	0	0	0
Maize	107,592	0	107,592	107,592	0	107,592	0	0	0	0	0	0
Aus	143,105	0	0	143,105	0	0	0	0	0	0	0	0

5.4.4 TOTAL FARM BENEFITS BY POLICY

All study districts in northwest Bangladesh have the potential to be better off under each of the optimized conditions. Depending on the district, those agricultural benefits vary when compared to agricultural benefits under the Baseline policy scenario. However, all show an increase. This provides evidence that the current situation with crop choice in all districts is far from the best case – they can all be improved and each district could get more agricultural benefits out of it.

Figure 5-3 shows district-wise total agricultural benefits estimated by the model for each of the developed scenarios and policies. The starting point of each district under the Baseline policy can be easily seen from this figure, and how it changes with each policy choice. Bogura district has the lowest and Rajshahi district has the highest agricultural benefits compared with the other districts in each of the policies. Another observation is that with each increase in risk level, agricultural benefits decrease in each district.

The main message in Figure 5-3 is that the policy of nutrition security (NFS) ensures higher total benefits than grain security (GFS). While the unconstrained policy (UNC) option is the highest, it is not feasible as a policy, and is included for comparison purposes only.

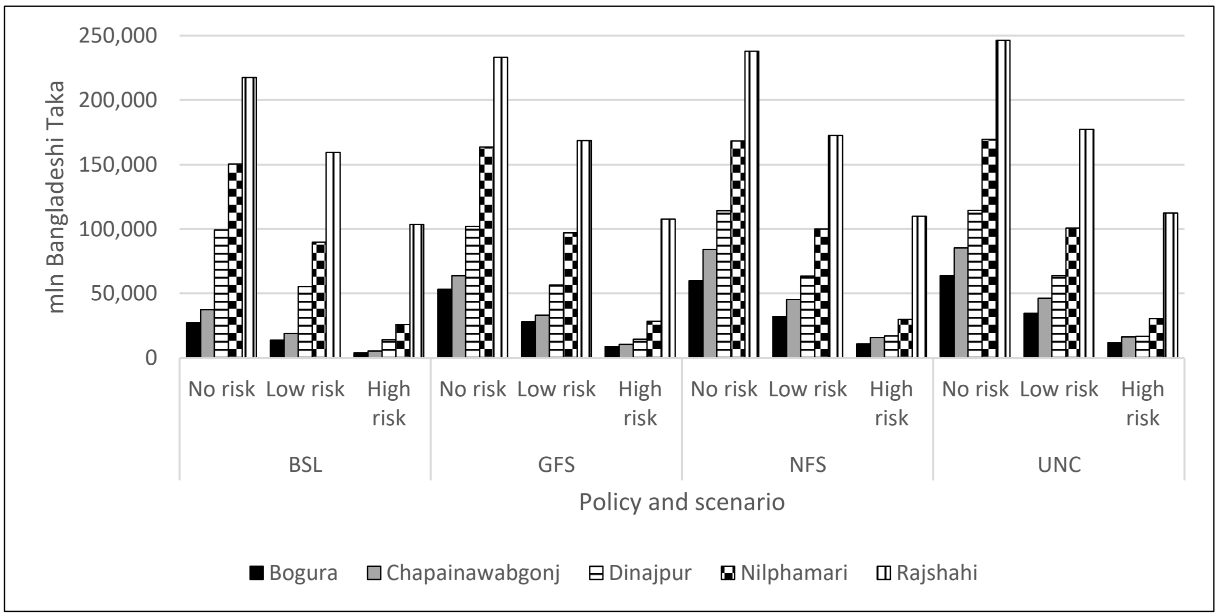


Figure 5-3 Agricultural benefits by districts, scenario, and policy

To examine the difference in agricultural benefits by scenarios and policies among the districts, Figure 5-4 has been compiled. Now one can see that Bogura district has a higher increase in agricultural benefits in any scenario in GFS policy than the other four districts. In the nutrition security (NFS) policy option, the lead is taken by the Dinajpur district. These two districts could potentially increase their agricultural benefits by manifolds while the other three districts have to increase by less than 20% in any of policy and scenario.

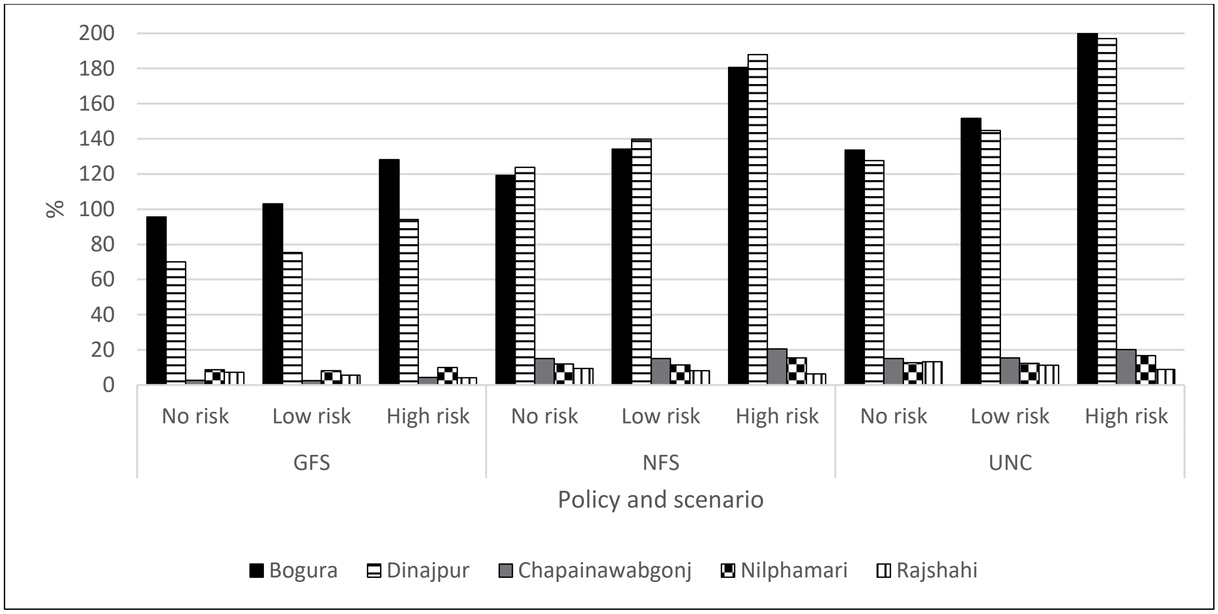


Figure 5-4 Comparison of each policy with the Baseline policy option by districts (% change in agricultural benefits)

In summary, all districts can increase their agricultural benefits with the reconsidered (optimal) crop choice conditions. These findings show the importance of selecting optimal crop choice depending on policy preference. While some districts could have a smaller increase than others, the overall optimized crop choice could supply considerable welfare gain for the region of northwest Bangladesh.

5.5 DISCUSSION AND LIMITATIONS OF THIS STUDY

Crops overproduction or excess production of food is a frequent problem in Bangladesh's agriculture. In 2014 farmers threw tons of paddy rice on the roads of the capital city of Dhaka; earlier that year tons of tomato were thrown in the roads of several cities (Capacity4dev 2014). In both cases, the farmers' agitation was caused by low prices for both crops which did not cover production costs. More recent cases are recorded in 2018 when a fall in tomato prices resulted in heavy losses for farmers – the reason is again overproduction, absence of storage facilities and traffic congestion (Hortidaily 2018). The situation is becoming worse – in 2019 farmers in several districts set fire and burnt their paddy rice fields frustrated by low rice prices which again did not cover production costs. It seems that the problem of excess crop production could be the outcome of a not well-set crop choice system. In many cases, farmers choose crops based on the last production season where, for example, the tomato was in big demand and prices were higher. Eventually, this brings a large and significant problem with no storage facilities and crop insurance system.

The study has addressed the issue by presenting results of the experimental crop choice model for northwest Bangladesh, an important case in agricultural production for which methodological approaches are widely discussed in the literature. The challenge facing the considered region is compelling, as it includes the increasing competition for the scarce land resources, decreasing rural population and problem of efficiency in agriculture. Important questions challenged by this study addressed the optimal allocation of scarce land area under available crops, in cropping seasons and districts of the region to ensure food security for those on a traditional diet based on rice or promote security about nutrition diversity. As such the analysis has focused on the optimization of cropping pattern in five districts of the northwest region of Bangladesh. Results support an optimistic outcome as there are higher agricultural benefits that can be secured in each district under each of the modelled policy scenarios. Moreover, agricultural benefits in nutrition food security policy supersede benefits obtained in the grain food security policy. However, the benefits vary significantly across the districts.

While the study has presented several important policy scenarios in cropping choice optimization, the following caveats apply:

- information on the elasticity of demand of majority crops for this region is not yet studied and thus numbers from another comparable part of the world have been used
- fruits and other important nutritional crops are not included
- a simplistic deterministic approach in optimizing crops' allocation about risk assessment factor was adopted, rather than a probabilistic approach
- a presumption that it is easy and desirable (for farmers) to quickly switch among crops which might not be the case for some crops.

Nonetheless, the analysis demonstrates that a diversified and optimized cropping system may secure dietary requirements for the population and increase household income and agricultural benefits of local farmers. The study reproduced the current cropping pattern in northwest Bangladesh, its monetary value and identified how optimal crop choice could increase farmers' income. The evidence from the empirical study offers insights into how the existing nonoptimal situation results in less agricultural benefits and how much economic gain could be achieved under a close to optimal cropping pattern system.

In this way, the modelling results can inform planners and policymakers to evaluate the different management options for crop choice and agricultural development in the region.

Chapter 6 GENDER ANALYSIS

6.1 GENDER-BASED PARTICIPATION

Gender analysis incorporates concepts of patriarchy and masculinity (Connelll, 2005) with an intersectionality perspective (Shields, 2008) to analyze men's views of women's involvement in farming and on-farm decision making. Both patriarchy and an intersectionality perspective have been integrated to address the perception of men and women in women's involvement in farming and decisions at farm and household cohorts as portrayed in Figure 6-1. In fact, patriarchy and intersectionality perspective offer methodological tools that support the development of gender research through in-depth attention to both heterogeneity of effects and causal processes producing gender inequalities. The intersectionality perspective varies based on masculine identities including age, education (year of schooling of wife), farming experience, occupation, income, and resource (see Figure 6-1). As shown in the diagram, both patriarchy (household headship, mobility, wife working hour, farm size, working member) and intersectionality perspective influence men's views in recognizing women's contribution in farming that lead to consultation between them. Taking these factors into account, the framework conceptualizes that including women in consultation processes may result in women having influence in the decision making. This concept is tested by adopting an econometric logistic regression model.

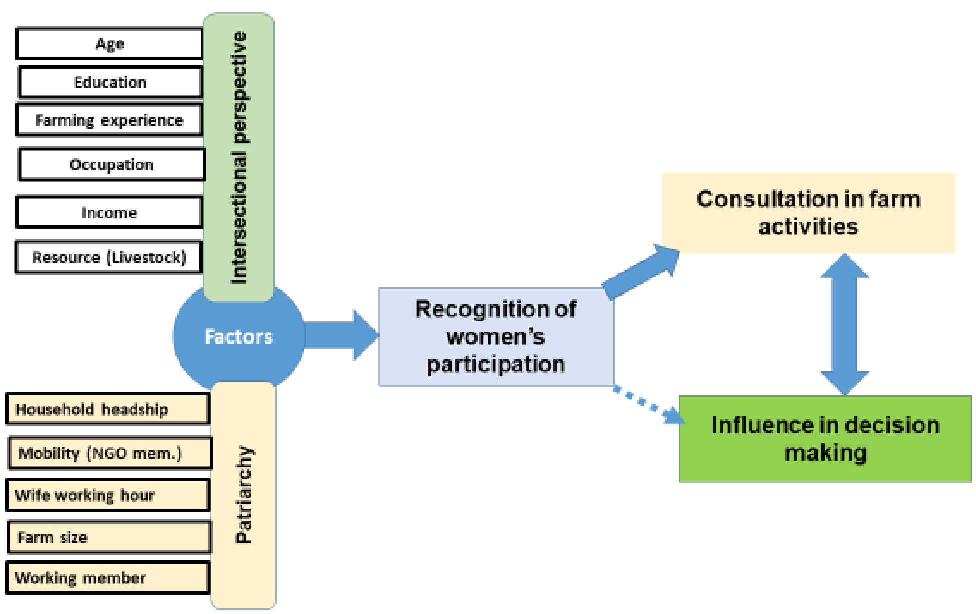


Figure 6-1 Conceptual framework for recognizing women's participation in farming and decision making

Nevertheless, to estimate the extent of participation, five categories of participation were developed as strong, high, moderate, weak and no. Strong implies the highest level of engagement and no implies not involvement. Table 6-1 shows the explanation of the categories.

Table 6-1 Extent of participation in farm activities based on category

LEVEL	EXPLANATION	SCORE
Strong	Wife solely participate in farm activities	100%
High	Both husband and wife participate in farm activities jointly, but the wife does most	70-99%
Moderate	Both husband and wife participate in farm activities jointly but wife play a significant role	50-69%
Weak	Wife has limited input	Below 50%
None	Wife has no involvement	0%

In addition, based on the patriarchal and intersectional perspectives, several determinants have been identified (through literature reviews) that might influence men to discuss or consult with their counterparts before making final farm decisions. To identify which (and how many) of these determinants are relevant in the context of northwest Bangladesh, a logistic regression econometric model has been adopted. Logistic regression is used widely to examine and describe the relationship between a binary response variable (jointly decided or alone) and a set of predictor variables (Fitzmaurice and Laird 2001). To explain the behaviour of a binary (dichotomous) dependent variable, two scenarios were used—(i) husband decides alone, and (ii) husband decides jointly with the wife. The response variable T_i is *binary*; that is, it can have only one of two possible outcomes, denoted as 1 (joint decision) and 0 (alone decision) based on the quantitative survey results. The outcome variable (T_i) was thought to be influenced by the independent variables (X_i). It was assumed that the model takes the form

$$\boldsymbol{Pr}(\boldsymbol{Z} = \mathbf{1}|\boldsymbol{B}) = \boldsymbol{\varphi}(\boldsymbol{B}^{\mathbf{1}}\boldsymbol{\delta}) \qquad \text{Equation 6-1}$$

where *Pr* denotes the probability, and φ is the function of the standard normal distribution. The parameter δ is typically estimated by maximum likelihood. It is also possible to motivate the logit model as a latent variable model. Suppose there exists an auxiliary random variable,

$$\boldsymbol{Z}_i^* = \boldsymbol{\delta}_k + \boldsymbol{\delta}_k \boldsymbol{b}_{ki} + \boldsymbol{w}_i \qquad \text{Equation 6-2}$$

where $w_i \sim N(0, 1)$. Then, *Z* can be viewed as an indicator of whether it is a latent variable and positive:

$$\boldsymbol{Z} = \mathbf{1}_{\{Z^*>0\}} = \{\mathbf{1} \text{ if } \boldsymbol{Z}^* > \mathbf{0}\} \text{ i.e } \text{-}\boldsymbol{w}_i < \boldsymbol{B}^i\boldsymbol{\delta}, \mathbf{0} \text{ otherwise.} \qquad \text{Equation 6-3}$$

The main difference between logit and probit regression models is that the logit has slightly flatter tails, i.e. the normal or probit curve approaches the axes more quickly than the logit curve. Qualitatively, while logit and probit regression models give similar results, their parameter estimates are not directly comparable. The choice between the logit and probit models is largely one of convenience and convention since the substantive results are generally indistinguishable. Hence, an empirical logit model was developed to determine the factors that significantly increase the probability that a husband will consult with his wife:

$$\boldsymbol{T}_i = \boldsymbol{\alpha}_0 + \boldsymbol{\beta}_i \boldsymbol{X}_i + \cdots + \boldsymbol{e}_i \qquad \text{Equation 6-4}$$

where

T_i = Husband consults with wife, or not, in the farming decision, $\alpha =$ Intercept, $X_i =$ Explanatory variables, $\beta_i =$ Coefficient of determinants, and $e_i =$ Error term.

The explanatory variables considered in the logit model are as set out in the framework described in Figure 6-1:

- X_1 = Age of respondent (years)
- X_2 = Wife's education (years of schooling
- X_3 = Farming experience (years)
- X_4 = Main occupation (farming = 1; otherwise =0)
- X_5 = Family income (Tk/year)
- X_6 = Number of livestock and poultry
- X_7 = Household headship (female = 1; otherwise = 0)
- X_8 = Non-governmental Organization membership (female = 1; otherwise =0)
- X_9 = Wife's time allocation in farming (hours)
- X_{10} = Farm size (decimal), and X_{11} = Number of working members in the family.

6.2 DIFFERENTIATE PERCEPTION ON FEMALE INVOLVEMENT IN RICE PRODUCTION

The stereotypical assumption is that 'men farm' and 'women only help'.

In this study, the male respondents held diverse opinions about the involvement of women in agriculture. Estimation (Figure 6-2) shows that men perceived that they do most of the farm production related activities. Looking at the crop-specific extent of participation by female, among 18 activities of rice production, on average man recognized that female was greatly involved in preparing the threshing floor, drying and storage of rice ranging from 51% to 68%. Importantly, females are recognized by man as being involved in all tasks, but the perceived rate of participation as reported by the male is below 15% except for the selection of seeds (45%), threshing (29%), managing by-product (32%) (Figure 6-2). In contrast, females reported that they participate at a slightly higher level what their spouse reported (Figure 6-2). For example, females reported participation at 77% for drying rice, while their spouses reported 69%. On average, 10% variations were reported by male and female. The differentiated perception might be regarded due to self-presentation. Self-presentation in the farm context is affected by hegemonic and gendered discourses shaping the identity of 'a farmer' as reported by Michael (1996).

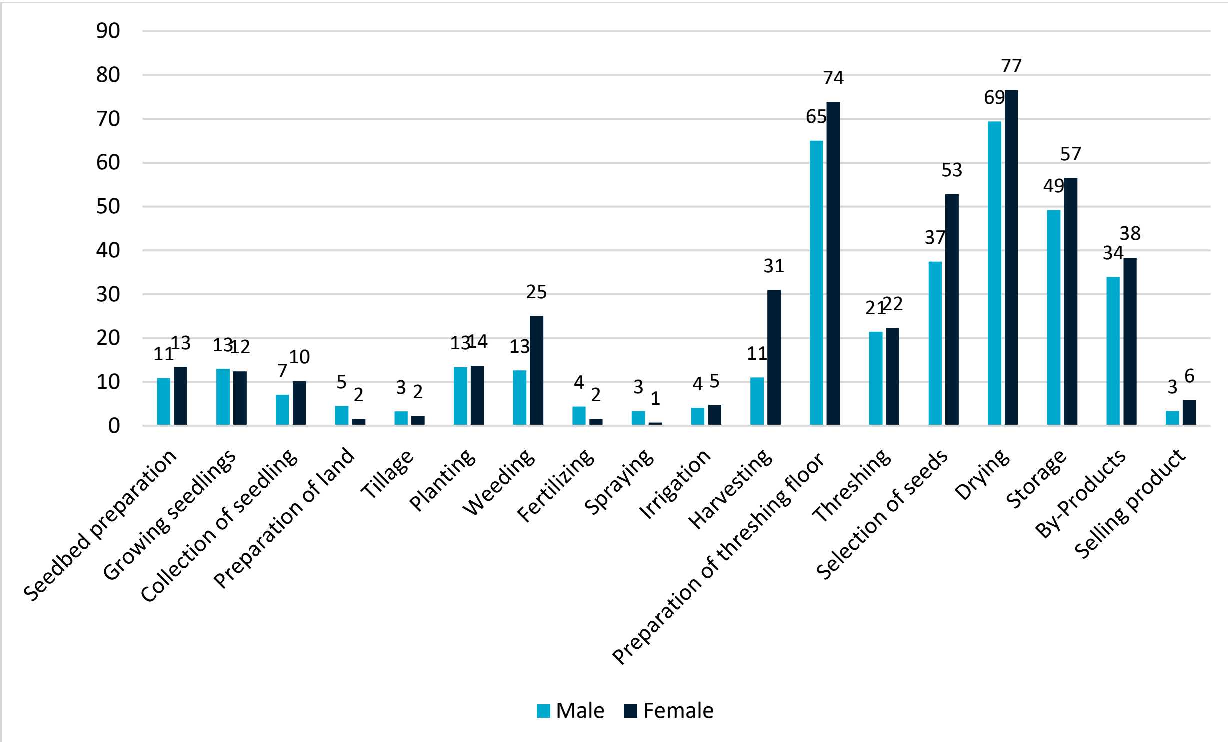


Figure 6-2 Male and female responses on female's participation in the rice production cycle

Figure 6-2 presents the extent of participation of female as reported by male and female respondents. The level of engagement is categorized as strong, high, moderate, weak and no. Among various engagement level, male recognized the highest for weak engagement (27%), followed by moderate (12 %), high (7%) and strong (5%), respectively. In contrast, women themselves recognized as moderate (19%), high (18%), strong (14%) and weak (13%) respectively. It is apparent that on average men recognized the contribution of women at weaker level than that of female. It might have a strong connection with gender norms that male feels a bit discomfort to recognize his wife's contribution publicly. Similar findings also report in a case study carried out in Syria, despite the women's increasing involvement in agricultural work and management, their role as farmers is underplayed or denied, and that various social determinants affect the ability and readiness of women themselves to assert an identity as farmers (Galie et al. 2013). In Bangladesh, men view that women cannot participate in agricultural work in the field or outside of the home; but they think wives are good for nursing and caring, preparing and serving food, making beds, taking care of children and cattle or poultry, and homestead agricultural work that requires less energy (Rahman et al., 2020; Islam, 2012).

Table 6-2 Male and female perception on the female level of engagement in rice production

ACTIVITIES	MALE PERCEIVED (response in percentage)					FEMALE SPOUSE PERCEIVED (response in percentage)				
	STRONG	HIGH	MODERATE	WEAK	NO	STRONG	HIGH	MODERATE	WEAK	NO
Seedbed preparation	-	3	4	34	59	-	-	-	25	75
Growing seedlings	1	3	6	30	60	-	-	-	24	76
Collection of seedling	1	1	3	29	66	-	-	-	12	88
Preparation of land	-	-	1	26	72		-	2	7	92
Tillage	-	-	-	26	74	2	-	-	5	93
Planting	5	4	3	28	61	13	-	-	9	78
Weeding	1	3	8	29	59	-	-	11	9	80
Fertilizing	-	-	-	30	69	-	-	-	10	90
Spraying	-	-	-	26	74	-	-	-	8	93
Irrigation	-	-	-	28	72	2	-	-	13	85
Harvesting	-	1	7	34	58	3	3	8	10	76
Preparation of threshing floor	31	20	19	23	8	40	30	13	8	9
Threshing	2	6	25	34	34	2	7	22	27	43
Selection of seeds	5	19	26	29	20	18	14	39	14	14
Drying	26	32	24	11	6	38	39	10	8	6
Storage	8	20	42	19	11	18	19	38	18	8
By-Products	5	10	38	22	26	8	11	40	10	32
Selling product		1	1	28	70			8	9	83

To justify the level of statistical significance of mean difference, an independent 't' test was performed (Table 6-3). Estimation shows that among 18 activities related to rice production, 11 were found to statistically significant at 1%, 5% and 10 % levels. There is a statistically significant difference between the mean value given a score by male (husband) that of female. Most of the cases mean difference showed that the mean value was positive or greater value; from this we can conclude that male (husband) gave a lower score than that of female spouse which is statistically significant at different levels. For example, weeding, irrigation, harvesting and selection of seeds were found to be statistically significant at less than 1% level. However, a few cases including preparation of land, fertilizer application and spraying revealed negative value implying that male gave a higher rate (score) than of female spouse.

Table 6-3 Results of independent 't' test for a rice production cycle

ACTIVITIES	T-TEST FOR EQUALITY OF MEANS	
	T	MEAN DIFFERENCE
Seedbed preparation	1.03	2.542
Growing seedlings	(0.18)	0.542
Collection of seedling	1.35	3.125
Preparation of land	(2.80)***	3.000
Tillage	(.808)	(1.083)
Planting	0.07	.292
Weeding	3.84***	(12.41)
Fertilizer application	(3.12)***	(2.875)
Spraying	(3.84)***	2.583
Irrigation	.40***	0.66
Harvesting	5.98***	19.91
Preparation of threshing floor	2.02**	8.83
Threshing	0.26	.83
Selection of seeds	3.97***	15.41
Drying	1.80*	7.16
Storage	1.91*	7.33
By-Products	1.13	4.41
Selling product	1.73*	2.50

Note: Parenthesis indicates the negative value

6.3 DIFFERENTIATE PERCEPTION ON FEMALE INVOLVEMENT IN VEGETABLE PRODUCTION

Like rice production, data were collected for twelve activities related to vegetable production (3). In most cases, men recognized the vegetable production cycle less than the female. Interestingly, although there is a variation between the groups (male and female spouse), these are in an orderly pattern. The highest variation was observed in the case of the seed selection task where male gave a score 39% to their partner (wives) while female spouse (wife) gave a maximum score 57 % to themselves. In contrast, a male (husband) gave a higher score for storage compared to a female spouse. Few cases including tillage and spraying depicted similar score for both respondents. It is apparent that men recognized their partners' involvement but varies for the different task.

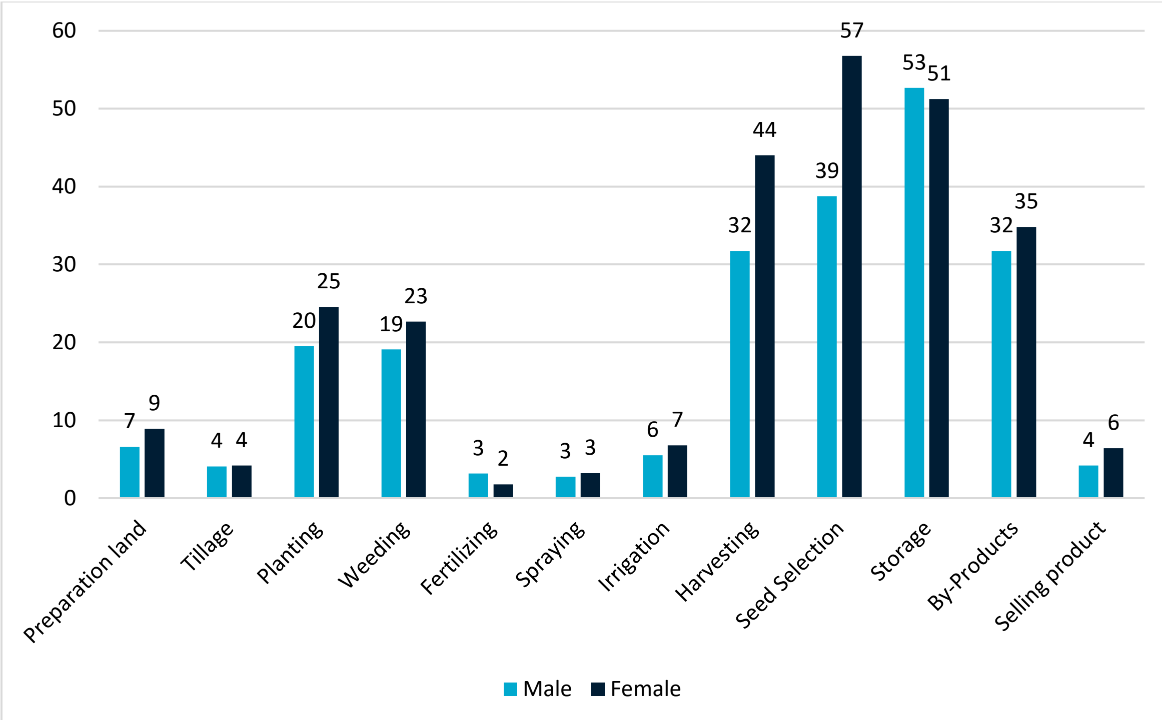


Figure 6-3 Male and female responses on female's participation in the vegetable production cycle

Table 6-4 shows the perception regarding female's level of engagement in vegetable production. It is apprehended from Table 6-4 that on average male perceived a weak level of engagement of their partner, like the rice production cycle. For seeds choice, the female spouse reported a strong level of engagement (24%) while it was reported only 3% by the male (husband). Similarly, for the storage task, female reported 19% as their strong involvement while male reported only 3%. In contrast, in many cases, it is depicted that male reported a higher level of engagement as an aggregate level than that of female spouse. For example, no involvement for land preparation was reported at 92% by the female spouse while it was 80% reported by male (husband). Women are involved in cultivation activities as well as post-harvest activities except for pre-planting activities such as ploughing (ESA 2011). In general, women are involved more in vegetable production than that of other field crops.

Table 6-5 shows the 't' test for the vegetable production cycle. Out of twelve activities, six were found to be statistically significantly different at the 1% and 5% levels of significance. Out of 6 significant variables, spraying, seed selection, and product selling were statistically significant at the 1% level, and the remaining 3 activities—fertilizing, irrigation, and harvesting—were statistically significant at the 5% level. The highest and positive mean differences were observed for seed selection (26.25), followed by harvesting (10.66), spraying (8.50), selling products (7.63), and fertilizing (6.42). These results indicate very little change in attitude from the earlier findings that, unfortunately, the role of women and their contributions in vegetable production are yet to be recognized (Kumari and Laxmikant 2015).

Table 6-4 Male and female perception on the female level of engagement in vegetable production

ACTIVITIES	MALE PERCEIVED (EXTENT OF ENGAGEMENT %)					FEMALE SPOUSE PERCEIVED (%)				
	STRONG	HIGH	MODERATE	WEAK	NO	STRONG	HIGH	MODERATE	WEAK	NO
Preparation land	1	1	6	14	80	3	-	5	-	92
Tillage	1		2	12	86		-	8		92
Planting	1	1	12	25	62	6	-	3	17	74
Weeding	2	1	6	21	72	10	-	-	8	82
Fertilizing	1		2	16	82	11	-	-	5	84
Spraying	1		1	14	85	11	-	1	16	73
Irrigation			4	19	77	8	-		12	80
Harvesting	2	5	28	23	44	8	-	15	5	72
Seed Selection	3	6	29	22	42	24	24	28	1	23
Storage	3	9	51	14	25	19	12	31	4	35
By-Products	6	5	15	5	70	8	-	12		80
Selling product	1		6	15	79	8	-	10	1	81

Table 6-5 Results of independent 't' test for a vegetable production cycle

ACTIVITIES	T	MEAN DIFFERENCE
Preparation land	0.725	1.75
Tillage	0.484	0.79
Planting	0.160	0.55
Weeding	0.108	0.42
Fertilizing	2.407**	6.42
Spraying	3.329***	8.50
Irrigation	2.047**	5.50
Harvesting	2.423**	10.66
Seed selection	6.349***	26.25
Storage	0.706	3.18
By-Products	0.787	3.75
Selling product	2.779***	7.63

= below 5% level of significance; *= below 1% level of significance

6.4 Decision-making status

Most decisions on-farm activities are made by men, as reported by both men and their wives as respondents (Figure 6-4). It is also true in the neighbouring country India women play only a supportive role in the farm decision-making process (Kumari and Laxmikant 2015). According to the male respondents, the knowledge about suitability of land for particular crops, time of tillage, time of planting and harvesting, fertilizer selection, irrigation, etc. are not well known by the females, and, as a result, decisions about these activities are mainly made by men. In the cases of seed storage, selling of products, by-products, selection of land, and selection of crops, both the husband and wife jointly decide. For example, 49% of males (husbands) report that they make the product selling decisions jointly, while females (wives) report that at 40%—there is about 10% variation. The differentiated results in our study indicate that men dominate in making farm decisions but express a higher level of joint decision-making than do the women (Figure 6-4). These results provide differentiated perceptions of males and females on who makes the decisions within the rice production cycle. It is clear from these results that, with a few exceptions, decisions related to rice production are made by males, as determined by patriarchal norms. However, focus group discussions revealed that social norms make men reluctant to publicly acknowledge their wives' influence on-farm decisions and the contributions they make. For example, women prefer to grow special varieties of rice that are used for making rice powder to prepare rice cake, which is usually taken care of by their husbands (allocating small plots), but they do not disclose this to outsiders. Similarly, qualitative findings reported that a husband should be 'all in all' and the main decision-maker in the family, and men should not take any advice from the wife. This is driven by fear of losing male authority (Karim *et.al*. 2018). Women's decision-making power in rice farming varies across and within countries. In Indonesia and Myanmar, men listen to women's opinions and make decisions jointly (Akter *et.al.* 2017). The highest amount of women's involvement in decision-making in rice farming is observed in Thailand and the Philippines (Akter *et.al.* 2017). Galie *et al.* (2013) suggest that change in the identity of women as farmers would need to be coupled to wider roles for women as farmers in social spaces currently dominated by men.

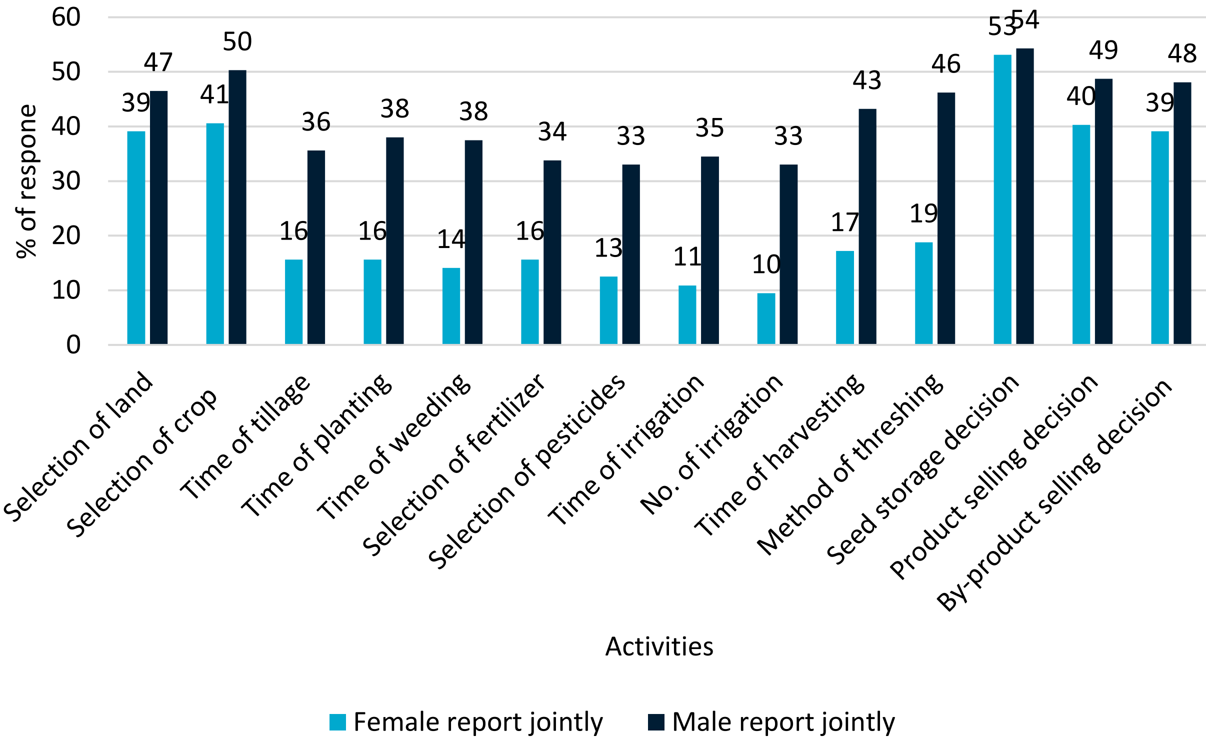


Figure 6-4 Male and female responses on female's participation in the decision-making process for the rice production cycle

Similarly, to how decisions are made in the rice production cycle, males dominate decision-making in farm activities related to vegetable production (Figure 6-5). Some males reported that decisions about the time of weeding and the number of irrigations were made jointly; however, their female spouses reported that this is not the case. In all activities, males gave a higher score for jointly made decisions than their female spouses (except for decisions about seed storage, where females (spouses) gave a higher score than that of their male counterparts). Despite women playing a greater role in vegetable cultivation, males continue to have a dominant role because of their greater decision-making power and land ownership (Joshi and Kalauni 2018). The lower participation of women in decision-making could be attributed to many things, including customs, tradition, social barriers, illiteracy, ignorance, and less participation in (and access to) agricultural extension programs (Kumari and Laxmikant 2015).

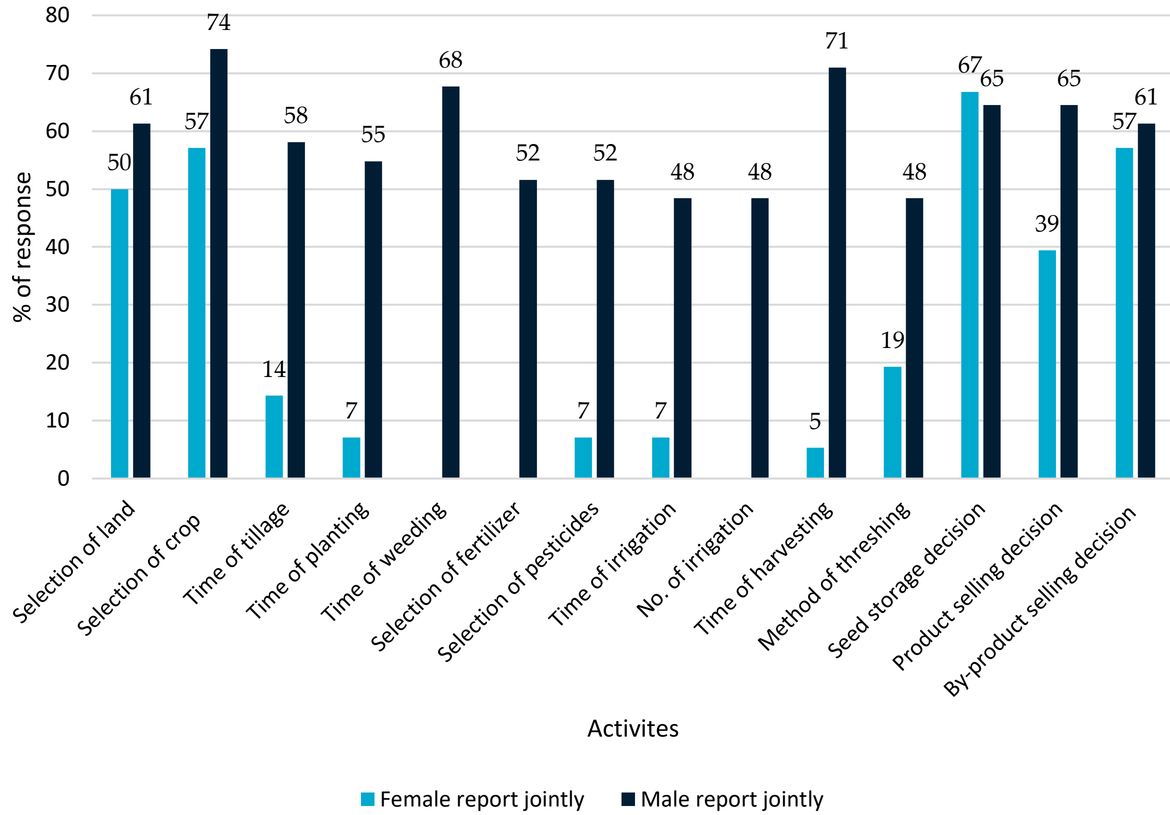


Figure 6-5 Male and female responses on female's participation in the decision-making process for the vegetable production cycle

6.5 HOUSEHOLD DECISIONS MAKING STATUS

Generally, males are responsible for crop production and protection of family assets, as well as for making all household and family decisions, while females manage the household, take care of the family members, and manage the homestead garden. Both husbands and wives reported that most household decisions are made jointly, which accounted for 89.1% (male response) and 87.7% (female response) (Table 6-6). For some activities, e.g. buying food items (15.4%), children's education (4.5%), and choosing credit institutions (5.3%), some females reported that they made the decisions alone. Almost similar findings were reported in six southeast Asian countries, with day-to-day household management decisions (such as the purchase of groceries or clothes and expenditure on school fees) commonly made by the wife alone, and decisions about credit made in mutual agreement (Akter *et.al.* 2017). An empirical study in Pakistan reported that about 23% of women are involved in household decisions, though few of them could exercise independent decision-making, as most decisions are made by the male members due to the strong patriarchal norms and values in that country (Jabeen *et.al.* 2020). In contrast, in Tanzania, husbands report more authority for their wives than wives to report in all activities (12 out of 13), except with which foods to feed the family (Anderson *et.al.* 2017) Encouragingly, women are comparatively more involved in household decision-making than in farm decision-making, as reported by both men and women.

Table 6-6 Male and female responses on household decision-making (%)

ACTIVITIES	MALE ALONE		FEMALE ALONE		JOINTLY	
	MALE RESPONSE	WIFE RESPONSE	MALE RESPONSE	WIFE RESPONSE	MALE RESPONSE	WIFE RESPONSE
Buying household assets up to Tk. 50,000	8.9	21.1	1.9	1.9	89.3	77
Buying household assets above Tk. 50,000	7.6	9	2	2	90.4	89
Buying food items	6.7	6.3	6.8	15.4	86.5	78.3
Buying non-food items	7	7	3.9	3.9	89.1	89.1
Buying land	10.9	11.1	1.2	0	87.9	88.9
Buying farm assets	24	25.2	1.2	0	74.8	74.8
Family planning	4.7	4.4	1.7	0	93.6	95.6
Children's education	4.2	2.2	1.9	4.5	93.9	93.3
Medical treatment	4.5	4.5	1.2	0	94.2	95.5
Marriage of children/siblings	4.4	4.4	1.1	0	94.6	95.6
Choosing credit institution	10	9.2	1.6	5.3	88.5	85.5
Join social club/community	14	14.1	1.1	1.1	84.8	84.8
Voting in the election	13.2	13.3	1.2	1.2	85.5	85.5
Migration	5.4	5.8	0.8	0	93.8	94.2
Overall average	9.0	9.8	2.0	2.5	89.1	87.7

6.6 INTERPRETATION OF LOGIT MODEL

A binary logistic regression was performed to assess the impact of several factors on the likelihood of husbands consulting with their wives for making decisions. The model contains 11 independent variables, as listed in Table 6-7 (and as described in the framework and Figure 6-1). The full model containing all predictors was statistically significant—Chi-square (5, N = 120) = 83.325, $p < 0.001$—indicating that the model was able to distinguish between the husbands who consult with their wives and those who do not. The model as a whole explained between 50% (Cox and Snell R square) and 72.3% (Nagelkerke R square) of the variance in consultation, and correctly classified 90.80% of cases. Furthermore, the log-likelihood function (57.925) and the proportions of samples correctly predicted for their likely status in consultation for farm decisions both indicate a good fit of the equation.

It can be seen from Table 6-7 that six explanatory variables, i.e. age, wife's education, Non-governmental Organization (NGO) membership, livestock number, family income, and wife's time allocation in farming, were statistically significant positive influences regarding consultation on-farm decisions. By far, the strongest predictor of consultation with the wife is the 'NGO membership'—its odds ratio of 12.926 indicates that, in households with NGO membership (mostly female), the likelihood of males consulting with their wives is about 13 times more than those with no NGO membership, controlling for all other factors in the model. NGOs like Grameen Bank, BRAC, and ASA (Association of Social Advancement) offer micro-credit, savings, and social services to rural women, and they have been able to demonstrate the effectiveness of their programs toward greater participation of women in income-generating activities and, thereby, decision-making processes in Bangladesh (Rahman *et.al.* 2012). The odds ratio of 1.74 for 'wife's education' indicates that the likelihood of consulting is 1.74 times more when the female (spouse) is educated, keeping all other factors the same in the model. Similarly, based on the odds ratio, there is a likelihood to consult 1.445 times more with a wife who spends more working hours in farming. The odds ratios for livestock number (1.292) and family income (1.00) imply that there is a likelihood to consult more in households that possess more livestock and have more family income. In contrast, the odds ratio for the age of the respondents resulted in less than one (0.899), which implies that the older farmers are less likely than young farmers to consult with their spouses regarding farm decisions. Using logistic regression analysis, Anderson *et al.* (2017) reported similar results; looking across 13 farm and household decisions simultaneously, more educated wives and wives with better health were associated with a higher likelihood of accord over household decisions, such as children's schooling and general farm decisions.

However, the positive association with more acres of landholdings reported in Anderson *et al.* (2017) was not found in this present study. In summary, it can be concluded that women's participation in NGOs, educational status, and more time in a farming report positive association for husbands consulting with them on-farm decisions. These findings match with the theoretical framework established for this study.

Table 6-7 Results of logistic regression against the 11 intersectionality and patriarchy variables

EXPLANATORY VARIABLES	B	S.E.	WALD	SIG.	OR
Age of the respondent	−0.107*	0.061	3.010	0.083	0.899
Wife's education (years of schooling)	0.555**	0.225	6.086	0.014	1.741
Farming experience (years)	0.145	0.093	2.441	0.118	1.156
Main occupation (farming = 1; otherwise 0)	−0.038	1.403	0.001	0.979	0.963
Family income (Tk.)	0.000*	0.000	3.180	0.075	1.000
Livestock number	0.256**	0.085	9.145	0.002	1.292
Household headship (female = 1; 0 = otherwise)	0.778	1.438	0.293	0.589	2.176
NGO Membership (female = 1; 0 = otherwise)	2.559***	0.675	14.376	0.000	12.926
Wife's time allocation in farming (hours)	0.368*	0.192	3.685	0.055	1.445
Farm size (decimal)	−0.001	0.003	0.107	0.744	0.999
Working member in the family	−0.088	0.278	0.100	0.752	0.916
Constant	−9.040	4.033	5.026	0.025	0.000

EXPLANATORY VARIABLES	B	S.E.	WALD	SIG.	OR
Model Summary					
Log-Likelihood	57.925				
Cox and Snell R Square	0.500				
Nagelkerke R Square	0.723				
Chi-Square	83.235***			0.000	
Overall mpdel Predicted (%)	90.8				

Dependent Variable: Consultation on the decision-making process of the farm.

Note: B= Co-efficient; S.E. = Standard Error; WALD= Wald chi-Squared Test (developed by Abraham Wald); SIG= Level of significant; OR = Odds Ratio; *p < 0.10; **p < 0.05; ***p < 0.01.

6.7 DAILY WORKING HOURS

In this section, we tried to unearth the spending hours both by male and female in household works such as cooking, cleaning, child caring, livestock rearing and leisure period. To unearth these, every respondent's spending hours on daily basis were measured. How much time did he/she spend for respective works, and not how much did his/her spouse spent? Spending hours in household works by male and female are shown in Table 6-8. The results are as presumed, female spent more time than male in household works. Importantly, male support on an average 0.63 hour for household work. Otherwise, females spent much more time in household work (5.39 hours/day), while male does most agriculture operations in the field. Male enjoyed more leisure time than female and also spent more time participating in social/community work. This finding justifies the general notion of developing country like Bangladesh that women are mostly confined with household cohort while men are responsible for the outside task including farming. Many of these activities are not considered as economically active employment, but they are all critical to the well-being of rural households (ESA 2011).

Table 6-8 Spending hours in household-related works in a day

WORK TYPE	MAN	WOMAN	GIRL	BOY
Household work (cooking, cleaning, taking care of children and elderly people)	0.63	**5.39**	0.24	0.07
Collection of drinking water	0.15	0.62	0.07	0.03
In field agricultural works	**4.84**	0.65	0.02	0.22
Home-based agricultural works	0.58	0.95	0.04	0.05
Livestock management	0.98	1.65	0.05	0.07
Community work	0.62	0.22	0.01	0.01
Recreation or leisure time	1.88	1.87	1.26	0.95
Total working hour	**9.67**	**11.35**	**1.69**	**1.39**

Chapter 7 Farmers perception of and adaptation to climate change impacts: an intra household analysis from northwest Bangladesh

Climate change is accepted as a global phenomenon with sweeping implications (IPCC 2007, 2014; Karl et al. 2009; Ali and Erenstein 2017). Studies show that regional climate change has already affected many physical and biological systems throughout the world. Developing countries contributing only 10% of the annual global carbon dioxide emissions but are the most prone to climate change and have minimal adaptive capacity (McCarthy et al. 2001; Maskrey et al. 2007). The situation is even worse in South Asia where most of the population live in rural areas and depend on agriculture (Ali and Erenstein 2017). It is widely documented that Bangladesh is one of the most vulnerable hotspots to the adverse impacts of climate change and climate-related extreme events. For instance, during the last 50 years, Bangladesh has experienced more than 20 droughts (IPCC 2007; Habiba et al. 2012; World Bank 2013). Moreover, climate change is adversely affecting the agricultural production and farmers' livelihoods and, consequently, risks to the food security of Bangladesh (Ahmed and Chowdhury 2006; FAO 2006; Sarker et al. 2012; Al-Amin et al. 2017). Northwest Bangladesh is the major rice-producing region of the country, yet it is vulnerable to frequent drought events that are causing crop yield losses (World Bank 2013). In the northwest region, seven of the ten most extreme climatic events from 1973 to 1998 were droughts (BBS 2016). It is a regular phenomenon in many parts of the country, but the northwest region is mostly a drought-prone and groundwater depleted area because of the high variability of rainfall (Shahid and Behrawan 2008). Together with much lower rainfall compared to the rest of the country (Paul 1998), this area is dry. In addition, the average annual rainfall in this part is 1,329 mm whereas in the northeast part it is 4,338 mm (West et al. 2007). Moreover, falling groundwater levels (Kirby et al. 2014) which lead to a lack of access to water for drinking (Haq 2014) and irrigation are the greatest concern for the northwest region of Bangladesh. Given its contribution to national food security and the potentially severe effect of climate change, this region demands more focus.

The threats of climate change are being tackled through adaptation, particularly by small landholders. However, adaptation in agriculture is influenced by the perception of climate change (Bryant et al. 2000). It is often seen that farmers respond to climatic parameters such as rainfall or temperature slowly as they do not face an immediate challenge to their farm practices. In contrast, farmers consider water stress as their immediate agricultural risk and respond rapidly to this risk through specific adaption strategies, i.e. water harvesting techniques, changes in crop planting dates, changes in agriculture practices, and changes in crops grown (Gandure et al. 2013). Therefore, it is necessary to study the farmers' perception and adaptation strategies to climate change and water stress which will facilitate effective government policies in northwest Bangladesh. Furthermore, the gender gap provides reasonable grounds for the expectation that women and men will generally be affected differently by the effects of climate change and water stress and will therefore respond to and benefit differently from climate protection and adaptation measures (Masika 2002; Mitchell et al. 2007; World Bank 2011; Ashby et al. 2012). A significant body of literature on gender and climate change shows that women and men perceive and experience climate change differently, and usually, women are more vulnerable due to their dependence on natural resources and structural inequity in their access and control of such resources (Ravera *et al*. 2016). It is, therefore, necessary to investigate how the role of gender and its interaction with cultural, social and economic factors work in determining the adaptive responses to climate change and water stress.

Based on the case of farmers in northwest Bangladesh, this research is designed to link the macro-level evidence of a rise in temperature, rainfall and water stress through capturing the extent of farmers' awareness and perceptions of climate change, water stress and the types of adjustments they make in their farming practices in response to these changes for sustainable agricultural development. All these aspects are examined from an intra-household gender-sensitive viewpoint to present an inclusive scenario of the farmers' attitude and behaviour towards the environmental constraints they are facing in their farming. Therefore, to do a more nuanced intra-household analysis and to advance the understanding of adaptation choices for climate change, this study analysed (i) how husbands and spouses perceive climate change and factors affecting their perceptions; (ii) what the major strategies adopted by the farmers to adapt climate change are, and (iii) how intra-household family decisions in addition to other factors affect the adaptation decision, and choice of adaptation methods in agriculture in the drought-prone environments of Bangladesh.

7.1 METHODOLOGY

7.1.1 SURVEY DESIGN

A cross-sectional intra-household survey was used which employed multi-stage random sampling techniques. Initially, three upazilas (administrative sub-districts, namely, Godagari, Kahaloo, and Parbatipur) were selected from Rajshahi, Bogura, and Dinajpur districts, respectively; after that, one union (a sub-district or upazila comprises several unions) was selected from each upazila, and 6 villages were chosen randomly from each union (i.e. the study covers 3 districts, 3 Upazilas, 3 unions, and 18 villages). During the survey, the study followed the sampling strategy of the Household Income and Expenditure Survey (HIES) and interviewed 20 farm households from each village as a sample (BBS 2010). Thus, our study interviewed 360 male-headed farming households and their spouses to assess intra-household dynamics. Therefore, the total sample size became 720.

A series of focus group discussions (FGD) and pilot surveys for the production year 2016–2017 were conducted to develop the survey instrument. During the FGDs, five types of participants (primary and/or high school teacher, NGO worker, Upazila Agricultural Officer (UAO), UP member, and six local inhabitants with equal numbers of male and female) were asked to give their opinion and summarize their climate change perception and adaptation strategies. During the final survey, the sample households were first approached through the local Sub Assistant Agriculture Officer (SAAO), after which two respected persons in each village were selected. These three well-accepted persons described the purpose of the study to the farmers and introduced them to the lead investigator and eight qualified enumerators. Among the eight enumerators, four female enumerators surveyed the wives and four female enumerators surveyed their husbands. The use of female and male enumerators helped mitigate the cultural and religious issues associated with illiteracy and the natural reserve of the farmers and ensured free conversation; the strategy helped ensure the validity of the data. At the end of each day's work, questionnaires were checked for inconsistencies and corrected.

7.1.2 ANALYTICAL TECHNIQUES

Farmers' perception of and adaptation to climate change and water stress were analysed through a useful set of descriptive and econometrics analysis. Before investigating that, the study primarily focused on the trends of climate change in the concerned three groundwater depleted areas. To build the quantitative justification for climate change, we conducted trend analysis for three major climate variables with time (t) as an explanatory variable over the entire period. Ordinary Least Square regression (OLS) estimation was selected for the annual average maximum temperature, minimum temperature, and rainfall of Rajshahi and Dinajpur district, while quantile regression (QR) was selected for the annual average maximum and minimum temperature of Bogura district. Moreover, the OLS estimation was also selected for the annual average rainfall of the Bogura district. These methods are best suited to estimate the central tendency of sample data. Nevertheless, the data set of our study encompasses more than 20 years of observations which require testing for stationarity (Chen *et al.* 2004). Therefore, this requirement needed further investigation of the data series to ensure that it was stationary before we estimated the regression. Accordingly, the study carried out an Augmented Dickey–Fuller (ADF) test (i.e. the presence of unit roots for each variable) (Dickey and Fuller 1979). Therefore, based on the distribution of the dependent variables the following regression models are employed:

$$\sum \epsilon_i^2 = \min_{\beta \in R^p} \sum_{i=1}^{n} (y_i - x_i\beta)2 \qquad \text{Equation 7-1}$$

where y_i is the endogenous variable, x_i is a vector of exogenous variables and β being a vector of p parameters to be estimated. The OLS regression may not be suitable when the distribution of the response is skewed because it may be upshot in misleading regression coefficients (Reeves and Lowe 2009). The OLS regression is also very sensitive to outliers and does not provide an accurate result if the assumptions of linearity, homoscedasticity, normality, and independence of the residuals are not satisfied (Rao and Toutenburg 1999). The quantile regression seeks to extend the estimation of conditional quantile functions—models in which quantiles of the conditional distribution of the response variables are expressed as functions of observed covariates (Koenker and Bassett 1978). Thus, quantile regression minimises the sum of absolute residuals, whereas ordinary least squares minimise the sum of squares. The quantile regression provides parameter coefficients for any quantile in the range from 0 to 1 conditional on the covariates or exogenous variables. This can be represented as:

$$\sum \epsilon_i^2(\tau) = \min_{\beta \in R^p} \sum_{i=1}^{n} \tau(y_i - x_i\beta)2 \text{ for any quantile } \tau\epsilon(0,1) \qquad \text{Equation 7-2}$$

The quantile model specification follows in equation (2) can be specified as

$$Q_\tau[y|X] = \alpha_\tau + X^\beta \qquad \text{Equation 7-3}$$

where y is the climatic variable, Q_τ[y|X] is the τ^{th} quantile of y conditional on the covariance matrix X that includes time.

The analysis of the study further followed three steps. Firstly, the study analysed the factors affecting intra-household (husband and wife) climate change perception. Secondly, the study identified the determinants of households' adaptation decision and finally, the study analysed the determinants of households' adaptation strategies. For the first two objectives, a binary logit model was used since the outcome or dependent variables in both objectives are binary variable (mutually exclusive and exhaustive).

For the first objective two separate logit models were run, one for the wife and one for her husband. To describe the binary logit model, let y be a binary variable indicating the husband's climate change perception, which takes the value y = 1 when the husband perceives climate change and 0 otherwise. Here P is the likelihood of perceiving climate change and 1-P indicates the probability of not perceiving climate change. Then a transformation of P known as the logit transformation is defined as y = g(x) = logit(P) = log(P/(1-P)), which is a function of explanatory variables. Therefore, the binary logit model can be expressed as follows:

$$y = g(x) = \text{logit}(P) = \beta_0 + \sum_{i=1}^{k} \beta_i X_i \qquad \text{Equation 7-4}$$

where X is a set of k predictors which may affect the husband's climate change perception. The choice of the predictors included in X is guided by previous empirical literature on perception of and adaptation to climate change (e.g. Mishra and Pede 2017; Ngigi *et al.* 2017; Alam 2015; Alauddin and Sarker 2014).

The determinants of households' adaptation decision also used a similar binary response model. In this case, the explanatory variables encompassed spouses' individual characteristics (e.g. age and education of each spouse), intra-household decisions, family characteristics, farm characteristics, institutional factors, climatic factor, and spatial characteristics.

On the other hand for the third objective, the multinomial logit (MNL) model was used because it permits the analysis across more than two categories, possible to estimate choice probabilities for different categories over a chosen base category (in our case, no adaptation was used as the base category) (Madalla 1983; Wooldridge 2002), computationally simple (Tse 1987) and easy to interpret the results using an odds-ratio (Long 1997; Kropko 2008). Furthermore, earlier adaptation studies used the MNL model (Deressa *et al.* 2009; Alauddin and Sarker 2014; Alam 2015). By following Deressa *et al.* (2009) to describe the MNL model, let y indicate a random variable taking values {1, 2, ... J} for J, a positive integer, and let X denote a set of explanatory variables. In our case, y indicates adaptation strategies and X includes husband and spouse individual characteristics, intra-household decisions, family characteristics, farm characteristics, institutional factors, climatic factor, and spatial characteristics (Table 7-1). The matter is how ceteris paribus changes X influence the response probabilities (P(y = j/X), j = 1, 2,... J. Let X is a 1 × K vector with initial element unity. The MNL model has response probabilities:

$$\boldsymbol{P(y = j/X)} = \frac{\exp(\boldsymbol{X\beta_j})}{[1 + \sum_{h=1}^{J} \exp(\boldsymbol{X\beta_h}), \ \boldsymbol{j = 1, \dots J}]} \qquad \text{Equation 7-5}$$

where β_j is K × 1, j = 1,... J. As the parameters of the MNL model cannot be interpreted directly, the Relative Risk Ratio (RRR), also known as the odds ratio is more meaningful and interpretable. Therefore, the present study uses the RRR for interpreting the results.

7.2 RESULTS AND DISCUSSION

7.2.1 TREND OF CLIMATIC VARIABLES

Before investigating farmers' perceived belief, the study primarily focused on the trends of climate change in the concerned three groundwater depleted areas using secondary data sources. In addition, to build the quantitative justification for climate change, the present study estimates trend models for three major climate variables with time (t) as an explanatory variable over the entire period. Nevertheless, the data set of the study encompasses 34 years (i.e. 1982–2015) of observations that require testing for stationarity, considering this study carried out an Augmented Dickey–Fuller (ADF) test.

To capture the actual variability, the study used seasonal trend analysis such as Kharif and Rabi and there is greater seasonal variability of climatic parameters.

Overall, Figure 7-1 illustrates that the temperature (i.e. annual and Kharif season) of the Rajshahi district increased dramatically whereas the rainfall and Rabi season temperature decreased sharply. Even though the annual average maximum temperature has climbed steadily over the last 34 years with high fluctuation, there is seasonal variability. In the Rajshahi district during Kharif season (March-September), the average maximum temperature increased sharply with minimal fluctuation whereas in the Rabi season (October-February) the average maximum temperature declined slightly following elevated fluctuation. Furthermore, the annual and Kharif season average minimum temperature increased dramatically but the Rabi season average minimum temperature remained constant with little fluctuation over the period. However, the annual and seasonal average rainfall decreased slowly with high fluctuation.

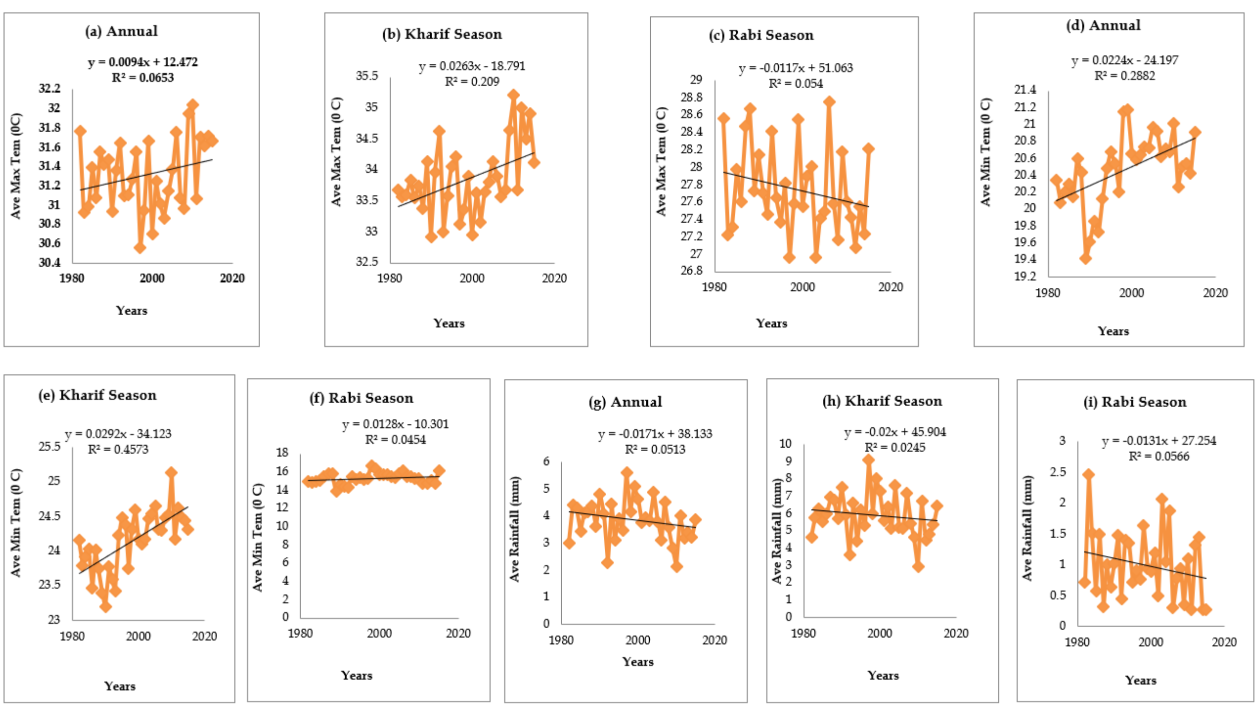


Figure 7-1 Trends of annual and seasonal average maximum temperature, minimum temperature, and rainfall of Rajshahi district

Figure 7-2 shows that the annual and Kharif season average maximum temperature of Dinajpur district rose rapidly whereas in Rabi season the average maximum temperature decreased slowly. Moreover, the annual and seasonal average minimum temperature increased rapidly but the annual and seasonal average rainfall decreased slightly.

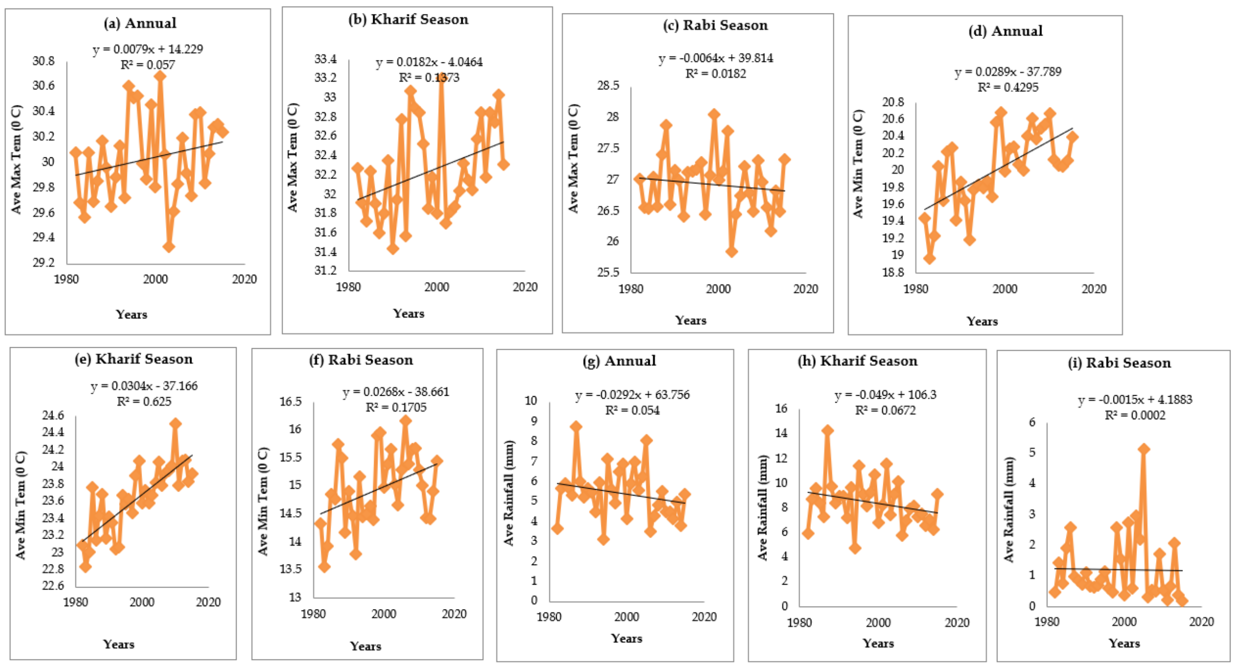


Figure 7-2 Trends of annual and seasonal average maximum temperature, minimum temperature, and rainfall of Dinajpur district

In Bogura, although the annual and Kharif season average maximum temperatures levelled off, the Rabi season average maximum temperature dropped steadily. However, the annual and seasonal average minimum temperature increased gradually but the rainfall decreased slowly (Figure 7-3).

The quantitative justification of climate change over the period is presented in Table 7-1. The study found that in the high water scarcity area (i.e. Rajshahi), the t-value for annual average minimum temperature associated with their p-value illustrates that the average annual minimum temperature is highly significant. The result shows that of an additional year the annual average minimum temperature has increased by 0.020C. In addition, the R-square value indicates that 29% of the variation in annual average minimum temperature is explained by time. Furthermore, in the low scarce area (i.e. Dinajpur), the annual average minimum temperature is significant at a 1% level. The result indicates that of an additional year the annual average minimum temperature has increased by 0.030C.

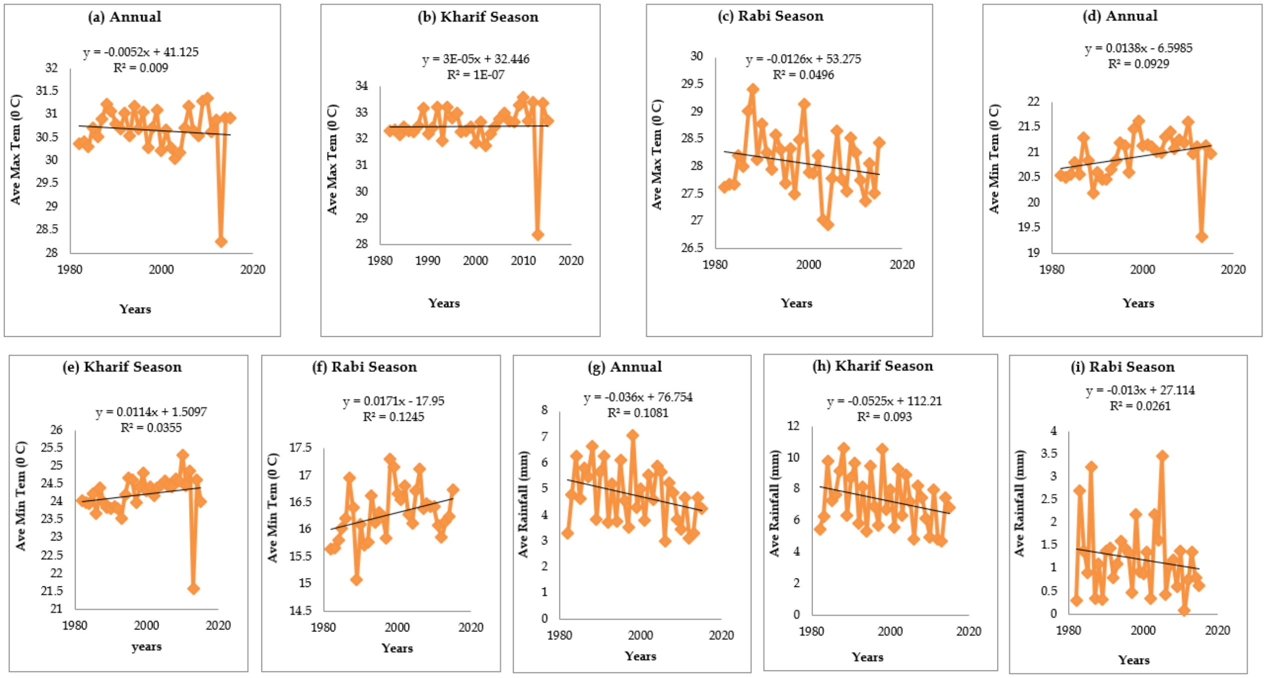


Figure 7-3 Trends of annual and seasonal average maximum temperature, minimum temperature, and rainfall of Bogra district

Table 7-1 Linear trend model of changes in climate variables for the 1982–2015 periods

Area	Climate variables	Intercept	Coefficient	t- value	p-value	R-squared
Rajshahi (High Scarce Area)	Maxt	12.472	0.009	1.50	0.145	0.0653
	Mint	-24.197	0.022***	3.60	0.001	0.2882
	Rainfall	38.133	- 0.017	-1.32	0.198	0.0513
Dinajpur (Low Scarce Area)	Maxt	14.229	0.008	1.39	0.174	0.057
	Mint	-37.789	0.029***	4.91	0.000	0.4295
	Rainfall	63.756	- 0.029	-1.35	0.186	0.054

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

The coefficient estimates for the 25th, 50th, and 75th %ile and the linear regression coefficient estimates for climatic variables are presented in Table 7-2. The quantile regression results of the annual average minimum temperature of the medium water scarcity area (i.e. Bogura) indicate that the time has a larger impact on the higher to lower quantiles valued as 0.023 (50th) and 0.025 (75th) of annual average minimum temperature distribution significantly. However, of an additional year, the annual average rainfall in this area has decreased by 0.04 mm.

Table 7-2 Quantile regression model of changes in climate variables for the 1982-2015 period for Bogura (medium scarcity area)

Climate variables	Test statistics	OLS	Selected quantiles		
			25th Percentile	50th Percentile	75th Percentile
Maxt	Intercept	41.125	20.855	6.249	38.774
	Coefficient	- 0.005	0.005	0.012	- 0.004
	t- value	-0.54	0.18	1.05	- 0.40
	p-value	0.593	0.856	0.300	0.690
	R^2/Pseudo R^2	0.009	0.014	0.003	0.000
Mint	Intercept	- 6.598	-12.862	-25.280	-28.482
	Coefficient	.0138*	0.017	0.023***	0.025**
	t- value	1.81	0.89	3.62	2.56
	p-value	0.080	0.381	0.001	0.015
	R^2/Pseudo R^2	0.093	0.185	0.194	0.086
Rainfall	Intercept	76.754			
	Coefficient	- 0.036*			
	t- value	-1.97			
	p-value	0.058			
	R^2/Pseudo R^2	0.108			

7.2.2 Summary statistics of variables

Even though Bangladesh faces worse climatic events, water stress (i.e. drought) is the main problem for northwest Bangladesh. This water stress acts as a bottleneck for agricultural productivity especially in these ground water depleted areas. Table 7-3 shows the socioeconomic characteristics of the farmers in the study areas. It is palpable that there was substantial variation among the spouses' perception about climate change. The adaptation decision of the households in the changing climatic situations also showed variability (mean value = 0.88, std. dev. = 0.32). There was variation in the choice of adaptation strategies. The mean and std. dev. shows that there was substantial age variation among the spouses in the study areas which is also evident by the two-sample mean comparison test (t = 10.5129; p = 0.0000). In the case of years of schooling of both sexes, the study found no significant variation. However, there were significant differences in the gender-sensitive family decisions. Of the 360 farm households, 60% of households took a joint family decision, 25% took the male-only family decision, and 15% took female-only decisions. The test statistic ($\chi 2 = 5.99$, $p = 0.000$) indicates significant variation in intra-household family decisions. The size of the household in the study areas varied widely (i.e. mean value = 4.81, while standard deviation = 1.46). The annual income and institutional facilities of the households varied substantially. Moreover, the intra-household family decision also varied significantly in the study areas.

Table 7-3 Definition and summary statistics of variables used in the analysis

Variable	Definition	Mean	Std. dev.
Dependent variable			
Husband's Perception	= 1 if the husband perceive climate change; 0 otherwise	0.9417	0.2347
Spouse's Perception	= 1 if the spouse perceive climate change; 0 otherwise	0.9500	0.2182
Adaptation decision	= 1 if the household adapt to climate change; 0 otherwise	0.8806	0.3248
Adaptation strategies	= 1 if the household adopted an adaptation option measures; 0 otherwise	1.9083	1.1895
Husband and spouse characteristics			
Husband age	Age of the husband (years)	45.9611	12.3170
Spouse age	Age of the spouse (years)	36.9333	10.6659
T-test	10.5129 (p = 0.0000)		
Years of schooling of the husband	Years of schooling of the husband (years)	5.6417	4.3358
Years of schooling of the spouse	Years of schooling of the spouse (years)	5.7306	4.1721
T-test	0.2803 (p = 0.7793)		
Intra-household decisions			
Family decision by the spouse	= 1 if the spouse takes family decision; 0 otherwise	0.1444	0.3520
Family decision by the husband	= 1 if the husband takes family decision; 0 otherwise	0.2528	0.4352
Family decision by both the husband and spouse	= 1 if both the husband and spouse take family decision; 0 otherwise	0.6028	0.4900
Chi-square test	5.99 (p = 0.000)		
Family characteristic			
Household size	Household size (persons per household)	4.8083	1.4643
Farm characteristics			
Total cultivated land	Total cultivated land (acres)	2.6436	2.6211
Electricity for irrigation	= 1 if the household has access to electricity for irrigation; 0 otherwise	0.8500	0.3576
Total income	Total income (Tk)	326204.0	231925.90
Institutional factors			
Extension frequency	Extension frequency (times/year)	13.4750	8.0807
Membership in any organisation	= 1 if the household is the member in any organisation; 0 otherwise	0.3972	0.4900
Awareness training	= 1 if the household has any awareness training; 0 otherwise	0.6361	0.4818
Agricultural subsidy	= 1 if the household has any agricultural subsidy; 0 otherwise	0.1472	0.3548
Saving	= 1 if the household has any savings; 0 otherwise	0.6222	0.4855
Credit facilities	= 1 if the household has any credit facilities; 0 otherwise	0.7111	0.4539

Variable	Definition	Mean	Std. dev.
Climatic factor			
Severe drought	= 1 if the household faces severe drought; 0 otherwise	0.8167	0.3875
Gender decisions			
Family decision by the spouse	= 1 if the spouse takes family decision; 0 otherwise	0.1444	0.3520
The family decision by the husband	= 1 if the husband takes family decision; 0 otherwise	0.2528	0.4352
The family decision by both the husband and spouse	= 1 if both the husband and spouse take the family decision; 0 otherwise	0.6028	0.4900
Spatial characteristics			
Low area (LSA)	=1 if the household located in low water scarcity area; 0 otherwise	0.3333	0.4721
Medium water scarcity area (MSA)	=1 if the household located in medium water scarcity area; 0 otherwise	0.3333	0.4721
High water scarcity area (HSA)	=1 if the household located in high water scarcity area; 0 otherwise	0.3333	0.4721

7.2.3 FARMERS' INTRA-HOUSEHOLD PERCEPTIONS OF CLIMATE CHANGE

The intra-household perceived beliefs about climate change are presented in Table 7-4. Most farmers thought that the severity of change in the study areas was high. There was a significant difference in the husband's and spouse's belief about the severity of change in high water scarcity areas (HSA) and low water scarcity areas (LSA) (in HSA - c^2 = 8.4419; p = 0.015 and in LSA - c^2 = 12.9351; p = 0.002), but in the medium water scarcity area (MSA) there was no significant difference. Most of both sexes perceived that temperature had increased, while only a minority had noticed no change. The chi-square test reveals that there was a statistically significant variation in the intra-household responses in both MSA and LSA. The results also show that about 75% male and 54% female in HSA believed that the rainfall had decreased over the last 20 years. In HSA and MSA there were significant differences in the responses of the sexes about rainfall intensity and timing.

A great majority of the husbands and spouses believed that water stress or droughts were natural phenomena, although a few believed that droughts result from manmade causes or a combination of natural and manmade causes. 80% of the husbands and 78% of the spouses in the high scarcity area (HSA) reported that drought occurs every year, while on average 20% of husbands and spouses in the medium scarcity areas MSA) reported that they experience drought every two years. The chi-square test reveals that there is no intra-household gender difference in responses of drought frequency in the study areas.

Table 7-4 Farmers' perceptions of climate change

Farmer's perceptions	HSA		MSA		LSA	
	Husband (%)	Spouse (%)	Husband (%)	Spouse (%)	Husband (%)	Spouse (%)
Severity of change						
High change	80.00	64.17	81.67	73.33	75.00	53.33
Medium change	19.17	31.67	15.83	24.17	20.83	33.33
Low change	0.83	4.16	2.50	2.50	4.17	13.34
Chi-square test	8.4419 (p = 0.015)		2.6210 (p = 0.270)		12.9351 (p = 0.002)	
Temperature						
Increased	89.17	79.17	90.83	84.17	95.00	75.00
Decreased	7.50	14.17	7.50	8.33	3.33	10.00
No change[a]	3.33	2.50	1.67	4.17	1.67	6.67
Don't know[a]	0.00	4.16	0.00	3.33	0.00	8.33
Chi-square test	4.5077 (p = 0.105)		4.8119 (p = 0.090)		19.6235 (p = 0.000)	
Intensity and timing of rainfall						
Increased	4.17	1.67	26.67	13.33	21.67	23.33
Decreased	75.00	54.17	35.83	27.50	34.17	29.17
Earlier/Later	9.17	24.17	19.17	31.67	20.83	16.67
Rains unexpectedly	0.83	3.33	6.67	10.83	6.67	13.33
Rainfall with strong storms or winds[b]	5.00	11.67	4.17	5.83	6.67	5.83
Rainfall with more thunder storms and lighting[b]	5.00	4.17	7.50	8.33	10.00	10.00
No change[b]	0.83	0.00	0.00	3.00	0.00	0.00
Don't know[b]	0.00	0.83	0.00	0.00	0.00	1.67
Chi-square test	16.7028 (p=0.002)		12.5869 (p=0.013)		3.7944 (p = 0.435)	
Water stress (drought)						
Natural disaster	84.17	77.50	79.17	78.33	69.17	83.33
Manmade disaster	5.00	8.33	8.33	10.00	7.50	8.33
Both	10.83	14.17	12.50	11.67	23.33	8.33
Chi-square test	1.8632 (p = 0.394)		0.2216 (p = 0.895)		10.1582 (p = 0.006)	
Drought frequency						
Every year	80.83	78.33	60.83	55.00	67.50	60.83
Every two years	5.00	5.00	20.83	19.17	20.00	16.67
Every three years	0.83	4.17	5.83	6.67	5.00	9.17
Every four years	5.00	3.33	4.17	2.50	5.83	5.00
Every five years	8.33	9.17	6.67	9.17	0.83	2.50
Don't know	0.00	0.00	1.67	7.50	0.83	5.83
Chi-square test	3.1614 (p = 0.531)		5.9307 (p = 0.313)		9.5267 (p = 0.090)	

Note: To calculate the Chi-square value the study aggregated no change and don't know categories together.

b These are aggregated for the test statistics.

7.2.4 FACTORS AFFECTING INTRA-HOUSEHOLD CLIMATE CHANGE PERCEPTION

Table 7-5 represents the determinants of husband's and spouse's perception regarding climate change. The husband's age and education were less likely to influence their climate change perception, whereas their access to credit facilities was more likely to increase their awareness of climate change. In the case of spouses, their age, education and saving opportunities were more likely to increase their perceived belief in climate change, whereas an increase in cultivated land was less likely to influence their climate change perception. The households in HSA and MSA were more likely to perceive climate change than households residing in LSA. In econometric analyses, cross-sectional data often show multicollinearity which results in inaccurate estimates of the parameter. The present study used the variance inflation factor (VIF) to detect multicollinearity and concluded that the explanatory variables are free from multicollinearity as the value of VIF for all the variables are less than 10.

Table 7-5 Determinants of intrahousehold climate change perception

Variable	Dependent Variable = Climate change perception	
	Husband's perception Estimated parameters	Spouse's perception Estimated parameters
Husband age	-0.3259*** (0 .0718)	-
Years of schooling of the husband	-0.1951* (0.1025)	-
Spouse age	-	0.2625*** (0.0728)
Years of schooling of the spouse	-	0.3577*** (0.1107)
Family decision by the spouse	Reference category	-1.8910 (1.2337)
Family decision by the husband	0.0181 (1.4232)	Reference category
Family decision by both the husband and spouse	-1.5785 (1.3459)	-0.9391 (1.0270)
Household size	-0.3050 (0.2948)	-0.0233 (0.2368)
log (Total cultivated land)	-0.4907 (0.6751)	-1.1226** (0.5634)
Electricity for irrigation	0.5003 (0.9683)	-1.7201 (1.3246)
log (Total income)	1.1117 (0.7783)	0.6712 (0.5762)
Extension frequency	-0.0488 (0.0539)	-0.0453 (0.0519)

Variable	Dependent Variable = Climate change perception	
	Husband's perception	**Spouse's perception**
	Estimated parameters	**Estimated parameters**
Membership in any organisation	-1.2728 (0.9285)	0.2282 (0.8183)
Awareness training	-1.6414 (1.1289)	-0.3450 (0.7486)
Agricultural subsidy	-0.7025 (0.9085)	-0.2756 (1.1085)
Saving	4.7254 (4.8586)	7.0321*** (1.9902)
Credit facilities	2.2708** (1.1605)	1.2099 (0.8086)
Severe drought	-0.2015 (1.1516)	-0.8297 (1.0316)
LSA	Reference category	Reference category
MSA	-1.1582 (1.2069)	2.7674** (1.3030)
HSA	-0.6948 (1.1278)	1.8410** (0.9024)
Constant	9.1918 (10.0545)	-18.7587** (8.2036)
Diagnostics		
Number of observations	360	360
LR chi-square	108.61***	74.75***
Log likelihood	-25.7431	-34.0922
Pseudo-R^2	0.6784	0.5230

Note: ***, **, * indicate the significance level at 1%, 5% and 10% respectively. The value in the parenthesis indicates standard errors

7.2.5 FARMERS' ADAPTATION MEASURES TO COPE WITH CLIMATE CHANGE

Depending on their perception and awareness, farmers adopt different adaptation strategies to mitigate the impacts of climate change. Through the FGDs and pilot surveys and literature review process the adaptation strategies were refined to four adaptation strategies, with no adaptation at all as the base category (Table 7-6). The results show that the majority of the farmers (29%) preferred short duration and drought-tolerant rice varieties (e.g. BRRI Dhan-56 and BRRI Dhan-57) as their prime adaptation strategy. Supplementary irrigation is the second most preferred adaptation strategy, used by 27% of farmers in the study areas. About 21% of the 360 farmers used non-rice rabi and horticultural crops as their prime adaptation strategy, while improved channels for irrigation and water harvesting is the fourth adaptation strategy adopted by 11% of farmers. However, 12% of farmers mentioned that they had not adopted any adaptation strategies. The chi-square test (c^2 = 76.3969, p = 0.000) shows that the adaptation strategies varied significantly in the three drought-prone and groundwater depleted areas. Husbands and spouses mentioned the same adaptation strategies, so there were no gender differences.

Table 7-6 Current adaptation strategies to combat climate change in the study areas

Adaptation Practices	**HAS**		**MSA**		**LSA**		**Overall**	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
No adaptation at all	12	10.00	14	11.67	17	14.17	43	11.94
Short duration and drought tolerant rice varieties	30	25.00	23	19.17	50	41.67	103	28.61
Supplementary irrigation for crop production	21	17.50	28	23.33	49	40.83	98	27.22
Non-rice *rabi* and horticultural crops	34	28.33	41	34.17	1	0.83	76	21.11
Improved channels for irrigation and water harvesting	23	19.17	14	11.67	3	2.50	40	11.11
Total	120	100.00	120	100.00	120	100.00	360	100.00
Chi-square test	76.3969, p-value = 0.000							

7.2.6 Determinants of farmers' adaptation decision

The determinants of climate change adaptation decision considering both with and without intra-household family decisions are presented in Table 7-7. The bottom lines of the table represent the diagnostics of the model. In our model for adaptation decision, together with other explanatory variables, the study focuses on the gender characteristics for adaptation decision as we know that intra-household gender plays a vital role in the agriculture of Bangladesh. In our model, the value of pseudo-R^2 is higher when we incorporate family decision variables in the model, indicating that the model explains about 32% of the variation in the data whereas without family decision variables it explains about 30% of the variation. To check the validity of the model, we used a Hosmer-Lemeshow chi-square, which shows that the model with family decision variables appears to fit the data reasonably well. The overall percentage of correct prediction in the case of the model with the family decision is 92%. In addition, the AIC value also reveals that the model with intra-household family decisions fits well.

Table 7-7 indicates that the age of the husband has a significant and negative influence on the adaptation decision. The odds ratio (0.92) reveals that holding the effects of other variables constant, the likelihood of taking adaptation decision is decreased by 0.92 times for a one year increase in the husband's age. On the other hand, the likelihood of taking adaptation decision is 1.21 times increased for a one year increase in the age of the spouse. There is a negative correlation between adaptation decision and household size. Credit facilities positively influence the adaptation decision of the farm households.

Table 7-7 Determinants of adaptation to climate change with and without family decision

Variable	Dependent Variable = Adaptation decision		
	Without family decision	With family decision	
	Estimated parameters	Estimated parameters	Odds Ratio
Husband age	-0.0812** (0.0423)	-0.0833* (0.0433)	0.9201*
Years of schooling of the husband	-0.0420 (0.0572)	-0.0484 (0.0588)	0.9527
Spouse age	0.1016** (0.0493)	0.1035** (0.0504)	1.1090**
Years of schooling of the spouse	0.0467 (0.0613)	0.0526 (0.0637)	1.0540
Family decision by the spouse	-	Reference category	
Family decision by the husband	-	0.7249 (0.5920)	2.0645
Family decision by both the husband and spouse	-	1.3746*** (0.5287)	3.9536***
Household size	-0.2857** (0.1370)	-0.3406** (0.1449)	0.7113**
log (Total cultivated land)	0.3176 (0.2710)	0.3599 (0.2999)	1.4332
Electricity for irrigation	-0.4067 (0.5571)	-0.3704 (0.5552)	0.6904
log (Total income)	-0.1389 (0.3528)	-0.1446 (0.3654)	0.8654
Extension frequency	0.0364 (0.0254)	0.0406 (0.0257)	1.0414
Membership in any organisation	-0.8103* (0.4468)	-1.0042** (0.4642)	0.3664**
Awareness training	-0.3391 (0.4461)	-0.2867 (0.4545)	0.7507
Agricultural subsidy	-0.9041* (0.5240)	-0.9328* (0.5392)	0.3934*
Saving	0.0322 (0.4665)	0.1604 (0.4764)	1.1740
Credit facilities	0.9920** (0.4338)	0.9970** (0.4494)	2.7101**
Severe drought	2.9468*** (0.4274)	2.9590*** (0.4440)	19.2793***

Variable	Dependent Variable = Adaptation decision		
	Without family decision	**With family decision**	
	Estimated parameters	**Estimated parameters**	**Odds Ratio**
LSA	Reference category	Reference category	
MSA	0.0726 (0.4869)	0.0032 (0.4994)	1.0032
HSA	0.2800 (0.5225)	0.2618 (0.5285)	1.2993
Constant	2.9149 (4.5421)	2.2467 (4.7541)	9.4564
Diagnostics			
Number of observations	360	360	
LR chi-square	78.62***	85.48***	
Log likelihood	-92.3820	-88.9518	
Pseudo-R2	0.2985	0.3246	
Hosmer-Lemeshow chi-square	4.21	5.46	
Prob>chi-square	0.8378	0.7079	
Correctly classified	91.11%	92.21%	
AIC	220.7640	217.9035	

Note: ***, **, * indicate the significance level at 1%, 5% and 10% respectively. The value in the parenthesis indicates the standard errors.

There is a negative association between adaptation decision and the farmers' membership in an organization. The result of access to credit shows that keeping the effect of other variables constant, the likelihood of taking adaptation decision is 2.7 times greater for the farmers who had credit facilities than the farmers who did not have such facilities. Moreover, drought severity is the most influential factor in taking adaptation decision. The joint decision by the husband and spouse highly influenced the adaptation decision.

7.2.7 Determinants of farmers' adaptation strategies

In discrete choice theory, the independence of the irrelevant alternatives (IIA) assumption requires that when people are suggested to select a set of alternatives, their odds of choosing one over another should not depend on whether some other alternative is present or absent. Therefore, it is necessary to investigate the assumption before selecting the final model. Our study uses the well-known Hausman test for justifying the IIA assumptions. The test statistics accept the null hypothesis and indicate that the MNL is suitable to model adaptation measures of the farm households (the chi-square ranged from 0.657 to 7.167 with p-values from 0.785 to 1.00). The results of the MNL model are presented in Table 7-8; likewise, the RRR is also presented.

The LR test result indicates high goodness of fit of the model which implies that the model has good explanatory power. It is evident from Table 7-8 that the age of the husband has a significant negative effect on the probability of adopting all the mentioned adaptation measures. However, the age of the spouse has a significant positive impact on the adaptation of short duration and drought-tolerant rice varieties (DTR), supplementary irrigation for crop production and improved channels for irrigation and water harvesting. Increasing family size negatively influences the adoption of DTR varieties, supplementary irrigation for crop production and cultivation of non-rice rabi and horticultural crops. Interestingly, the actual amount of land on which crops were grown in a year had a significant positive impact on the supplementary irrigation for crop production and non-rice winter and horticultural crops adoption. The adoption of DTR varieties and supplementary irrigation for crop production were positively associated with an increase in extension personnel visits. Our study shows that the cultivation of non-rice winter and horticultural crops were negatively influenced if the farm households received an agricultural subsidy. There was a positive association between households' severe drought experience and adoption of all strategies. Intra-household joint family decisions positively influenced the adoption of DTR varieties and supplementary irrigation for crop production. Furthermore, households of the HSA and MSA were more likely to adopt non-rice winter and horticultural crops and improved channels for irrigation and water harvesting than the households in LSA.

Table 7-8 Parameters estimates of the multinomial logit climate change adaptation model

Variable	**Dependent Variable = Adaptation strategies**							
	Short duration and drought tolerant rice varieties		**Supplementary irrigation for crop production**		**Non-rice *rabi* and horticultural crops**		**Improve channels for irrigation and water harvesting**	
	Estimated parameters	**Relative risk ratio**	**Estimated parameters**	**Relative risk ratio**	**Estimated parameters**	**Relative risk ratio**	**Estimated parameters**	**Relative risk ratio**
Husband age	-0.0840 * (0.0487)	0.9195*	-0.0801 (0.0491)	0.9230	-0.0693 (0.0522)	0.9330	-0.1240* (0.0651)	0.8834*
Years of schooling of the husband	-0.0657 (0.0633)	0.9364	-0.0178 (0.0644)	0.9824	-0.0040 (0.0688)	0.9960	-0.0738 (0.0743)	0.9289
Spouse age	0.1068 * (0.0570)	1.1127*	0.0965* (0.0574)	1.1013*	0.0916 (0.0593)	1.0960	0.1371* (0.0738)	1.1469*
Years of schooling of the spouse	0.0334 (0.0684)	1.0339	0.0227 (0.0693)	1.0230	0.0364 (0.0734)	1.0371	0.1421* (0.0821)	1.1527*
Family decision by the spouse	Reference category		Reference category		Reference category		Reference category	
Family decision by the husband	0.7944 (0.6706)	2.2130	0.9581 (0.6804)	2.6069	0.4339 (0.7218)	1.5433	0.3935 (0.8200)	1.4821
Family decision by both the husband and spouse	1.6491*** (0.5974)	5.2022***	1.5880*** (0.6140)	4.8937***	0.8876 (0.6531)	2.4293	0.9357 (0.7262)	2.5490
Household size	-0.3762** (0.1604)	0.6865**	-0.4123** (0.1632)	0.6621**	-0.4232** (0.1764)	0.6550**	-0.1214 (0.1821)	0.8857
log (Total cultivated land)	0.2360 (0.3219)	1.2661	0.5834* (0.3356)	1.7920*	0.8469** (0.3667)	2.3325 **	-0.0831 (0.3686)	0.9202
Electricity for irrigation	-0.3447 (0.5995)	0.7084	-0.1510 (0.6272)	0.8599	-0.7061 (0.6707)	0.4935	-0.4023 (0.7348)	0.6688
log (Total income)	-0.2165 (0.3990)	0.8053	-0.5272 (0.4076)	0.5903	0.1469 (0.4376)	1.1582	0.7853 (0.4860)	2.1931
Extension frequency	0.0495* (0.0282)	1.0508*	0.0699 ** (0.0289)	1.0724**	0.0023 (0.0303)	1.0023	0.0350 (0.0331)	1.0356
Membership in any organization	-0.9413* (0.4998)	0.3901*	-0.7162 (0.5092)	0.4886	-0.9754* (0.5515)	0.3770*	-1.0607* (0.5953)	0.3462*

Variable	Dependent Variable = Adaptation strategies							
	Short duration and drought tolerant rice varieties		Supplementary irrigation for crop production		Non-rice *rabi* and horticultural crops		Improve channels for irrigation and water harvesting	
	Estimated parameters	Relative risk ratio	Estimated parameters	Relative risk ratio	Estimated parameters	Relative risk ratio	Estimated parameters	Relative risk ratio
Awareness training	-0.1603 (0.4886)	0.8519	-0.7650 (0.4936)	0.4653	0.1561 (0.5476)	1.1690	-0.1507 (0.5932)	0.8601
Agricultural subsidy	-0.5864 (0.5905)	0.5563	-0.7644 (0.6162)	0.4656	-1.8928*** (0.7018)	0.1507***	-0.7891 (0.6904)	0.4542
Saving	0.1966 (0.5194)	1.2173	-0.0866 (0.5300)	0.9170	-0.3555 (0.5654)	0.7008	0.7796 (0.6431)	2.1807
Credit facilities	1.0243** (0.4935)	2.7850**	0.7913 (0.4998)	2.2063	1.0239* (0.5337)	2.7840*	1.5057** (0.6169)	4.5074**
Severe drought	2.8499 *** (0.5101)	17.2862***	3.2337*** (0.5443)	25.3741***	3.4023*** (0.6050)	30.0321***	2.4223*** (0.6400)	11.2721***
LSA	Reference category		Reference category		Reference category		Reference category	
MSA	-0.9289* (0.5579)	0.3950*	-0.6595 (0.5625)	0.5171	4.0020*** (1.1514)	54.7082***	1.8288** (0.8392)	6.2267**
HSA	-0.4872 (0.5819)	0.6144	-0.9144 (0.6080)	0.4007	4.1760*** (1.1740)	65.1029***	2.7321*** (0.8518)	15.3651***
Constant	2.4221 (5.1561)	11.2690	6.0664 (5.2569)	431.1387	-5.8514 (5.7065)	0.0029	-14.0009** (6.3756)	8.31e-07**
Diagnostics								
Base category	No adaptation at all							
Number of observation	360							
LR chi-square	256.37***							
Log likelihood	-425.68739							
Pseudo-R^2	0.2314							

Note: ***, **, * indicate the significance level at 1%, 5% and 10% respectively. The value in the parenthesis indicates the standard errors.

7.3 SUMMARY FINDINGS

The empirical results showed that there is greater seasonal variability of climatic parameters. The temperature (i.e. annual and Kharif season) of Rajshahi district increased dramatically while the rainfall and Rabi season temperature decreased sharply. Likewise, the annual and Kharif season average maximum temperature of Dinajpur district rose rapidly while in Rabi season the average maximum temperature decreased slowly. The annual and seasonal average trends of temperature and rainfall of Bogura district show that the annual and Kharif season average maximum temperature are levelled off, the Rabi season average maximum temperature dropped steadily. However, the annual and seasonal average minimum temperature increased gradually but the rainfall decreased slowly. Finally, it is vividly evident that the climatic parameters (i.e. maximum temperature, minimum temperature, and rainfall) change over the period.

The results show that there is a significant difference in husbands' and spouses' perceptions about the severity of climatic change in HSA and LSA. Both the husband and spouse in HSA mentioned that every year they must struggle with drought. To mitigate climate change impacts, the farmers in the study areas adopted certain adaptation strategies in which two strategies were related to irrigation and the other two allied with rice and non-rice enterprise choice. The results of the study show that the adaptation measures varied according to the water scarcity levels. Likewise, spatial characteristics and joint family decision are the most significant determinant for adaptation decision and strategies.

Based on the findings of the study, several policy guidelines are suggested. The area-wise differences in perception and adaptation strategies indicate that 'one size fits all' policies will not work to adapt to climate change. Location-specific policies are needed. As perceptions of drought also influence the adaptation decision and strategies, and perception differ between husband and spouse, the study suggests that disseminating adequate gender-appropriate knowledge and climate-related information will accelerate farm-level adaptation to climate change impacts. Institutional factors such as extension visit and access to credit for the farmers should be encouraged as such factors positively influence the choice of climate change adaption strategies. Priority should be given towards gender-specific climate change information dissemination and technology development. It would be rational to incorporate intra-household gender sensitivity at the time of planning and implementing climate change-related policies and adaptation strategies. Local government and non-governmental authorities should interact with rural communities including women and involve them in decision-making processes for boosting agricultural production and abating the impacts of climate change, and ultimately ensure the food security of the country.

Chapter 8 CONCLUSIONS AND POLICY RECOMMENDATIONS

8.1 OVERVIEW

The northwest region of Bangladesh is the food bank of the country. It contributes 60% of the total rice production. Groundwater plays a major role in irrigation. Sustaining irrigation in the region is a priority of the government. The availability of groundwater for irrigation has a multi-dimensional effect on rice yield and return on investment in the northwest region of Bangladesh.

Results of the study project show positive net returns and the undiscounted BCRs of the selected crops. This means that the production of these crops is profitable at the current market conditions. The returns from all variety of rice are higher than those of the non-rice crops. This finding partially explain the slow diversification of crop production observed over time. Besides profit, reliability and self-consumption are major driving forces to grow rice. The functional analysis shows that tillage, urea, and pesticides are important factors for cultivating these crops. If modern inputs and production technology can be made available to farmers in time, yield and production will increase and improve farmers livelihoods standards. It can help in improving the nutritional status of the rural people.

The cropping choice optimization investigation illustrates that choice based on nutrition diversification could increase farm incomes and may help in poverty reduction. Nevertheless, farmers will need support from central and local government and nongovernmental organisations. This support should be in promoting high-value crops, efficient marketing, extension, and crop insurance services in addition to farmers' training, agribusiness credit and crop production systems. Direct help is needed to setup storage facilities to help farmers to keep excess production and avoid price fall.

An in-depth empirical investigation of gender roles in farming communities verifies the statement that 'women contribute greatly to growing crops year-round but are not recognized'. The findings reveal that women's growing involvement in farming is not adequately recognized by husbands. Men were uncomfortable to admit wives' influence on on-farm decisions due to prevailing social norms. It is apparent that the society will take a time to recognize women's contributions in farming if husbands do not come forward to recognize their wives' roles in farming. Both husbands and wives reported that most household decisions are made jointly like other south and east Asian countries. While both make decisions on household matters, females spent more hours for cooking, cleaning, child caring, and livestock rearing. Decision-making processes are not uniform across households, rather, they depend on the patriarchal and intersectional perspectives of the households. Explicitly, four intersectional (age, wife education, income, and livestock number) and two patriarchal (NGO membership and time allocation in farming) factors influence the husband to consult with his spouse (wife) when making decisions. Women who spend more hours in farm activities are associated with more involvement in farm-related decision-making processes. More importantly, women who are educated and have NGO membership have a higher opportunity to participate in the decision-making process and able to influence the decisions.

Another interesting finding is the impact of groundwater depletion on rural household's livelihood capitals. Remarkable inequality was found in five forms of livelihood assets directly related to groundwater availability, access, and institutions. The households living in low water scarcity region have a comparatively lower farming area that reflects on their yearly income from crop farming. In the case of agricultural extension services (social capital), farm household living in the low scarcity area got the highest priority in the study areas. Multinomial logistic regression identifies business, job, farm size, farm income, fish income, wage and salary, household expenditure, farm expenditure and availability of electricity as the main determinants influencing the level of livelihood status. The study did not identify superior or preferred livelihood capitals but showed that livelihoods influenced by specific household characteristics.

The northwest Bangladesh faces problems related to climate change and water stress. Both secondary and primary data have consistent results although the perceptions about these changes vary between women and men. The results show a significant difference in husbands' and spouses’ perceptions about the severity of climatic change in high water scarcity and low water scarcity areas. Both the husband and spouse in the high water scarcity area mentioned that every year they struggle with drought. To mitigate climate change impacts, the farmers adopted adaptation strategies. Two strategies were related to irrigation while the other two were allied with rice and non-rice enterprise choice. The adaptation measures varied according to the water scarcity levels. Likewise, spatial characteristics and joint family decision are the most significant determinant for adaptation decision and strategies.

8.2 POLICY RECOMMENDATIONS

Despite noticeable progress in crop production, farmers still require support from local and central government about the promotion of high-value crops, efficient marketing, extension advisory and crop insurance services. Pilot based **crop insurance** is implemented in the country that should be upscaled with necessary improvement/modification. In addition, direct aid is needed in **establishing storage facilities** to help farmers to keep excess production and avoid price fall.

The study has found the diverse perception of husband and wife on women’s participation in farming. It also reveals that women who are educated and have NGO membership have a higher opportunity to take part in the decision-making process and to be able to influence the decisions. This evidence can inform future agricultural policy interventions designed to recognize the role that women play in agricultural production and can affect gender integration into crop farming in Bangladesh in line with promoting women’s education and NGO membership.

The quantification of groundwater depletion stress on livelihood assets recommends that diversification in income-generating activities like wages from **non-farm activities, domestic remittance**, income from small **business,** etc. can improve the livelihood status of the water scarcity regions. Policymakers can intervene by influencing different livelihood capitals in desired directions to contribute and secure livelihood outcomes.

The study suggests that giving adequate gender-appropriate knowledge and climate-related information will accelerate farm-level adaptation to climate change impacts. Institutional factors such as extension visit and access to credit for the farmers should be encouraged as such factors positively influence the choice of climate change adaption strategies. Priority should be given towards **gender-specific climate change information dissemination and technology** development by the local government and non-governmental authorities.

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