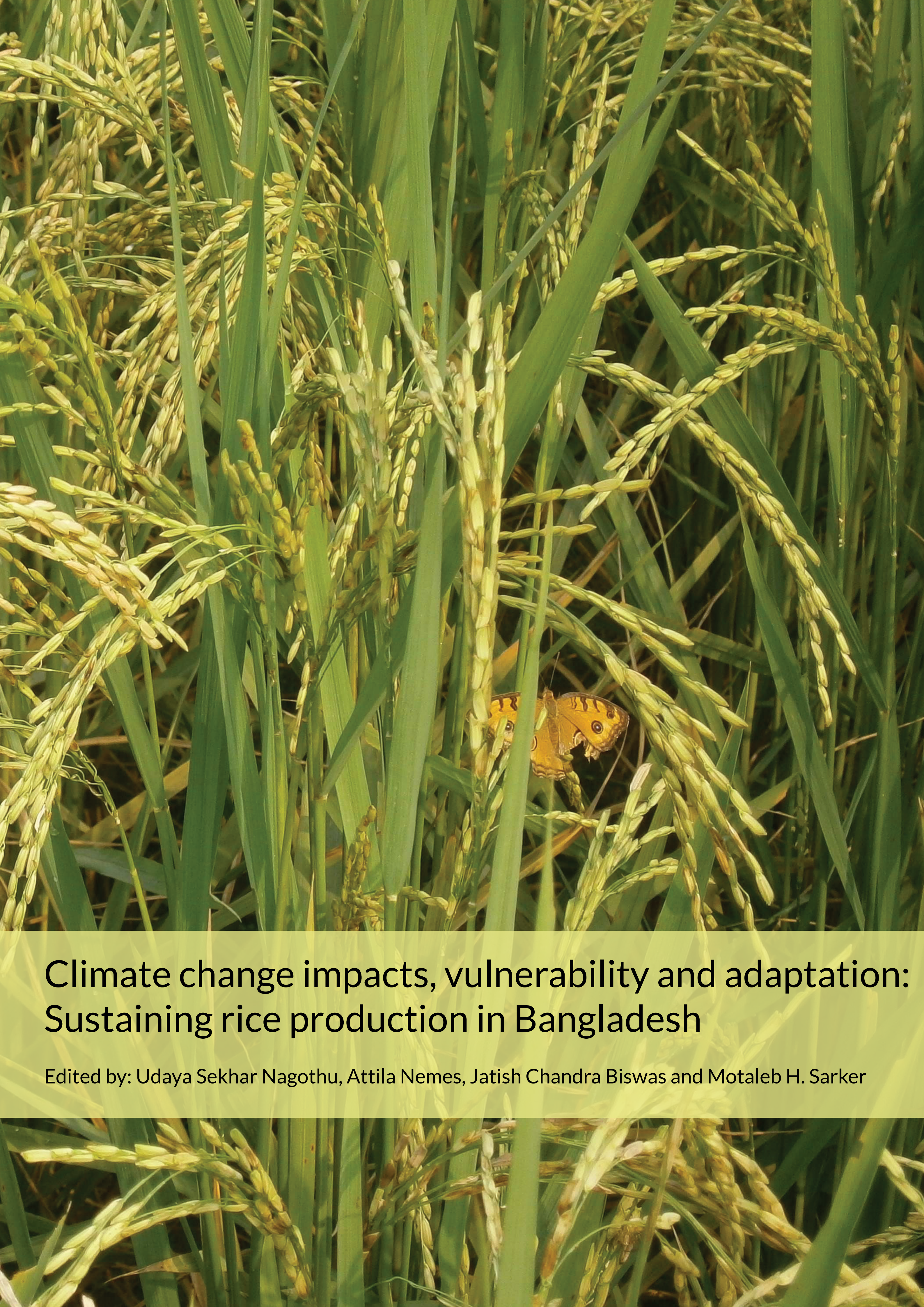

Climate change impacts, vulnerability and adaptation: Sustaining rice production in Bangladesh

Edited by: Udaya Sekhar Nagothu, Attila Nemes, Jatish Chandra Biswas and Motaleb H. Sarker

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Foreword

The project partners thank the Ministry of Foreign Affairs, Norway/ and The Royal Norwegian Embassy, Dhaka for the funding support and cooperation extended during the project. We also thank all the government and the non-government agencies in Bangladesh for their participation in various project workshops and positive feedback. We would like to specially thank the farmers and women groups who participated in the Focus Group Discussions, interviews, workshops and pilot demonstrations in the field that has immensely helped the scientists to gain a good insight into the challenges, farmer perceptions, and developing the adaptation measures. However, there are a still a number of gaps to be filled and needs to be addressed, which are not within the scope of this project.

The findings summarized in this report will contribute to the existing knowledge and help stakeholders and policy makers in Bangladesh while devising future strategies for addressing climate change impacts on agriculture and rice production in the country. This compendium has been edited based on project reports and other project outputs prepared jointly by the Norwegian Institute for Agricultural and Environmental Research (Bioforsk), the Bangladesh Rice Research Institute (BRRI) and the Center for Environmental and Geographic Information Services (CEGIS), by the following contributors:

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Contents

Project Summary

The three year (Dec 2011 to Dec 2014) RiceClima project (www.riceclima.com) focused on the important subject of "Climate change and impacts on rice production and agriculture in Bangladesh". Agriculture is the sector that more than two thirds of the population in the country depends on. Currently, rice accounts for 92% of the total food grain production and it is grown on approximately 11.25 million hectares of land, covering about 82% of the total cropped land in Bangladesh. Thus any adverse impacts of climate change on rice production will have serious implications for food security in the country. Food security is now on the top of the government agenda, and is a highly sensitive issue, given the increasing population, economic changes and urbanization in Bangladesh. The RiceClima project directly addressed the key issue of food security. The project was implemented in two provinces, namely Rajshahi (focusing on the impacts of drought on rice production and agriculture) and Barisal (focusing on the impacts of salinity and impacts due to sea level rise). The project strengths include multidisciplinary framework, pilot testing climate smart agriculture (CSA) technologies, quality assurance of results, stakeholder engagement at different levels, targeted dissemination, science-policy linkage, and consideration of gender dimensions in climate change.

Multidisciplinary and integrated approach

The project used a multi-disciplinary framework to address the complex issue of climate change impacts that needs an integrated approach and communication across different scientific disciplines (climate and hydrology modelling, ecological and socio-economic vulnerability impact assessment, agronomy, water management, pest and disease management). Lacking such an approach has been one of the main weaknesses of the scientific community who tend to operate within their own disciplines. For example, the outputs from climate and hydrology modelling tasks (Work Package 1) provided inputs to the vulnerability assessment (Work Package 3), and adaptation measures were planned based on the vulnerability in the two regions (Work Package 2). Stakeholder feedback was used in planning project activities and developing recommendations wherever possible.

Climate smart farming technologies

The project has worked with selected adaptation technologies that can address some of the threats rooting from climate change and apparent, pre-existing vulnerability. Work component two (WP 2) in the project focused on piloting selected technologies. Some of these include testing the performance of short duration drought- and saline-resistant rice varieties, shifting sowing windows, improving water use efficiency (WUE) through alternative rice growing systems (Alternative Wetting and Drying Irrigation), new irrigation systems to improve WUE, crop rotation and mixed cropping systems. Recommendations and guidelines, and a basket of adaptation measures have been developed for the benefit of farmers and stakeholders.

Stakeholder interaction in the project

In the first year, about 30 Focus Group discussions (FGDs) were conducted in the two project areas to interact with farmers, local officials and women involved in the farming sector. This provided first-hand knowledge of farmers' perceptions about climate change, their vulnerability, current adaptation measures they use and their needs for future adaptation. Most of this information was used used to plan the different work components. In addition, two major stakeholder workshops (back to back with a project workshop and an annual review meeting) were conducted, where representatives from more than 20 relevant national and regional agencies/departments were present. Project results were shared with them and their feedback was taken to improve the results. Some of the feedback or suggestions made by stakeholders were not within the scope of this project due to time and resource constraints. For example, the demand for more training and capacity building, breeding and testing salt tolerant varieites, crop insurance and other such measures. Individual meetings with some key stakeholders were also arranged up by BRRI and CEGIS whenever possible.

Science-policy linkage

The project team believed that policy development, especially policy and adaptation strategies to address climate change, should be based on scientific inputs. Stakeholder interaction was seen as one of the means to ensure that, and such interaction was attempted in the project with certain degree of success. However, it takes time to show the importance of science in policy development, as political priorities often dominate over science; though it is perceptible that good, evidence-based scientific knowledge and detailed analyses can provide relevant inputs. There is reason for optimism as the Minister for Agriculture in Bangladesh herself as well as other senior policy makers participated in the RiceClima stakeholder workshops (2012, 2013 and 2014).

Gender and climate change

Gender is a sensitive subject in Bangladesh due to long standing cultural traditions. Precautions had to be taken as to how to approach this issue and promote gender mainstreaming in the project. The project has found it difficult to address this issue, but has made some attempts to increase the involvement of women at different levels. The first level of involvement was attempted in the field, and several Focus Group discussions were conducted exclusively for women. But we have also observed participation of women in mixed groups along with male farmers. Women officials and scientists actively participated in the stakeholder workshops, capacity building (training on the AQUACROP simulation modeling tool) and provided feedback on how the role of women in climate adaptation can be increased. The project engaged women researchers in various tasks wherever possible. More efforts are still needed to increase the involvement of women.

Dissemination and capacity building

The Riceclima project has made several efforts to disseminate project results to targeted stakeholders including the staff of the Department of Agriculture, Department of Agricultural Extension, and other agencies. A number of deliverables are available on the project website. Key results were also made available in local language for the benefit of farmers, local field officials, and the interested general public. A monograph was prepared summarizing results from the project. A project website has been developed and maintained by Bioforsk for public dissemination. The project results were also shared at various regional and international workshops throughout the three year project period. Attempts are also being made to publish some of the project results in peer reviewed scientific journals.

Regional workshops and final project conference

The project organized two regional workshops in the first half of 2014 one each in Rajshahi and Barisal provinces. The project has followed the planned schedule: organized partner meetings at least once every six months and completed semi-annual and annual reporting accordingly. The project has not faced any major risks or deviations and most of the planned outputs were delivered in time. Overall, the partners strongly feel that the cooperation was useful, provided mutual benefits and generated some interesting results for adaptation to climate change in Bangladesh.

Quality assurance

Measures were taken in order to ensure scientific quality of the work done. While planning the various activities or tasks, the teams were oriented on the importance of quality data and standard procedures. At the next stage, all the outputs/deliverables and data analysis at the draft stage were reviewed in detail by project scientists working with respective tasks. During the February 2014 workshop two external reviewers, well versed with Bangladesh, were invited to review the project outputs. At the workshop on 25 February, 2014, at CEGIS, Dhaka, the project results from each work package were presented to the reviewers, and based on their feedback improvements were made.

1. Project background and justification

There is ample evidence that the climate on Earth is changing, and further changes cannot be avoided (Solomon et al. 2007). Forced with increases in greenhouse gases (GHG) emissions, present-day climate models' projections indicate significant changes in the behavior of major monsoon systems. In particular, the impacts of climate change on extreme events such as floods, droughts and on the spatial and temporal distribution of the monsoon rains will certainly impact agriculture, fisheries and water sectors. These are the sectors where a majority of the small and marginal farmers, landless poor and rural women are dependent on, for their livelihoods. Since the 70s, technological advances such as improved crop varieties and new irrigation systems have helped to increase agricultural productivity, despite rapid population increase, increasing market demands and environmental degradation. But, weather and climate are still the key factors in determining agriculture productivity in the South Asian region. Often the linkage between these key factors and production losses is obvious, but in other cases the linkages are complex, less direct.

The impacts of climate change on food production are global concerns, and they carry strategic importance for countries such as Bangladesh, that is among those identified to be at 'extreme risk'. Agriculture is the largest sector of Bangladesh's economy, which accounts for about 35% of the GDP and about 70% of the labor force (Basak *et al* 2010). Climate change impacts are likely to influence the monsoon which can lead to spatial or temporal changes in the distribution of rainfall and thereby impact rice production and food security in Bangladesh. Apart from that, the uncertainty related to potential impacts is a big challenge to address for the scientific community and state agencies. Agriculture in Bangladesh is already under pressure both from huge and increasing demands for food, and from problems of agricultural land and water resources depletion (Ahmed et al., 2000). The country needs to increase its rice yield and at the same time increase crop diversity with other food crops in order to meet the growing demand for food and nutritional security, driven by population and economic growth. Irrigated rice or Boro rice can be a promising area for increasing rice yield, which currently accounts for about 50% of total rice production in the country (BRRI, 2006).

However, climate change is a potential threat towards attaining these production targets. Any variations in the seasonal mean monsoon rainfall and temperature could significantly influence rice production. For example, a mere ten per cent fluctuation in monsoon rainfall could result in either flood or drought conditions, leading to adverse impacts on yields. It is therefore very important to understand the effect of climate change on rice production, especially boro rice production. Another, but even more uncertain climate-dependent factor in agricultural production is plant pests and diseases. Today, still significant parts of potential crop yields are lost to pests. For rice, more than 30% of the crop is lost to pests, diseases and weeds altogether (Oerke, 2006). While it is uncertain what the effects will be, it is certain that climate change will affect crop-pest interactions. Therefore, the strategies and tools used to cope with-, within- and between crop season weather variability must be strengthened to adapt to climate change.

Climate change induced problems are complex and require deeper knowledge from a multi-disciplinary scientific perspective. The natural science component provides, based on climate change scenarios and other scenarios (demographic, economic, etc) the implications climate change is expected to pose for food production. On the other hand, stakeholder integration is a necessary but not a sufficient condition; a stronger integration of scientific knowledge and stakeholder experience is required to develop adaptation strategies and policy guidelines (design, development, implementation and review). In many instances, however, this is still far from being the case, due to a lack of a clear coordination mechanism between scientific research and policy making. Scientists should view the end-users at the policy level in the project as "legitimate" clients for their research results, but there is a significant lack of transfer mechanisms that would allow passing the relevant information to the stakeholders. The latter group is often bound by administrative, financial and/or time constrains in their capacity to translate research results into policy (Hughes, 2011).

In the RiceClima project, our main aim was to get an understanding of the impact of climate change on the distribution of rainfall (both in terms of frequency and intensity) at regional and country scales, and assess the resulting changes in water availability and rice production, potential adaptation options and stakeholder involvement. In summary, our primary focus was to help find solutions for Bangladesh to adapt to climate change driven future changes in the agriculture sector, and in particular rice production.

1.1 Main Goal and Purpose of the Project

1.1.1 The Main Goal and Purpose

The main goal of the project was to contribute to the development of an integrated adaptation framework in order to sustain and improve rice production under different climate change scenarios in Bangladesh.

The purpose of the project was to study the climate change vulnerability (exposure, sensitivity) and adaptation in two selected rice growing sub divisions (Rajshahi and Barisal) and enhance the adaptive capacity at different levels to address climate change impacts on the agriculture sector in general and rice production in particular in Bangladesh.

1.1.2 Objectives

The following were the main objectives of the project:

1. To assess the impacts of climate change on water resources and rice yields in the selected rice growing sub-divisions using climate-, hydrological-, crop-, and pest models and develop future scenarios together with stakeholders.
2. To identify and develop suitable adaptation measures to minimize the negative impacts of salinity (due to tidal floods) and drought on rice production.
3. To analyse the socio-economic vulnerability, in particular the loss of livelihoods , farmers' ability to adapt in the two selected case study areas; identify needs for capacity development, and assess how policy can address the needs.
4. To disseminate results to policy makers, farmers, scientific community and to increase their overall awareness to improve the adaptive capacity.

1.2 Description of the project areas

Bangladesh has a sub-tropical climate that allows growing crops throughout the year. However, rainfall and temperature patterns vary across the country and thus crop production patterns also vary. To characterize the impact of climate change on rice production, two case studies, one from the northwestern and one from the southern part of the country, have been considered which represent the two different geographical and climatic conditions.

The northwestern project site (Rajshahi division) is drier and cooler in winter months also having less precipitation during the wet season compared to other parts of the country. The onset of the pre-monsoon is highly variable: sometimes dry, sometimes wet. On the other hand, rainfall in monsoon (June-October) can be as low as around 700 mm in a dry year and about 1500 mm in a wet year (UNDP, 1988). This implies that supplemental irrigation is essential for satisfactory rice production in dry years. Both drought and seasonal water logging along with ground water depletion are making crop production difficult in this region. The highest temperatures can reach 45 ^{o}C in May and observed low temperatures are as low as 6 ^{o}C in January. Soils of the northwestern site vary from light textured to heavy clays, typically containing less than 1% organic matter. The natural soil fertility is characterized to be moderately low because of widespread Zn and S deficiencies.

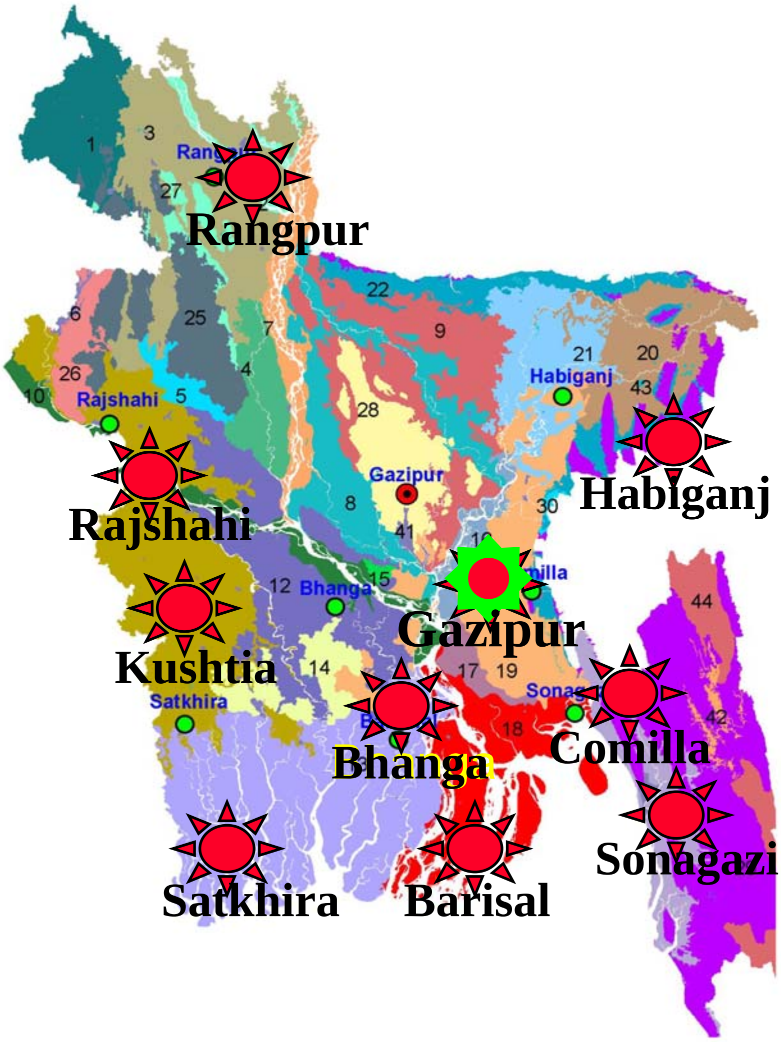


Figure 1.1 Map of Bangladesh showing different sub-divisions.

The southern project site (Barisal division) is characterized by a dense network of interconnected tidal rivers and creeks. Water and soil salinity levels as well as the depth and extent of flooding vary throughout the season. Flooding is mainly shallow, but moderately deep in some basin centers. Annual rainfall ranges from 1700 to 3300 mm and the monthly average temperatures range from about 15 ^{o}C (in January) to somewhat below 40 ^{o}C in May (UNDP, 1988). However, the project site lies within the cyclone zone and thus is predisposed to crop damage almost every year. Most soils are intermediate to heavy textured and nitrogen is the main limiting macro-nutrient for rice production. Rain-fed lowland rice (transplanted aman rice) is the main crop in the wet season followed by grass pea (*Lathyrus sativus*) and chili in some areas. But, vast areas remain fallow during the dry season due to soil and water salinity concerns.

1.3 Description and implementation mechanism of the project

The project was divided into four main work packages (WPs) for convenience of implementation, and one partner was made responsible for each WP. Within the WPs, each task had a lead partner and the task leader gathered necessary inputs, implemented the task together with other project partners as required, and was made responsible to deliver the final results from the task to the WP leaders. The four WPs and tasks within each WP together covered natural, social, economy and policy issues in the project. Inter-linkages between WPs were established as required within the project.

The project started off with an inception workshop in February 2012, where all partners met and discussed the various project components and prepared a work plan. The details of the work plan were determined at the inception workshop and followed-up at semi-annual meetings. At the workshop, each WP leader met the scientists responsible for different tasks within the respective WPs, discussed in detail the data needed for carrying out each task within the WP, the time line, the methodology, the final outputs and mode of dissemination. The inputs from the discussions at the workshop were the basis to develop annual work plans that were jointly prepared and approved by WP leaders and the Project Coordinator (PC). The progress of WPs, tasks and results was reviewed every 6 months by the PC, and delays were addressed by the respective WP leaders and the PC when needed. The PC documented progress and prepared annual and semi-annual progress reports.

WP1: CEGIS led WP1. It coordinated the 5 tasks within WP1 and each was led by one partner. CEGIS and Bioforsk determined the data needs, sources of data, types of model to be used, scenarios to be developed and quality checked the results from each task together with the task leaders. The types of scenarios and other outputs were presented to stakeholders at the annual workshops for feedback.

WP2: BRRI took the lead for WP2. It coordinated the 6 tasks within WP2 and each task was in turn led by one scientist from respective fields. BRRI and Bioforsk jointly prepared the implementation plan for WP2. WP1 provided some of the inputs for WP2, in addition to the inputs from secondary sources, government documents/reports and BRRI experiences from its own research in Bangladesh. BRRI coordinated the identification and development of suitable adaptation measures, the field preparation for testing of selected technologies in liaison with various agencies and farming groups. The final output from this WP was the development of a tool box of adaptation measures.

WP3: Bioforsk and BRRI jointly took the lead for WP3. The inputs to WP3 were mostly based on primary data collection and analysis, and partly from WP1 and WP2. WP3 also determined how prepared were the stakeholders (from the stakeholder workshops) and the farming community (via Focus group discussions) to address climate change impacts, and what efforts were needed to improve their adaptive capacity. Stakeholder workshops were organized as part of the stakeholder analysis.

WP4: Bioforsk coordinated WP4 in its capacity as Project Coordinator. It had the overall responsibility of project coordination and planning, communication with all partners, reporting project progress, ensuring the implementation of all project activities and outputs. The results from WP1-WP3 were disseminated in various forms (technical reports, technical and policy briefs, website, etc) targeting various end users and stakeholders. The outputs from WP1-WP3 were assessed and monitored regularly by the respective WP leaders and the overall progress by the PC. The reports and results were published on the website (www.riceclima.com) and also presented at the annual meetings and stakeholder workshops.

2. Benchmarking in *Rajshahi* division

2.1 Executive Summary

The benchmark survey was conducted in nine agricultural blocks of Rajshahi and Chapai Nawabganj districts. A multi-disciplinary team was involved in conducting the survey during April, 2012 to: (a) do a situation analysis of the project areas; (b) identify broader aspects of local competency and adaptive capacity of farmers, women and local stakeholders to address climate change impacts; and (c) to map the socio-economic profile of the farmers, their perceptions and needs. A total of 300 farmers participated in the survey and several group discussions.

The project site is characterized by low average annual rainfall (<1500 mm) having a cropping intensity of 191-262%. The cropping intensity is above the national average (180%) because of the increased availability of irrigation facilities, developed by Barind Multipurpose Development Authority (BMDA). The major crops currently grown in this region are rice and wheat. The minor crops are potato, tomato, gram, maize, brinjal, etc. Boro-Fallow-T. Aman is the dominant cropping pattern at the study sites.

Climatic variations, as compared to 15 years before, adversely affected rainfall and its distribution as well as temperature patterns, which in turn unfavorably affected drought duration, groundwater reserves, the occurrence and severity of insects and pest diseases and irrigation costs. Earlier, farmers used to cultivate kalokuchi, shaitta, dharial, sonasail, mugi, raghusail, magusail, jhingasail, BR10, BR11 and IR20 varieties. At present, pariza, sada sawrna, guti sawrna, BINA dhan7, BRRI dhan28, BRRI dhan39 and BRRI dhan36 are grown in the same areaa. Farmers are growing short duration rice varieties to reduce the effect of drought in the T. Aman season. Moreover, they are growing tomato, mustard, potato, etc to minimize irrigation water requirements in the dry season.

Grazing land and forested areas have decreased tremendously because of increased cropping intensity and so does the soil fertility. Forest/vegetation cover has decreased moderately. Irrigation rules and regulations are not followed properly at the field level. Irrigation fees collected from farmers were Taka 90/ha for one cusec water discharge-capacity pumps and Taka. 120/hr for 1.5-2 cusec discharge-capacity pumps, which is collected through pre-paid cards. However, the groundwater level is depleting alarmingly because of its over-exploitation, which constitutes a serious concern to be addressed.

A shortage of good quality seeds, inadequate drought tolerant varieties, high pest prevalence, low soil organic matter content, extreme high and low temperatures are some of the main bottlenecks for agricultural development in the study areas. The farmers of this locality are very much interested in better access to water as well as drought resistant varieties of different crops. They showed interest in awareness building through training and technological support for growing modern crop varieties. Rice fields are being converted to mango orchards as alternative cropping patterns to address frequent droughts and water scarcity. Some farmers are also setting up brick kilns in the crop fields as an alternative source of income. These changes may threaten food security in the near future if not addressed immediately.

2.2 Objectives and methodology

Benchmarking of the following variables were taken up in Rajshahi division

- knowledge, attitude and practices of farmers in the agriculture sector;
- farmers perceptions about climate change and impacts;
- physical, biological, environmental and socio-economic conditions of the study area;
- current farming systems;
- water resources and their use;

- problems hindering productivity;
- resources development in the locality; and
- the role of gender in managing households and farm activities.

2.3 Methodology

The study was conducted at Rohanpur, Chotodadpur and Jinarpur Blocks under Gomastapur Upazila of Chapai Nawabganj district; Ayhy, Nabagram and Bidirpur Blocks under Godagari Upazila and Kaliganj, Mundumala and Kalma Blocks under Tanore Upazila of Rajshahi district. A multi-disciplinary team including agronomists, irrigation engineers, an entomologist, and a social scientist/agricultural economist along with extension personnel of the Department of Agricultural Extension took part in the FGDs. A total of 300 farmers in 9 blocks (33 farmers from each block), including 250 men and 50 women participated in the focus group discussions (FGDs) and surveys.

FGD, a widely practiced diagnostic tool, was used and all the necessary steps of FGD methodology were followed to do the benchmarking. A field level Sub-Assistant Agricultural Officer (SAAO) of DAE assisted in selecting the farmers and organizing FGDs in each block. An Upazila Agricultural Officer (UAO) and an Agricultural Extension Officer (AEO) of DAE participated and assisted in organizing the program.

2.4 Results and Discussion

Socio-economic profile, agriculture and development patterns
The population density of Godagari, Tanore and Gomostapur upazilas varied from 726 to 877 persons/sq. km (Table 2.1). The male-female ratio is close to 1:1. The grass root level extension service providers, ranged from 16 to 27 per upazila.

Table 2.1 Basic information of different upazilas in Rajshahi Division

Item	Upazila		
	Godagari	**Tanore**	**Gomastapur**
Total Area (sq. km)	476.00	259.39	318.12
Total Population (no.) Male Female	345353 170670 174683	188196 92216 95980	278973 141736 137237
Agricultural Block (no.)	27	16	20

The greatest number of landless farmers was recorded in Tanore upazila (52.69%), whereas the lowest number was found in Gomastapur upazila (19.21%). The greatest proportion of marginal farmers(40.48%) were found in Godagari upazila (Table 2.2). There were significantly more marginal and landless farmers than larger farm owners in Godagari and Tanore, but not in Gomastapur. In general, there were less than 5% of large farmers in the examined area.

Table 2.2 Farmer categories based on land holdings of different upazilas in Rajshahi Division

Farm family	Godagari		Tanore		Gomastapur	
	No.	**(%)**	**No.**	**(%)**	**No.**	**(%)**
Landless (<0.2 ha)	10874	28.05	16046	52.69	7735	19.21
Marginal (0.21- 0.6 ha)	15694	40.48	6677	21.92	11151	27.69
Small (0.61- 1.0 ha)	6022	15.53	2968	9.75	11105	27.58
Medium (1.01-3.0 ha)	4700	12.12	3709	12.18	8205	20.37
Large (>3.0 ha)	1483	3.82	1056	3.47	2075	5.15
Total	38773	100	30455	100	40271	100

The Barind tract region is characterized with low average rainfall (cca. 1500 mm). Before the introduction of irrigation facilities through the Barind Multipurpose Development Authority (BMDA), mostly rainfed T. Aman rice was cultivated, resulting in very low cropping intensity. However, after the introduction of irrigation facilities, most of the area (above 80%) of that locality was brought under cultivation (Table 2.3). Not only has a majority of that locality come under double or triple cropping, but in some cases even more than three crops are grown a year. The cropping intensity varies from 191 to 262%, which is more than the national average (180%), primarily due to the irrigation facilities developed by BMDA. The major crops of these localities are rice and wheat (Table 2.3). Rice is grown in all three main growing seasons, whereas wheat grows only in the winter season. The minor crops grown are potato, tomato, gram, maize, eggplant, etc. Today, establishing mango orchards are becoming popular in the region and the farmers claim to reap harvest within 5-7 years. Boro-Fallow-T. Aman is the pre-dominant cropping pattern of the study area followed by Boro-T. Aus-T. Aman with an exception in Gomastapur Upazila, where Boro-Fallow-Fallow is the second most frequent cropping pattern (Table 2.4).

Table 2.3 Land use with crops of different Upazila in Rajshahi Region

Item	**Upazila**		
	Godagari	**Tanore**	**Gomastapur**
Total land (ha)	47563	25939	31812
Total cultivable land (ha)	39525 (83%)	22665 (87%)	24850 (78%)
Total cultivable fellow (ha)	215	333	325
Single cropped land (ha)	5100	344	8010
Double cropped land (ha)	20742	7844	11250
Triple cropped land (ha)	13683	14497	5590
Cropping intensity (%)	221	262	191
Major crops	rice, wheat, tomato	rice, wheat, mustard	rice, wheat, mustard
Minor crops	maize, mustard, onion, gram	potato, tomato, gram, maize, bringal	potato, tomato, maize, gram

Table 2.4 Main cropping patterns with area coverage of different upazilas in Rajshahi Region

Upazila	**Cropping patterns**	**% area coverage**
Godagari	Boro-Fallow-T. Aman	33
	Boro-T. Aus-T. Aman	13
	Fallow-Aus-T. Aman	12
Tanore	Boro-Fallow-T. Aman	42
	Boro-T. Aus-T. Aman	21
	Potato-T. Aus-T. Aman	4
Gomastapur	Boro-Fallow-T. Aman	28
	Boro-Fallow-Fallow	24
	Fallow-T. Aus-T. Aman	18

Farm size

Most of the respondents were landless (ranged from 32 to 79%). There were few large farmers (cca. 4%) and a considerable number of small farmers (ranged from 14 to 47%). Due to in-migration, the number of landless people is relatively high. On the other hand, the existence of high absentee land owners/farms reflects greater number of marginal and small farms.

Table 2.5 Percentage of respondent farmers per cultivated farm size (%)

Land category	**Upazila**		
	Gomastapur	**Godagari**	**Tanore**
Landless (<0.20 ha)	32	79	55
Marginal (0.21-0.60 ha)	25	10	19
Small (0.61-1.0 ha)	22	4	18

Medium (1.01-3.0 ha)	17	4	5
Large (>3.0 ha)	5	3	3
All	100	100	100

Infrastructure and Institutional Network

The road communication networks between districts and upazilas and among the blocks were found to be in good condition. In this regard, similarly to the irrigation facilities, BMDA played a vital role in road communication development in this region. Other institutional services like post offices, health care centres, agricultural block offices, schools and NGO activities were also functioning in the surveyed blocks (Table 2.6).

Table 2.6 Infrastructure and communication network in the surveyed area

Infrastructure	**Gomastapur***	**Godagari***	**Tanore***
Roads	Mainly well communicated	Mainly well communicated	Mainly well communicated
Post office	3	2	6
Health care center	2	4	5
Veterinary services	1	1	1
Primary Agriculture Cooperative	-	-	12
Irrigation Dept.	-	-	-
Agricultural Block Office	3	2	1
Financial Institutions/Bank/NGO	1	-	7
Schools including Madrasa	27	25	43
Hospital	-	1	-
College	2	-	6
University	-	-	-

* Figures include only the three blocks mentioned earlier

Migration

Table 2.7 shows that there was no out-migration from the surveyed blocks. However, about 17% of the farm families migrated in to Godagari upazila followed by cca. 5% in Gomastapur and Tanore upazilas. Most of the in-migrated people came from other districts, or places from 10 to more than 30 km distance. Farmers reported that in-migrated people significantly contributed to the improvement of agricultural production practices in their locality and helped satisfy seasonal labor demand.

Table 2.7 Migration status in the surveyed area

Upazila/Block	**Categories**		
	In-migration (%)	**Out-migration (%)**	**Distance of migration (km)**
Gomastapur			
Rahonpur	3	-	>30
Chotodadpur	6	-	>30
Ginerpur	6	-	<10
Godagari			
Ayhy	20	-	10-20
Nabagram	25	-	20
Bidirpur	5	-	<10
Tanore			
Kaliganj	3	-	30
Mundumala	10	-	20-30
Kalma	2	-	>30

Transport facilities

The main mode of transport is bus, van, bicycle, and votvoti - a kind of locally assembled engine driven vehicle (Table 2.8). People use bus for long distance travel, but for local communication they use vans, votvoti and bicycles. A good number of local and bigger markets also exist in the surveyed areas, but no warehouses and processing facilities exist for locally made commodities, which result in higher prices in the off-season. Local markets are situated typically within 1 to 3 km distance, while bigger markets, are typically available within 3 to 10 km. Hospital facilities lie in between 3 to 20 km distance.

Credit source and utilization

Farmers generally borrow money from Krishi Bank, BRDB, Grameen Bank, BRAC, Asha, CARB, CARITAS, etc. The prevailing interest rate is 8-10% from Governmental Organizations and 35-40% from NGO-s. The main credit sources are the NGO-s, from which about 75-80% farmers, mostly landless and marginal, receive credit for livestock and vegetables production.

Table 2.8 Transport services and access to key places.

Upazila / Block	Mode of transport	Local market		Bigger market		Hospital distance (km)	District town distance (km)
		No.	Distance (km)	No.	Distance (km)		
Gomastapur							
Rahonpur	Bus, Human driven van, Votvoti*, Bicycle	-	-	1	3	3	34
Chotodadpur	Bus, Human driven van, Votvoti, Bicycle	9	1-1.5	1	9	9	36
Ginerpur	Bus, Human driven van, Votvoti, Bicycle	1	<1	1	12	14	41
Godagari							
Ayhy	Bus, Human driven van, Votvoti, Bicycle	1	2	1	10	3	42
Nabagram	Bus, Human driven van, Votvoti, Bicycle	-	-	1	7	7	38
Bidirpur	Bus, Human driven van, Votvoti, Bicycle	1	5	1	10	8	20
Tanore							
Kaliganj	Bus, Human driven van, Votvoti, Auto Ricshaw, Cart, Bicycle	1	<1	1	<1	4	23
Mundumala	Bus, Human driven van, Votvoti, Auto Rickshaw, Bicycle	1	1	1	1	12	40
Kalma	Bus, Human driven van, Votvoti, Bicycle	2	3	2	3	20	50

* locally assembled vehicle driven by an engine

2.4.1 Climate change and variability

The majority of farmers perceived more frequent extreme weather variations during the last 15-20 years. The impacts were noticed mostly in the form of erratic rainfall and distribution patterns, change in temperature, drought, depletion of groundwater reserves, more pest and disease problems and water scarcity. Some of these are of course only indirectly linked to climate change and variability.

Table 2.9 Farmers' perception of climatic and environmental changes in last 15 years

Items	Gomastapur		Godagari		Tanore		Remarks
	Quantity variation	**Temporal variation**	**Quantity variation**	**Temporal variation**	**Quantity variation**	**Temporal variation**	
Amount of rainfall	Decreased	Little earlier	Decreased	Little earlier	Decreased	Little earlier	Due to climate change
Temperature	Slightly increased	Little earlier	Slightly increased	Little earlier	Slightly increased	Little earlier	Unusual variation
Flood occurrence	-	-	-	-	-	-	-
Flooding duration	-	-	-	-	-	-	-
Drought occurrence	Highly increased	Little earlier	Highly increased	Little earlier	Highly increased	Little earlier	No definite pattern
Drought duration	Increase	Slightly	Increase	Slightly	Increase	Slightly	
Monsoon	Decreased	Unusual	Decreased	Unusual	Decreased	Unusual	
Cyclones	-	-	-	-	-	-	-
Storms	Decreased	Slightly	Decreased	Slightly	Decreased	Slightly	
Pests	Increased	Highly	Increased	Highly	Increased	Highly	
Diseases	Increased	Highly	Increased	Highly	Increased	Highly	
Crop production	Increased	Highly	Increased	Highly	Increased	Highly	
Water availability (irrigation)	Increased	Slightly	Increased	Slightly	Increased	Slightly	
Number of irrigations	Increased	Slightly	Increased	Slightly	Increased	Slightly	
Ground water extraction depth	Increased	Highly	Increased	Highly	Increased	Highly	
Water quality (iron, salt, etc.)	No change	-	No change	-	No change	-	
Irrigation costs	Increased	Moderately	Increased	Moderately	Increased	Moderately	
Livelihood in the village	Increased	Slightly	Increased	Slightly	Increased	Slightly	
Other (earth crack frequency)	Increased	Moderately	Increased	Moderately	Increased	Moderately	

2.4.2 Crop Variety Replacement

Farmers used to cultivate local rice varieties like; kalokuchi, shaitta, dharial, sonasail, mugi, raghusail, magusail, jhingasail etc. and a few high yielding varieties (HYV) of rice, such as BR10, BR11, IR20 (Table 2.10). Today they mostly grow pariza, sada sawrna, guti sawrna, BINA dhan7 and BRRI dhan39, which cover practically 100% of the rice area in the T. Aman season. However, due to improved irrigation facilities and the availability of new varieties farmers are cultivating BRRI dhan28 and BRRI dhan36 as well, which cover about 70-80% of the land in the dry (Boro) season. Farmers are growing short duration rice varieties to reduce the effect of drought in the T. Aman season. To minimize the irrigation water requirement, farmers are also growing tomato, mustard, potato, etc. in dry season.

Table 2.10 Crops replaced during the last 15 years

Upazila/Block	Previous crop variety	Presently cultivated variety	% coverage	Reasons for change
Gomastapur				
Rahonpur	Kalokuchi, Shaitta, Dharia	Pariza, Gutisawrna	100	High yield, high milling out turn
Chotodadpur	BR10, BR11, Lalshorna	Sada sawrna, Pariza, and Chiniatap BRRI dhan28 and BRRI dhan36,	100 70-80	High yield and short duration
Ginerpur	Sonasail, Mugi, Roghusail, Magusail	Sada shawrna, Jira, Sawrna5, Pariza, BRRI dhan28	100 70-80	High yield, drought resistant, Old variety had high pest infestation but high milling outturn
Godagari				
Ayhy	Jhingasail, Sonakathi, Roghusail	Pariza, Nayon moni, Panchoboti BRRI dhan28, BRRI dhan36, BRRI dhan48	100 70-80	High yield, low irrigation due to short duration
Nabagram	BR10, BR11, Roghusail	Sada sawrna, Guti sawrna	100	Short duration and drought resistance
Bidirpur	BR4, BR10, BR11	Pariza, Guti sawrna, Sumon sawrna	100	Old variety had high ShB infestation
Tanore				
Kaliganj	Roghusail, Jhingasail, Dudkolom, Indrosail	BINA dha7, BRRI dhan32, BRRI dhan39	100	High yield and short duration
Mundumala	BR10, BR11, Raghusail	Sada sawrna, Lal sawrna BRRI dhan28	100	High milling outturn
Kalma	BR10, BR11, China, IR20, Raghusail, Indrosail	Sada sawrna, Lal sawrna, Jira, Nayonmoni BINA dha7, BRRI dhan28, BRRI dhan39, BRRI dhan49, BRRI dhan50	100 70-80	High yield, old variety had past and disease infestation

2.4.3 Farmers Need for Assistance for Better Adaptation

The main problems identified in the Barind Tract area are water scarcity and drought. Therefore, farmers of this locality are very much interested in better access to water and, simultaneously, the availability of drought tolerant varieties of the different crops they cultivate(Table 2.11). They showed interest in awareness building through training and technological support for growing modern crop varieties. They showed the least interest towards direct funding and food provisioning.

Table 2.11 Farmers' perfeption of assistance needs to allow better adaptation to adverse climate

Upazila/ Block	Direct funding	Technological support in farming	Providing tolerant crops	Awareness by experts	Better access to water	Food provision
Gomastapur						
Rahonpur	5	3	4	2	1	6
Chotodadpur	5	4	3	2	1	6
Ginerpur	5	3	1	4	2	6
Godagari						
Ayhy	2	1	3	5	4	6
Nabagram	6	4	2	3	1	5
Bidirpur	5	4	1	2	3	6
Tanore						
Kaliganj	5	3	1	2	4	6
Mundumala	5	4	2	3	1	6
Kalma	5	2	1	4	3	6

1 = most important to 6 =least important

Table 2.12 Environmental concerns in the surveyed area

Items	Gomastapur		Godagari		Tanore		Remarks
	Status	Level of concern	Status	Level of concern	Status	Level of concern	
1. Soil & Crops							
1.1. Status of grazing land	Decreased	Very low	Decreased	Very low	Decreased	Very low	Seasonal fallow land used for grazing
1.2. Soil erosion	Mild erosion	Moderate	Mild erosion	Moderate	Mild erosion	Moderate	Due to terrace land
1.3. Soil fertility	Decreased	High	Decreased	High	Decreased	High	Limited scope for use of organic manure
1.4. Effects of change in cropping pattern on soil	Exist	Moderate	Exist	Moderate	Exist	Moderate	
1.5. Effects of change in cropping pattern to water	Increased	High	Increased	High	Increased	High	
2. Water							
2.1. Availability of water resources in general	Increased	Moderate	Increased	Moderate	Increased	Moderate	Due to BMDA activities
2.2. Water quality for irrigation	No change	High	No change	High	No change	High	
2.3. Water quality for drinking	Improved	High	Improved	High	Improved	High	
3. Natural Environment							
3.1. Loss of forests/vegetation cover	Decreased	Moderate	Decreased	Moderate	Decreased	Moderate	Due to increased public awareness
3.2. Prevalence in pests (Insects, Diseases, weeds)	Increased	High	Increased	High	Increased	High	Emerged new race of disease and insect
3.3. Effects on general biodiversity (plants, animals)	Decreased	Moderate	Decreased	Moderate	Decreased	Moderate	
4. Human health							
4.1. Through food consumption (bacteria, chemicals, etc)	Decreased	Moderate	Decreased	Moderate	Decreased	Moderate	Due to increased food contamination
4.2. Through the accumulation of chemicals in the soil (eg. Fertilizers, pesticides, etc)	Increased	Moderate	Increased	Moderate	Increased	Moderate	Due to high land, low out-wash

2.4.4 Major agricultural and social issues

The status of agricultural productivity, loss of land, competition for natural resources and health and safety hazards were observed to be of moderately important to important in scale, presenting variable levels of concern in the surveyed areas (Table 2.13). The increased role of middlemen and traders/agents was seen as a serious concern due to their lack of concern for farmers' welfare.

Table 2.13 Perception of major agricultural, social and societal issues' effects on livelihood in the surveyed area

Items	Gomastapur		Godagari		Tanore		Remarks
	Status	Level of concern	Status	Level of concern	Status	Level of concern	
1. Agricultural and Social Issues							
1.1 Agricultural productivity	Important	High	Important	High	Important	High	
1.2 Loss of land to non-agricultural use	Moderate	Moderate	Moderate	Moderate	Less	Moderate	
1.3 Shortage of fodder / grazing area	Moderate	low	Moderate	low	Moderate	Low	
1.4 General competition for natural resources (land, water, wood)	Important	Moderate	Important	Moderate	Important	Low	
1.5 Increased role of middlemen, agents, traders	Moderate	High	Moderate	High	Moderate	High	
2. Societal Issues							
2.1 Healthy and safety hazards	Important	Moderate	Important	Moderate	Important	Moderate	Public health activities increased
2.2 Poverty and indebtedness	Moderate	High	Moderate	High	Moderate	High	
2.3 Unequal access to inputs	Very important	High	Very important	High	Very important	High	
2.4 Unemployment	Moderate	High	Moderate	High	Moderate	High	
2.5 Drudgery for women	Important	High	Important	High	Important	High	
2.6 Migration	Important	High	Important	High	Important	High	
2.7 Social conflicts	Important	Moderate	Important	Moderate	Important	Moderate	

2.4.5Water Resources and their Utilization

Water Users Association (WUA)

There are rules and regulations for the installation of tubewells and drawing groundwater. But these rules and regulations are not properly followed in the field (Table 2.14).

Table 2.14 WUA and the rules and regulations for water use

Items	Upazia			Remarks
	Gomastapur	Godagari	Tanore	
By-law for governing water use	No	No	No	As per Govt. irrigation principle WUA should be formed
Regulation prohibiting water extraction	Not practiced	Not practiced	Not practiced	As per Govt. irrigation principle, water extraction regulations exist
WUA	No	No	No	-
Establishment of WUA	No	No	No	-
Farmers under WUA	No	No	No	Informal pump operation and water distribution committee exists
Other activities of WUA	Nil	Nil	Nil	Maintenance works of irrigation channels
Regulating water use by WUA or others	-	-	-	Govt. organization like BMDA, BWDB regulating water use

Irrigation equipment and area

The use of irrigation equipment and the size of the irrigated area has increased tremendously during the last two decades (Table 2.15). Increased irrigation facilities resulted in greater cropping intensity. Irrigation through Deep Tube Wells (DTWs) that are managed by BMDA dominates in this area. Some of the Shallow Tube Wells (STWs) and Low Lift Pumps (LLPs) are managed by farmers in these locations.

Table 2.15 Irrigation equipment availability and irrigated area of selected upazilas in Rajshahi District

Irrigation equipment	Godagari		Tanore		Gomastapur	
	No.	Area (ha)	No.	Area (ha)	No.	Area (ha)
DTW	715	20225	569	13070	414	11650
STW	2365	1610	411	3250	1770	3980
LLP	504	420	155	530	1203	5050
Total	3584	22255	1135	16850	3387	20680

Irrigation water price

BMDA determines the per hour irrigation fee for utilizing water through DTWs managed by them. The fees are Taka 90/ha for one cusec discharge-capacity pumps and Taka 120/hr for 1.5-2 cusec discharge-capacity pumps, which is collected through pre-paid cards. Under privately managed irrigation, the fee charged is determined by the owner of the pump unit or an informal pump operation committee. The prevailing fee varies from Tk. 10,500 to 11,500 per hectare.

Tubewell installation costs and area coverage

During 2010-11, the construction cost of a 1-2 cusec capacity pump unit (HP 20-30) was 1.3-1.5 million taka. The full-capacity command area of a one cusec pump unit is about 27 ha and the actually irrigated area varies between 20-23 ha. Similarly, the full-capacity command area of a 2 cusec pump unit is about 32 ha, but the actually irrigated area is smaller, it varies between 25-28 ha. However, the designated irrigation area has been decreased due to the increased depth of the groundwater table (Fig. 1). Typically, 80-85 farmers from 1-2 or more villages share a single irrigation pump unit. In recent years, a large number of privately owned mini-DTWs are being installed in the Barind tract area without following irrigation regulations. This may have contributed to the acceleration of groundwater depletion in the Barind tract area. The pump ownere sold water to the neighboring farmers for cash.

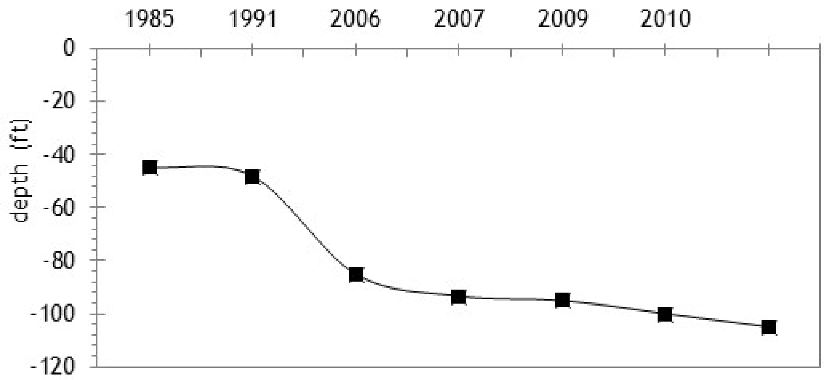


Figure 2.1 Change of depth to the groundwater table over the years 1985-2010 in the Barind tract area, Rajshahi **(Source: The Daily Ittefaq, 29 April, 2012)**

2.4.6 Major Constraints for Agricultural Development

Based on the perception of farmers in this locality, the constraints for agricultural development were summarized in Table 2.16. Lack of quality seeds, inadequate availability of drought tolerant varieties, high pest prevalence, low soil organic matter content, extreme high and low temperatures, etc were some of the main constraints for agricultural development.

Table 2.16 Farmers' perceptions of major constraints for crop production and livelihoods due to climate change

Gomastapur	**Godagari**	**Tanore**
A. Crop production related		
Lack of quality seeds		
Lack of proper production technologies		
Lack of drought tolerant varieties		
High degree of pest infestation		
High input costs		
Losses and costs incurred during harvest		
Low organic matter content of soil in the farm		
Technological improvement to drought tolerance		
Lack of training		
B. Environment related		
High temperatures during the dry period		
Short duration of winter		
Uneven distribution of rainfall		
C. **Water resources related**		
• Lack of availability of irrigation water	• Improve the surface water availability from the Padma	• Lack of availability of irrigation water
• Lack of pond water use in crops	• Excavation of canal for irrigation	• Lack of pond water use in crops
• High irrigation cost	• Excavation of existing ponds	• High irrigation cost
• Increased water level depth	• Increased water level depth	• Increased water level depth
D. **Credit related**		
Credit problem at cultivation time		
High interest rates for borrowing money from NGO-s and money lenders		
E. Others		

Reduce middlemen activity
Direct purchase from farmers

2.4.7 Emerging and priority issues to be addressed

- Replacement/transformation of crop land to mango orchard;
- Sharp increase of groundwater depth in the Barind tract area;
- Development of brick kilns in crop fields, leading to the loss of topsoil; and
- Use of pond waters solely for fish culture.

Priority issues

Based on discussions with the farmers, the following issues were identified as some of the main concerns to be addressed by the RiceClima project and other similar projects or initiatives:

A. Improved varieties:

- Drought tolerant genotypes/varieties for better adaptation capacity of farmers;
- Quality seed production of rice and non-rice crops;
- Short duration Aus and Aman rice varieties to better tolerate late season drought;

B. Cultural practices

- Alternative cropping systems;
- Improved soil conservation and health management;
- High value crops;
- Integrated pest and weed management;

C. Water Management

- Introduction of water saving technologies;
- Installation of micro-irrigation structures
- Assessment of water resources for domestic and commercial purposes.

D. Environmental issues

- Unusual temperature changes and their impact on crop production;
- Loss of bio-diversity to be evaluated

E. Socio-economics

- Land tenure system to be made more transparent to benefit the landless
- Marketing channels to be improved
- Increase the role of women in decision making during the production process

2.5 Conclusions and Recommendations

The survey behind this chapter was conducted at nine agricultural blocks of Rajshahi and Chapai Nawabganj districts, which represent the typical drought prone Barind tract area. The average rainfall is about 1500 mm, and the area has a cropping intensity between 191% and 262%. The major crops grown in the area are rice and wheat. The minor crops are potato, tomato, gram, maize, eggplant, etc. Boro-Fallow-T. Aman is the major cropping pattern of the study sites. Since groundwater availability is on the decline, crops that demand less water may need to be introduced.

Climatic variations, compared to 15 years before, adversely affected rainfall and its distribution as well as temperature patterns, which in turn unfavorably affected drought duration, groundwater reserves, the occurrence and severity of insects and pest diseases and irrigation costs. More research on drought tolerant varieties and management should be developed.

Soils in the area are often degraded because of the terrace-based land type, high cropping intensity and imbalanced fertilizer management. Therefore, a proper soil health management program should be developed and practiced at the farm level. Due to changes to the climate, new species of pests and diseases are emerging. Specific prevention and response measures should be developed.

A scarcity of water resources for crop production exists in this study area. Therefore, alternative water conservation practices should be developed to improve water productivity and overall water use efficiency. Rice fields in this area are often being converted to mango orchards, which needs to be assessed not to compromise food security on a longer term. Finally, farmers’ awareness should be improved through training and demonstrations, as well as field days to introduce improved technologies, and help farmers’ adaptation to those.

3. Benchmarking *Barisal* Province

3.1 Executive Summary

The survey was conducted in nine agricultural blocks of Patuakhali and Barguna districts in Barisal Division. A multi-disciplinary team was involved in conducting a situation analysis, including local resources and capacity to adapt to climate change, socio-economic profile and farmers perceptions to climate change impacts and adaptation. The study took place in June 2012, and a total of 245 farmers participated in the Focus Group Discussions and surveys.

The project site is characterized by an intermediate amount of rainfall (about 2000 mm) annually. The cropping intensity of 173-199% in this area is close to the national average (180%). The land type of this area is medium low to medium high, where maximum flooding depth is about 90 cm during the monsoon season. Rice is the major crop in the area, but many crops are cultivated as minor crops, such as pulses, potato, chili, mustard, sunflower, watermelon, groundnut, various spices, etc. Pulse-Fallow-T. Aman is the dominant cropping pattern (55% of the area) followed by Rabi crops-Fallow-T. Aman (20%) in Kalapara Upazila. In Amtali Upazila, Green pea - T. Aus-T. Aman is the major pattern (48%), followed by Fallow - T. Aus - T. Aman (24%), while in Patharghata Upazila the most dominant cropping pattern is Fallow-Fallow-T. Aman (40% of the area) followed by the Green pea-Fallow/T. Aus-T. Aman pattern (25%).

Changes in climatic conditions and extreme events in the past few years have adversely affected rainfall and its distribution as well as temperature patterns, which in turn unfavorably affected drought duration, the occurrence and severity of insects and pest diseases. Earlier, farmers used to cultivate rice varieties such as Kajalsail, Sadamota, Lalmota, Laxmibilash, Rajasail, Shaitta, Brindamoni, Rangalaxmi, Shitabhog, Kutiagni, Betichikon, Jhingasail and Matichak, and a few high yield rice varieties (HYV) such as BR11 or BR22. At present, only Sadamota, Vajan, BR11, BR22, BR23, BRRI dhan27, BRRI dhan40, BRRI dhan41 and BRRI dhan49. are commonly grown, which cover 60-99% of the land in the T. Aman season, and about 90% of the land in the T. Aus season.

Seasonally fallow land is often used for grazing in the study areas. Although decreased soil fertility was found to be of important concern, farmers are more worried about the availability of fresh water for crop production. The prevalence of insect pests and diseases have increased substantially, and the development of pesticide resistance is of great concern for the farmers. This also has implications for the environment, human health and biodiversity.

There is plenty of water available in the wet season, but scarcity or shortage of water resources can be a problem from February to June, depending on the amount and distribution of rainfall starting from February. The study areas are located within the poldered areas, which were primarily constructed for flood protection and as preventive measure against saline water intrusion. At present, the sluice gates are not properly maintained and many of them are out of order. As a combined result of a shortage of river-water from upstream and the ineffective sluice gates, irrigation canals are seasonally filled with saline water that is unsuitable for irrigation. In many cases, canal sections near sluice gates are increasingly filled with sediments (siltation), hindering effective drainage.

Generally, tidal flooding occurs in this study area twice a day, and the depth of tidal floods varies with the amount of monsoon rainfall. As a result, crop production becomes more challenging, especially for crop establishment and fertilizer management during the T. Aus and T. Aman seasons. Inadequate availability of salt-tolerant varieties, high pest prevalence, adulterated fertilizers, lack of farm machinery, lack of training on modern crop production technologies, etc have been identified as the most significant bottlenecks for agricultural development and adaptation to climate change. However, lack of an adequate amount of fresh water in the dry season is the single greatest challenge for agricultural development. Moreover, the progressive intrusion of saline water is destroying the ecological and hydrological balance of this locality. Since agriculture is the main source of income, any improvement to livelihood depends, to a large extent, on agricultural development.

3.2 Objectives

The benchmark survey attempted to:

- map farmers' knowledge, attitude and perceptions of climate change;
- characterize the site in terms of physical, biological, environmental and socio-economical parameters;
- map prevailing agricultural practices and farming systems;
- understand the dynamics of water resources and their use;
- identify, and diagnose the problems hindering farm productivity;
- identify existing opportunities for resources development in the locality;
- identify gender specific roles in managing households and farm activities.
- identify future needs to adapt to predicted climate change.

3.3 Methodology

The study was conducted in East Tiakhali, South Chokomoya and Nilganj Blocks under Kalapara Upazila of Patuakhali district; Karaibaria, Charpara and Nilganj Blocks under Amtoli Upazila and Char Lathimara, Charduani and Kalomegha Blocks under Patharghata Upazila of Barguna district. The study areas are situated in the south central region of the country at $89^0$50' to $90^0$24' longitude and $21^0$46' to $22^0$18' latitude (Fig. 1) and are characterized by severe storm surges, tidal flooding and intruding salinity. The study areas are mainly bound by the Bay of Bengal on the southern side, Tetulia river in the eastern side of Kalapara upazila, Buriswar river on the western side of Amtali upazila, and Biskhali and Baleswar rivers on the eastern and western sides of Patharghata upazila, respectively.

A multi-disciplinary team including agronomists, irrigation engineers, an entomologist, a social scientist/agricultural economist as well as extension personnel of the Department of Agricultural Extension (DAE) was assembled to conduct the focus group discussions (FGDs). A total of 245 farmers residing in 9 blocks, including 205 men and 40 women respondents, took part in the group discussions and surveys.

FGD, a widely practiced diagnostic tool, was used to assess the problems and opportunities for improved production practices. A field level Sub-Assistant Agricultural Officer (SAAO) of DAE assisted in selecting the farmers and organizing FGD in each block. An Upazila Agricultural Officer (UAO) of DAE participated and assisted in organizing the program.

3.4 Results and Discussion

3.4.1 Demographics, socio-economic profile, agriculture and development patterns

Population density at Kalapara, Amtoli and Patharghata upazilas varied from 378 to 445 persons/km^2 (Table 3.1). The male female ratio is close to 1:1. The number of Agricultural Block, i.e. the root level, extension service providers, ranged from 17 to 30 per Upazila.

Table 3.1 Basic information of selected Upazilas in Barisal region

Item	Upazila		
	Kalapara	**Amtali**	**Patharghata**
Total area (sq. km)	492.10	720.76	387.36
Total population (no.) Male Female	218920 111280 107640	272486 139347 133139	169938 89620 80318
Agricultural Block (no.)	21	30	17

The proportion of farmers based on land holding varied in the different Upazilas. The greatest percentage of landless was recorded in Patharghata Upazila (13.79%), whereas the smallest was recorded in Kalapara Upazila (9.73%). The greatest proportion of marginal farmers was also found in Patharghata Upazila (33.09%, Table 3.2).

Table 3.2 Farmer categories based on land holdings in the selected upazilas in Barisal region

Farm family	Kalapara		Amtali		Patharghata	
	No.	**(%)**	**No.**	**(%)**	**No.**	**(%)**
Landless (<0.2 ha)	3438	9.73	5733	12.09	3468	13.79
Marginal (0.21- 0.6 ha)	1495	4.23	13098	27.63	8322	33.09
Small (0.61- 1.0 ha)	7877	22.30	18623	39.29	6723	26.73
Medium (1.01-3.0 ha)	7314	20.71	7510	15.84	5986	23.80
Large (>3.0 ha)	2490	7.05	2439	5.15	650	2.58
Total	35318	100.00	47403	100.00	25149	100.00

Amtali, Patharghata and Kalapara are all located within the Ganges Tidal Floodplain. The land type of this area is mainly medium low to medium high land (Table 3.3), where maximum flooding depth is about 90 cm during the monsoon season. Topsoil texture of the Kalapara upazila is mainly loamy, but in Patharghata and Amtali upazilas it is mainly clay to clay loam. The greater part of the study area has gentle relief dominated by large saline areas.

Table 3.3 Area covered (ha) by land type in selected upazilas of Barisal region

Item	Upazila		
	Kalapara	**Amtali**	**Patharghata**
Highland	-	2695 (7)	750 (4)
Medium highland	31400 (80)	21560 (56)	19318 (96)
Medium lowland	7850 (20)	14245 (37)	-
Lowland	-	-	-
Total	**39250**	**38500**	**20068**

The tidal saline prone region is characterized with an intermediate amount of annual rainfall (ca. 2000 mm). T. Aman rice is cultivated as rainfed crop during the wet season, while most land remains fallow due to lack of irrigation facilities. However, after the construction of polders, primarily for the purpose of flood protection, some areas have been transformed into double (about 35% of the area) and triple cropping (about 9-23% of the area) (Table 3.4), resulting in an overall 173 to 199% cropping intensity, which is close to the national average (180%). Some medium low land areas are converting into medium high land because of siltation, facilitating the introduction of high yielding rice varieties instead of local varieties.

The major crop in the area is rice (Table 3.4). Rice is grown mainly in the T. Aman and T. Aus seasons, whereas pulses are predominantly grown in the winter season. Minor crops grown in the area are potato, chili, mustard, sunflower, watermelon, groundnut, spices, etc. Pulse-Fallow-T. Aman is the dominant cropping pattern in Kalapara Upazila (on 55% of the area), followed by the Rabi crops-Fallow-T. Aman pattern (20%). In Amtali Upazila, Grass pea-T. Aus-T. Aman is the dominant pattern

(48%), followed by Fallow-T. Aus-T. Aman (24%), while in Patharghata Upazila Fallow-Fallow-T. Aman (40%) is followed by the Grass pea-Fallow/T. Aus-T. Aman pattern (25%).

Table 3.4 Land use patterns in the selected upazilas of Barisal region

Item	**Upazila**		
	Kalapara	**Amtali**	**Patharghata**
Total land (ha)	49210	40450	30626
Total cultivable land (ha)	40590	38500	20068
Total cultivable fallow (ha)	70	1950	1235
Single cropped land (ha)	11998 (24)	17360 (43)	5899 (19)
Double cropped land (ha)	17187 (35)	14155 (35)	11166 (34)
Triple cropped land (ha)	11405 (23)	6985 (17)	2895 (9)
Cropping intensity (%)	199	173	187
Major crops	Rice, pulses (fellon, grass pea, green gram)	rice, pulse (grass pea, green gram)	rice, pulse (grass pea, green gram, Lentil, Gram, fellon)
Minor crops	chili, potato, sweet potato, watermelon, bangi	chili, watermelon, groundnut	vegetables, chili, potato, mustard, sunflower, spices

Table 3.5 Main cropping patterns with area coverage in the selected upazilas of Barisal region

Upazila	**Cropping patterns**	**% area coverage**
Kalapara	Pulse-Fallow-T. Aman	55
	Rabi crops-Fallow-T. Aman	20
	Fallow-Aus-T. Aman	10
Amtali	Grass pea-T. Aus-T. Aman	48
	Fallow-T. Aus-T. Aman	24
	Grass pea-Fallow-T. Aman	12
Patharghata	Fallow-Fallow-T. Aman	40
	Grass pea-Fallow/T. Aus-T. Aman	25
	Green gram-Fallow/T. Aus-T. Aman	20

Farm size

The percentage of landless farmers was lower in Kalapara Upazila than in the other two examined upazilas (Table 3.6). Marginal, landless and small farmers were observed to dominate in the selected study areas (23%, 27.33% and 28.67%). There were a few large farmers (5-9%), which figure is greater than that in other areas of the country. There were very few migrant farmers in the area compared to the Rajshahi area.

Table 3.6 Percentage of respondent farmers per cultivated farm size (%)

Land category	**Upazila**			**Mean**
	Kalapara	**Amtali**	**Patharghata**	
Landless (<0.20 ha)	17	33	32	27.33
Marginal (0.21-0.60 ha)	28	23	35	28.67
Small (0.61-1.0 ha)	27	24	18	23.00
Medium (1.01-3.0 ha)	19	12	10	13.67
Large (>3.0 ha)	9	8	5	7.33
All	100	100	100	100

Infrastructure and Institutional Network

The road communication networks between districts and upazilas were found to be in good condition, but within-blocks communication facilities are under-developed. Flood protection polders play a vital role in road communication in this area, but they are not well managed and maintained. Other institutional services like post offices, health care centres, primary agricultural cooperatives (like integrated crop management (ICM) and integrated pest management (IPM) clubs), and schools are also functioning in the surveyed blocks (Table 3.7).

Table 3.7 Infrastructure and communication network in the surveyed area

Infrastructure	Kalapara*	Amtali*	Patharghata*
Roads	Poorly communicated	Poorly communicated	Poorly communicated
Post office	2	-	2
Health care center	2	2	2
Veterinary services	-	-	-
Primary agriculture cooperative	ICM, IPM	IPM	ICM
Irrigation dept.	-	-	-
Agricultural block office	-	-	-
Financial institutions/bank/NGO	-	1	-
Schools including madrasa	26	11	30
Hospital	-	-	-
College	-	1	-
University	-	-	-

* Figures include only the three blocks mentioned earlier

Migration

Data in Table 3.8 reveals that there was no out-migration from the surveyed blocks, while some 8% of farm families migrated into Amtali upazila, and some 6% into both Kalapara and Patharghata upazilas. Most of the migrants came from other districts/places or the same district, like Kuakata, from 20 km to up to more than 50 km distance. Farmers reported that in-migrated people have no contribution to the improvement of agricultural production practices in their locality, and that sometimes causes social tension.

Table 3.8 Migration and commuting status in the surveyed area

Upazila/Block	Categories		
	In-migration (%)	Out-migration (%)	Distance of migration/commuting (km)
Kalapara			
East Tiakhali	5	-	>30
South Chokomoya	1	-	>30
Nilganj	-	-	-
Amtali			
Karaibaria	2	-	20
Charpara	5	-	>50
Nilganj	1	-	20
Patharghata			
Char Lathimara	5	-	>30
Charduani	-	-	-
Kalamegha	2	-	>30

Transport Facilities

The main modes of transportation are bus, van, motor cycles, bicycles and votvoti – a kind of locally assembled engine driven vehicle (Table 3.9). People use buses for long distance travel only, primarily along the Barisal-Kuakata road. For local communication, people predominantly use vans, votvoti, motor cycles and bicycles. Due to the poor development of road connections within the blocks, they face a major problem in mobility, especially in the wet season. During those times the only way of communication is on foot. The status of local markets is very poor. Only one bigger market existed in the surveyed areas; but they did not have any warehouse or processing facilities. The main market is situated away from the surveyed areas (5-16 km). A hospital facility lies in between 2 to 16 km distance.

Credit Source and Utilization

Farmers generally borrow money from local banks- Sonali Bank, Krishi Bnak, Agrani Bank, BRDB, Grameen Bank, BRAC, Asha, Sankalpa, Sangram etc. Interest rate varies from 8-10% (at Government banks) and 35-40% (at local lenders). The main credit sources are the local money lenders, used by 75-80% of the farmers, mostly the landless and marginal farmers, who receive credit for livestock rearing and vegetable production.

Table 3.9 Transport services and access to key facilities

Upazila / Block	Mode of transport	Local market		Bigger market		Hospital distance (km)	District town distance (km)
		No.	Distance (km)	No.	Distance (km)		
Kalapara							
East Tiakhali	bus, van, votvoti*, motor cycle, bicycle	-	-	1	5	5	44
South Chokomoya	van, votvoti, motor cycle, bicycle	-	-	1	9	9	36
Nilganj	bus, van, votvoti, motor cycle, bicycle	-	-	1	8	2	48
Amtali							
Karaibaria	votvoti, motor cycle, bicycle	1	1	1	16	16	30
Charpara	motor Cycle, bicycle	-	-	1	4	4	20
Nilganj	bus, votvoti, motor cycle, bicycle	-	-	1	10	10	30
Patharghata							
Char Lathimara	van, votvoti, motor cycle, bicycle	4	2-3	1	5	5	35
Charduani	van, votvoti, motor cycle, bicycle	-	-	1	3.5	7	50
Kalamegha	van, votvoti, motor cycle, bicycle	1	3	1	5	6	30

* Votvoti is a locally made, engine driven vehicle

3.4.2 Climate Change and Variability

Farmers perceived variations in rainfall, temperature, flood, drought and storm patterns, as well as the prevalence of pests and diseases, water availability and quality, and as a result, in their livelihood, as shown in Table 3.10. Farmers cited that the amount of rainfall has decreased compared to the situation 15 years before, and there is a more uneven distribution of rainfall in recent years, with prolonged periods of drought. Temperatures and the occurrence of cyclones have slightly increased. Although the cropping intensity improved in the recent past, damage caused by insects and diseases have also increased greatly. Fresh water sources have been decreasing over the years, partly because of siltation in rivers and canals. Although livelihood has increased compared to the previous decade, indebtedness has also increased.

Table 3.10 Farmers' perception of climatic and environmental changes in last 15 years

Items	Kalapara		Amtali		Patharghata		Remarks
	Quantity variation	**Temporal variation**	**Quantity variation**	**Temporal variation**	**Quantity variation**	**Temporal variation**	
Amount of rainfall	Decreased	Uneven distribution	Decreased	Uneven distribution	Decreased	Uneven distribution	
Temperature	Increased	Slightly	Increased	Slightly	Increased	Slightly	Unusual variation
Flood occurrence	No change	-	No change	-	No change	-	Tidal flood, twice a day
Flooding duration	No change	-	No change	-	No change	-	-
Drought occurrence	Increased	Moderately	Increased	Little	Increased	Moderately	No definite pattern
Drought duration	Increased	Moderately	Increase	Moderately	Increase	Slightly	
Monsoon	Decreased	Unusual	Decreased	Unusual	Decreased	Unusual	
Cyclones	Increased	Slightly	Increased	Slightly	Increased	Slightly	-
Storms	Decreased	Moderately	Decreased	Slightly	Decreased	Slightly	
Pests	Increased	Highly	Increased	Highly	Increased	Highly	Pesticide resistance developing
Diseases	Increased	Highly	Increased	Highly	Increased	Highly	
Crop production	Increased	Highly	Increased	Highly	Increased	Highly	Double
Water availability (irrigation)	Decreased	Slightly	Decreased	Slightly	Decreased	Slightly	Irrigation is not an usual practice
Number of irrigations	-	-	-	-	-	-	
Ground water extraction depth	-	-	-	-	-	-	900-1000 ft
Water quality (iron, salt, etc.)	Salinity increasing	-	Salinity increasing	-	Salinity increasing	-	
Irrigation costs	-	-	-	-	-	-	
Livelihood level in the village	Increased	Moderately	Increased	Moderately	Increased	Moderately	20-25% increased
Others	-	-	new diseases emerging	Slightly	-	-	

3.4.3 Crop Variety Replacement

Farmers traditionally cultivated several local rice varieties including Kajalsail, Sadamota, Lalmota, Laxmibilash, Rajasail, Shaitta, Brindamoni, Rangalaxmi, Shitabhog, Kutiagni, Betichikon, Jhingasail and Matichak, but also few HYV varieties, such as BR11, BR22 (Table 3.11). Today they mostly grow Sadamota, Vajan, BR11, BR22, BR23, BRRI dhan27, BRRI dhan40, BRRI dhan41, BRRI dhan49 etc., which cover 60-99% of the land in the T. Aman season, and about 90% of the land in the T. Aus season. However, due to shortage of fresh water for irrigation during the Boro season, BRRI dhan28 and BRRI dhan29 is cultivated in limited areas (about 10% of the land) in that season. Farmers have also started to grow short duration and salinity tolerant rice varieties to reduce the effect of salinity in later parts of the T. Aman season. Better salinity tolerant rice and other crop varieties are very much needed for Barisal.

Table 3.11 Crop varieties used during the last 15 years

Upazila/Block	Previous crop varieties	Presently cultivated varieties	% coverage	Reasons for change
Kalapara				
East Tiakhali	Kajalsail, Sadamota, Lalmota	BR11, BR23, BRRI dhan30, BRRI dhan41, Vajan	80	High yield, high profit, slightly saline resistant
South Chokomoya	Laxibilash, Rajasail, Shaitta	BR11, BR23, BRRI dhan27, BRRI dhan28, Vajan	60	High yield, high profit and lodging resistant
Nilganj	Kajalsail, Brindamoni, Rangalakhi, Sadamota	Sadamota, BR11, BR23, BRRI dhan40, BRRI dhan41	99	High yield, siltation in depressed land facilitating cultivation of BRRI varieties
Amtali				
Karaibaria	Rajasail, Sadamota, Lalmota, Shitabhog, BR11, BR22	BRRI dhan41, BRRI dhan53, BINA8	20-25	High yield, Salinity resistant
Charpara	Rajasail, Supply, Lalchikon, Shitabhog, Shaitta	Guta IRRI, BR11, BR22, BR23, BRRI dhan40, BRRI dhan41, BRRI dhan49	60-70	High yield, lodging, drought and salinity resistant
Nilganj	Rajasail, Saitta, Shitabhog, Kutiagni, Kajalsail, Jhingasail, Betichikon	Mala, BR5, BR11, BR22, BR23, BRRI dhan28, BRRI dhan29, BRRI dhan32, BRRI dhan40	Aman 65 Aus 90	High yield and some salinity resistant
Patharghata				
Char Lathimara	Rajasail, Kajalsail, Sadamota, Lalmota, Kalamota	Kajalsail, Sadamota, Lalmota, Kalamota, BRRI dhan41, BRRI dhan42	70-80	High yield and some salt resistance
Charduani	Rajasail, Kajalsail	Rajasail, Kajalsail, BR22, BR23	60	High yield and some salt resistance
Kalamegha	Rajasail, Lalchikon, Shitabhog, Matichak	Sadamota, Lalmota, BRRI dhan40, BRRI dhan41, BRRI dhan46, BRRI dhan48	70-80	High yield, lodging and salt resistant

3.4.4 Farmers Need for Assistance for Better Adaptation

The main constraint in the saline prone coastal area is the seasonal lack of fresh water. Therefore, farmers of this locality are very much interested in better access to fresh water, followed by the availability of salinity tolerant crop varieties (Table 3.12). They also showed interest in awareness and knowledge building through training and technological support for growing modern crop varieties. They also reported interest in improving mechanized cultivation in the area. They showed least interest towards direct funding and food provisioning.

Table 3.12 Farmers' perception of assistance needs to allow better adaptation to adverse climate

Upazila/ Block	Direct funding	Technological support	Tolerant crop varieties	Awareness by experts	Better access to water	Food provision
Kalapara						
East Tiakhali	5	4	2	3	1	6
South Chokomoya	5	4	1	2	2	6
Nilganj	6	4	2	3	1	5
Amtali						
Karaibaria	6	3	4	2	1	5
Charpara	5	3	1	4	2	6
Nilganj	5	4	2	3	1	6
Patharghata						
Char Lathimara	5	2	3	4	1	6
Charduani	5	4	1	3	2	6
Kalamegha	5	4	2	3	1	6

1 = most important to 6 =least important

3.4.5 Environmental Concerns

Seasonally fallow land is used for grazing, however, this practice is on a decline (Table 3.13). Farmers cited decreasing soil fertility and fresh water availability and they expressed their concerns about the future of agriculture in the area. The area under forest cover has decreased moderately lately. The prevalence of insect pests and diseases have increased. Many of these factors – directly or indirectly – can also have substantial effects on human health and biodiversity. Adulterated food has been cited as great concern for their health.

Table 3.13 Environmental concerns in the surveyed area

Items	Kalapara		Amtali		Patharghata		Remarks
	Status	**Level of concern**	**Status**	**Level of concern**	**Status**	**Level of concern**	
1. Soil & Crops							
1.1. Status of grazing land	Decreased	Low	Decreased	Low	Decreased	Low	Seasonal fallow land used for grazing
1.2. Soil erosion	Low erosion	Very low	Low erosion	Very low	Low erosion	Very low	Siltation in depressed area
1.3. Soil fertility	Decreased	High	Decreased	High	Decreased	High	Fertility improved in silted area
1.4. Effects of change in cropping pattern on soil	Exist	Moderate	Exist	Moderate	Exist	Moderate	
1.5. Effects of change in cropping pattern to water	Increased	High	Increased	High	Increased	High	
2. Water							
2.1. Availability of water resources in general	Decreased	High	Decreased	High	Decreased	High	Sea water intrusion increased
2.2. Water quality for irrigation	Decreased	High	Decreased	High	Decreased	High	
2.3. Water quality for drinking	Scarcity	High	Scarcity	High	Scarcity	High	Drinking water source is in very deep aquifer (900-1000 ft)
3. Natural environment							
3.1. Loss of forests/vegetation cover	Increased	Moderate	Increased	Moderate	Increased	Moderate	Forest area decreasing
3.2. Pest prevalence (insects, diseases, weeds)	Increased	High	Increased	High	Increased	High	
3.3. Effects on general biodiversity (plants, animals)	Decreased	High	Decreased	High	Decreased	High	
4. Human health							
4.1. Through the food consumption (because of bacteria, chemicals, etc)	Decreased	Moderate	Decreased	Moderate	Decreased	Moderate	Adulterated food
4.2. Through the accumulation of chemicals in the soil (eg.	Less	Low	Less	Low	Less	Low	

fertilizers, pesticides, etc)							

3.4.6 Major Agricultural and Social Issues

The status of agricultural productivity, competition for natural resources and health and safety hazards were observed to be of moderately important to important in scale, presenting varied levels of concern in the surveyed areas (Table 3.14). Drudgery for women has decreased in every surveyed Upazila in this region. There is less poverty and unemployment, but indebtedness has increased compared to the last decade.

Table 3.14 Perception of major agricultural and social impacts' effects on livelihood in the surveyed areas

Items	Kalapara		Amtali		Patharghata		Remarks
	Status	**Level of concern**	**Status**	**Level of concern**	**Status**	**Level of concern**	
1. Agricultural and Social Issues							
1.1 Agricultural productivity	Important	High	Important	High	Important	High	
1.2 Loss of land to non-agricultural use	Low	Low	Low	Low	Low	Low	
1.3 Shortage of fodder/ grazing area	Moderate	Low	Moderate	Low	Moderate	Low	
1.4 General competition for natural resources (land, water, wood)	Important	Moderate	Important	Moderate	Important	Moderate	
1.5 Increased role of middlemen/agents/ traders	Moderate	High	Moderate	High	Moderate	High	
2. Societal Issues							
2.1 Health and safety hazards	Important	Moderate	Important	Moderate	Important	Moderate	Public health activities improved
2.2 Poverty and indebtedness	Moderate	High	Moderate	High	Moderate	High	Indebtedness increased
2.3 Unequal access to inputs	Low	Low	Low	Low	Low	Low	
2.4 Unemployment	Decreased	High	Decreased	High	Decreased	High	
2.5 Drudgery for women	Decreased	Low	Decreased	Low	Decreased	Low	
2.6 Migration	No change	Low	No change	Low	No change	Low	
2.7 Social conflicts	Decreased	Low	Decreased	Low	Decreased	Low	

3.4.7 Water Resources

There is plenty of fresh water available during the wet season, but water scarcity of varied severity is experienced from February to June; its severity depends on rainfall patterns during the year. Salinity levels of river water depend on the flow patterns of rivers and the distance measurement from the sea shore. The study areas are within the polders, which were constructed mainly for flood protection and to prevent the intrusion of saline water. At present, the sluice gates are not properly maintained and many of them are out of order. In many cases, canal sections near sluice gates are increasingly filled with sediments (siltation), hindering effective drainage.

Agro-ecological conditions of the studied areas favor growing rainfed crops only, especially T. Aman and T. Aus rice. Social conflicts exist in the study areas over water use from the reservoirs during the dry season, driven by the general water scarcity. Some farmers are interested in preserving fresh water in the reservoirs (like canals, ponds, etc) for crop production, while others are interested in shrimp cultivation with saline water.

Tidal flooding occurs twice a day in the study areas. The depth of tidal floods depends on the amount of monsoon rainfall. The crop growing environment becomes more challenging - especially for crop establishment and fertilizer management during the T. Aus and T. Aman seasons - because of such tidal flooding.

Fresh water can be found in very deep aquifers (at 900-1000 ft depths), but the size of those reserves is not certain and their use may not be cost-effective for irrigation purposes. However, ongoing groundwater exploration may cause intrusion of saline waters into those deeper aquifers, making these areas even more vulnerable to natural hazards.

3.5 Constraints in Agricultural Development

Based on the perception of farmers in the surveyed area, the main constraints for agricultural development are summarized in Table 3.15. These include, lack of quality seeds, inadequate salinity tolerant varieties, high pest prevalence, adulterated fertilizers, lack of farm machinery, and the lack of training on modern crop production technologies, among others. Lack of fresh water in the dry season is seen as the greatest challenge for agricultural development in this region. Moreover, the intrusion of saline water is damaging the ecological and hydrological balance of the locality. Since agriculture is the main source of income in the area, improvement to livelihood depends, to a large extent, on agricultural development.

Table 3.15 Farmers' perception of major constraints for crop production and livelihood improvement

<table>
<tr><th>Kalapara</th><th>Amtoli</th><th>Patharghata</th></tr>
<tr><td colspan="3">F. Crop production related</td></tr>
<tr><td colspan="3">Lack of quality seeds</td></tr>
<tr><td>Lack of training on improved production packages</td><td colspan="2">Lack of proper production technology</td></tr>
<tr><td>Lack of saline tolerant varieties</td><td></td><td></td></tr>
<tr><td colspan="2">Adulterated fertilizer</td><td>Lack of training</td></tr>
<tr><td colspan="3">Lack of farm machinery</td></tr>
<tr><td colspan="3">Unavailability of fertilizer at the right time</td></tr>
<tr><td colspan="3">G. Environment related</td></tr>
<tr><td colspan="3">Uneven distribution of rainfall</td></tr>
<tr><td colspan="3">Increase the salinity after SIDR in 2007</td></tr>
<tr><td colspan="3">Intrusion of saline water is damaging ecological and hydrological balance</td></tr>
<tr><td colspan="3">Biodiversity reduced</td></tr>
<tr><td colspan="3">H. Water resource related</td></tr>
<tr><td colspan="3">Lack of fresh water for crop cultivation from February to June</td></tr>
<tr><td colspan="3">Siltation of canals</td></tr>
<tr><td colspan="3">Malfunction of sluice gates</td></tr>
<tr><td colspan="3">I. Credit related</td></tr>
<tr><td colspan="3">Credit problem at cultivation time</td></tr>
<tr><td colspan="3">J. Others</td></tr>
<tr><td colspan="3">Lack of communication facilities</td></tr>
</table>

3.6 Emerging and Researchable Issues

During FGDs, farmers showed great concern for some of the issues on agriculture and the environment, which are summarized as follows:

Emerging Issues

- Sedimentation/siltation of water reservoirs and crop fields;
- Increased water salinity and its distribution towards agricultural lands;

Based on discussions with the farmers, the following issues were identified as the main priorities to be addressed:

F. Agricultural practices, crop varieties

- Selection/release and dissemination of salt tolerant crop varieties;
- Quality seed and seedling production at the farmers level,
- Planting time adjustment to avoid damage by salinity,
- Introduction of high value crops,
- Integrated nutrient management,
- Mechanization,
- Integrated pest management

G. Water management

- Assessment of water resources for crop production,
- Rain-water harvesting and storage
- Canal excavation for better drainage and water storage
- Sluice-gate operation for seasonal water control, in relation to the tidal schedule

H. Environmental issues

- Impact of climatic change on crop production,
- Shrimp cultivation in Gher with brackish water and its impact on soil properties,
- Biodiversity

I. Socio-economics

- Land tenure system,
- Marketing and communication systems,
- Decision making process in crop production and processing
- Awareness and knowledge building of farmers on improved technologies through training, demonstrations and dissemination

4. Modelling

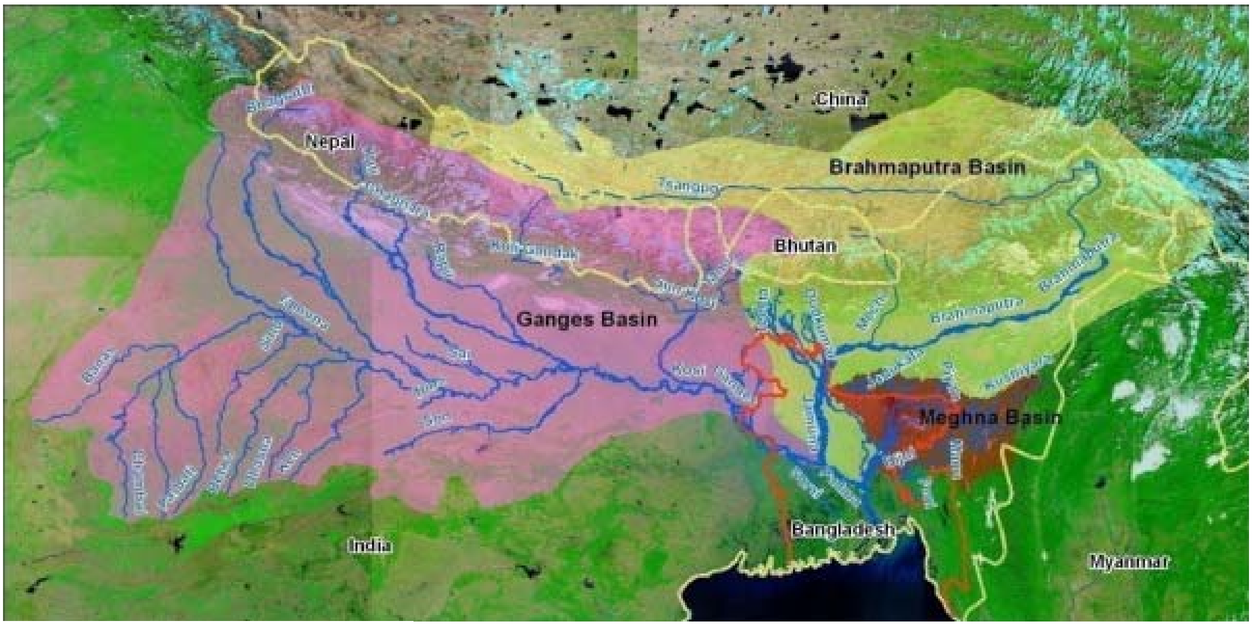
Towards increasing preparedness and adaptation needs to anticipated climatic changes in Bangladesh: The modeling framework and synthesis of modeling results

4.1 Introduction

4.1.1 Climatic challenges to food security in Bangladesh

Bangladesh's general geographical and climatic characteristics

Bangladesh is located in South-East Asia, North of the Bay of Bengal, and in general in the lower sections and the floodplain of the Ganges, Brahmaputra and Meghna river systems. Being on a flood-plain of a large and very active river-system (Figure 4.1), by definition, most of Bangladesh's area is very flat, and much of the densely populated and agriculturally active area is within a few meters above mean sea level. Bangladesh's climate is tropical, with generally high daytime temperatures throughout the year. The annual average precipitation varies geographically between cca. 1500 to 3000 mm in most of Bangladesh, with larger amounts, all the way to the extremes – falling in the extreme North and the North-East of the country. About 80% of the annual rainfall over Bangladesh – and its surroundings - occurs during the summer monsoon season (i.e. June to September), which poses two major, but opposite type challenges to land-based agriculture, and people's living in general: (a) during the monsoon season, surface water resources are abundant, extensive floods frequently occur, and the quick removal of excess water from large areas of land is essential to minimize the impact on daily life and agricultural production; while (b) in the longer, dry part of the year, evapotranspiration overwhelmingly exceeds precipitation, requiring nearly any agricultural production in any part of the country to rely on the availability and operation of irrigation facilities.



Ganges Basin	
Catchment area (sq km)	10,00,000
Av. Annual rainfall (mm)	1,200
Av. Annual discharges (cumec)	11,000
Max. Discharge (cumec)	78,000
Sediment transport (m ton/yr)	550

Brahmaputra/Jamuna Basin	
Catchment area (sq km)	5,73,000
Av. Annual rainfall (mm)	1,900
Av. Annual discharges (cumec)	20,000
Max. Discharge (cumec)	1,00,000
Sediment transport (m ton/yr)	590

Meghna Basin	
Catchment area (sq km)	77,000
Av. Annual rainfall (mm)	4,900
Av. Annual discharges (cumec)	4,600
Max. Discharge (cumec)	20,000
Sediment transport (m ton/yr)	13

Figure 4.1 River basins of Bangladesh's three main river systems.

Both challenges put a strain on Bangladesh's agriculture, and while large-scale storage and the delayed use of monsoon water would sound like a logical solution, constructing the necessary infrastructure to facilitate that in a flat and very densely populated country would most likely be unfeasible, and would also lead to the displacement of many inhabitants. The effect of the two opposite challenges related to rainfall is further amplified by the fact that the vast majority of the water carried by the three major river systems downstream actually originates from outside Bangladesh's boundaries (cf. Figure 4.1), exposing Bangladesh to the effects of strategic decisions by foreign entities.

Also related to climatic and geographic features of the country, in the southern, coastal zone, there is an added challenge for agriculture and livelihood in the form of salinity intrusion into the area. The occurrence and severity of salinity intrusion varies annually and seasonally, and is in correlation with rainfall amounts, its distribution, and the distance from the sea. Water and salinity related natural hazards affecting Bangladesh are summarized in Figure 4.2. A map of the extent and severity of dry season drought is shown in Figure 4.3.

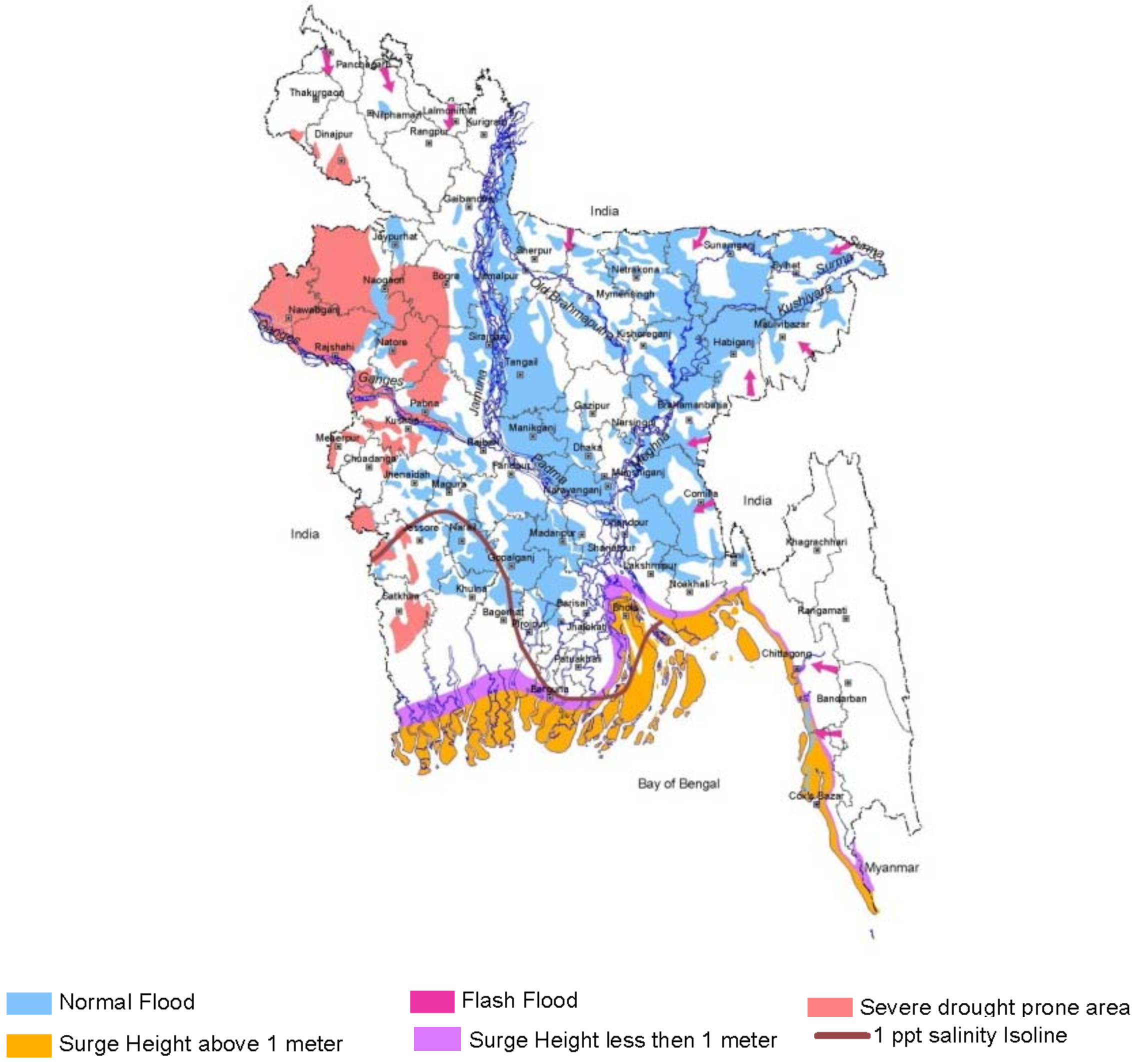


Figure 4.2 Water and salinity related natural hazards in Bangladesh.

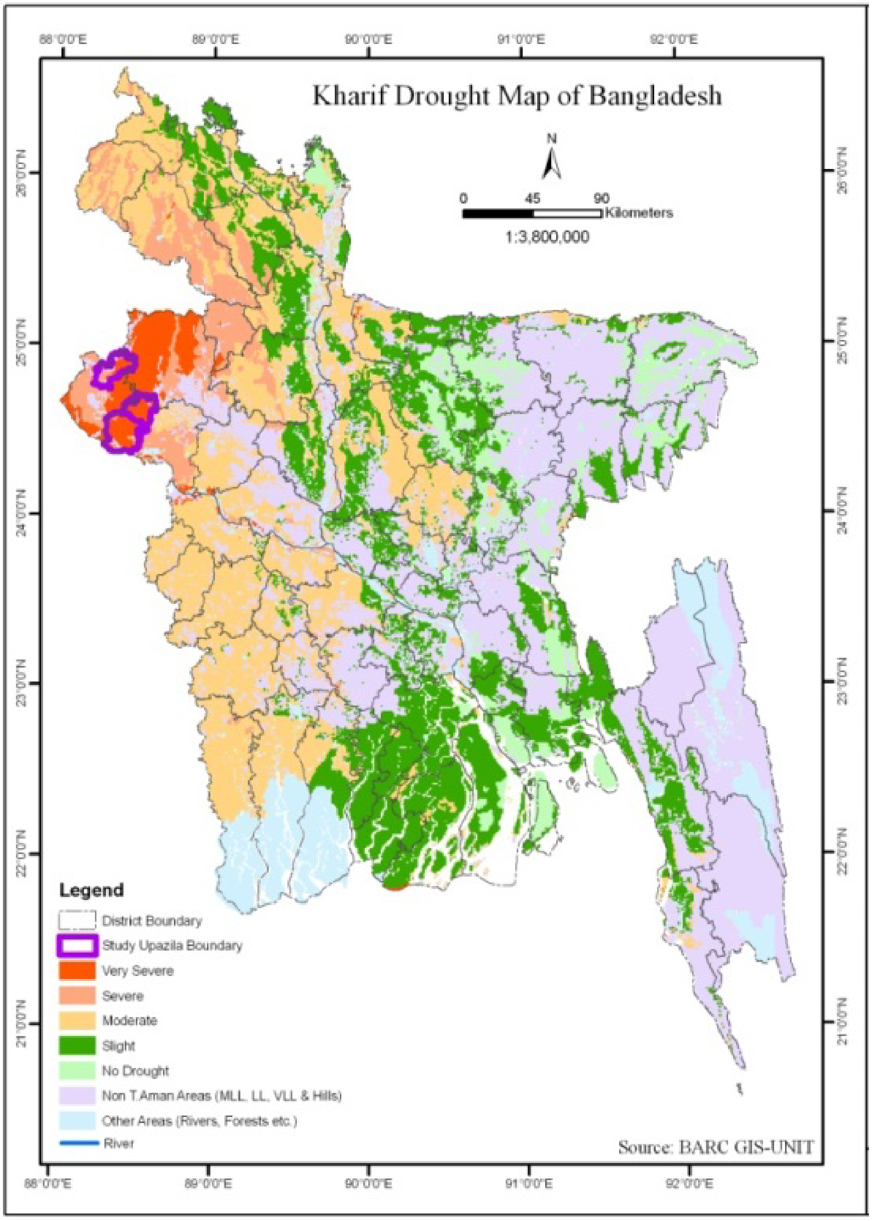


Figure 4.3 Kharif (dry) season drought map of Bangladesh.

Trends in Bangladesh's climate, and its potential implications

It has now been recognized that the Earth's climate is undergoing changes. It is recognized that human induced changes, mostly emissions, contribute to the shifting of an earlier balance in atmospheric processes, thereby leading to further changes. Among the major climatic factors, any changes to temperature and precipitation patterns are perhaps the most widely noticeable and comprehendible to/by the general public. Referring to the project's relevant report on climatic changes, reportedly, an examination of seasonal rainfall trends and anomalies during the period 1949 to 2009 indicated that Bangladesh is experiencing a decreasing trend in rainfall. Moreover, there appears to be a change in the distribution of monsoon rainfall in that the earlier single peak rainfall pattern tends to become bi-modal, with a less predictable onset of monsoon rains. Field visits to the chosen study areas confirmed that not only official statistics show such patterns, but local farmers widely conceived that such trends put them into new dilemmas when making decisions in crop management – from sowing and transplanting, through irrigation, to harvesting.

Changes to climatic factors can affect people and economy at multiple scales. While the individual farmer or family can suffer devastating effects from a lack of adaptive steps (at the individual level to the Government level), affected areas, and the country as a whole can be exposed to unexpected impacts on food security, the economy and/or the society. Such systematic changes have diverse impacts on human lives, and the best general adaptation strategy is to quantify expected changes and their impacts, and develop strategies of preparedness and adaptation.

WP1 of this project was intended to help understand ongoing changes and their potential implications, by quantifying processes in the atmosphere-water-soil-plant system using physically based simulation models and existing collections of data on the natural environment.

Choice of study areas

The choice of study areas that represent a range of conditions for Bangladesh's rice production points beyond the modeling part only, but was primarily driven by the recognition that a wide range of existing problems and concerns can be studied if the study areas are chosen from the Rajshahi and Barisal Divisions. These divisions greatly differ in their characteristics and can represent a multitude of concerns and dilemmas that most of the rest of the country is facing. The site characteristics are described in detail by technical reports of the project as well as earlier chapters of this monograph, we only provide a brief summary here.

Rajshahi Division is found in the NW part of Bangladesh, bordering India, and laying along the Ganges River, as Figure 4.4 also depicts. The area is somewhat undulating in its relief. Most importantly, this area, while being a rice producer, has the smallest amount of precipitation in the country, posing a drought problem to essentially the entire area. Despite the physical closeness of the Ganges River, it can only facilitate irrigation in its immediate proximity in the dry season – at least with the currently used technology. Shallow and deep tube wells and other local solutions have been facilitated in the last cca. two decades by Government agencies or by local (groups of) farmers, providing new potential water resources for agricultural use. The area is excellent for studying e.g. drought conditions and its effects on agricultural production, the use and sustainability of irrigation alternatives, the use of drought tolerant crop varieties, and drought-adaptive crop rotation options.

The Barisal Division study site – while also posing a degree of the water deficit problem in the dry season – exposes another problem group that Bangladesh already faces, and may face even more pronouncedly in the future. Barisal is located in the South of Bangladesh in the river delta area of the Brahmaputra/Ganges River (Figure 4.5). Being a river delta, the area is generally flat and very low lying, being exposed to wide-spread and potentially frequent flooding. River branches are abundant, as well as channels that can supply irrigation water. The ground water level is much shallower than in the Rajshahi region. The specific extra challenge that this area is facing is the intrusion of saline water. River water salinity, ground water salinity and soil salinity are present – seasonally and to a varied extent – but the area that faces this particular problem is apparently growing. Any potential reduction in river water yield, or any increase to sea level will further the seasonal salinity intrusion up-stream, and thereby to the irrigation water canals, the ground water and into the soil. Such effect is apparently accelerated by practices in shrimp farming – i.e. the application of brackish water to dry land. Salinity, through causing physiological drought, negatively impacts or prohibits crop production. The area can serve studies on e.g. drought conditions, the use of drought and salinity tolerant crop varieties, and to study alternatives to limit salinity intrusion to crop lands.

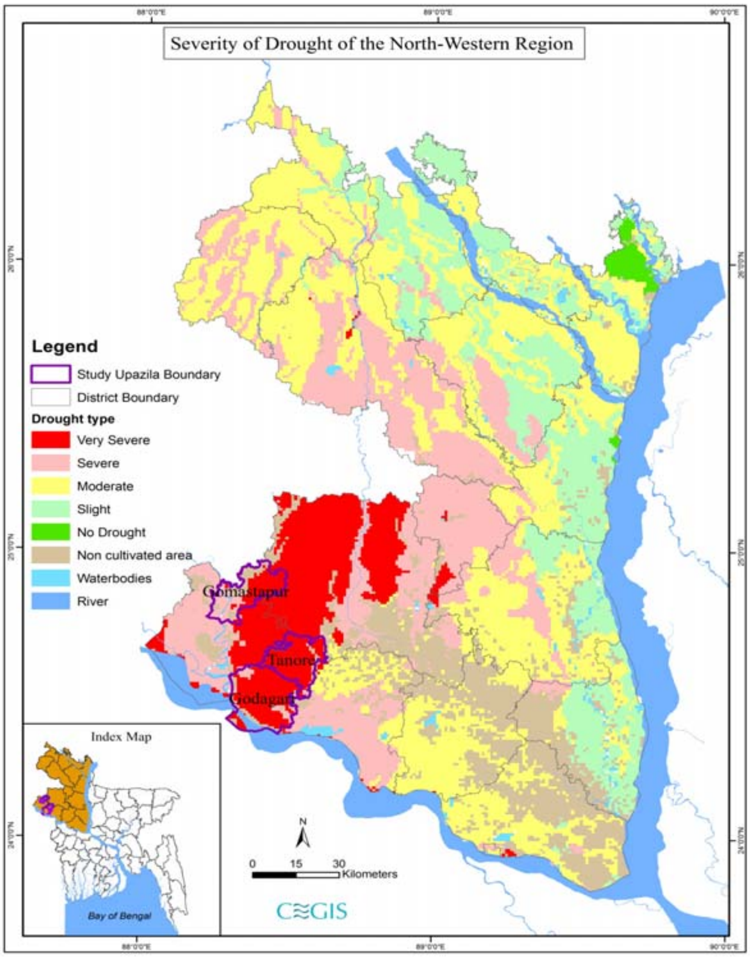


Figure 4.4 Base map and drought status of the drought prone study area around Rajshahi, NW Bangladesh, with Tanore, Godagari, Gomostapur upazilas marked.

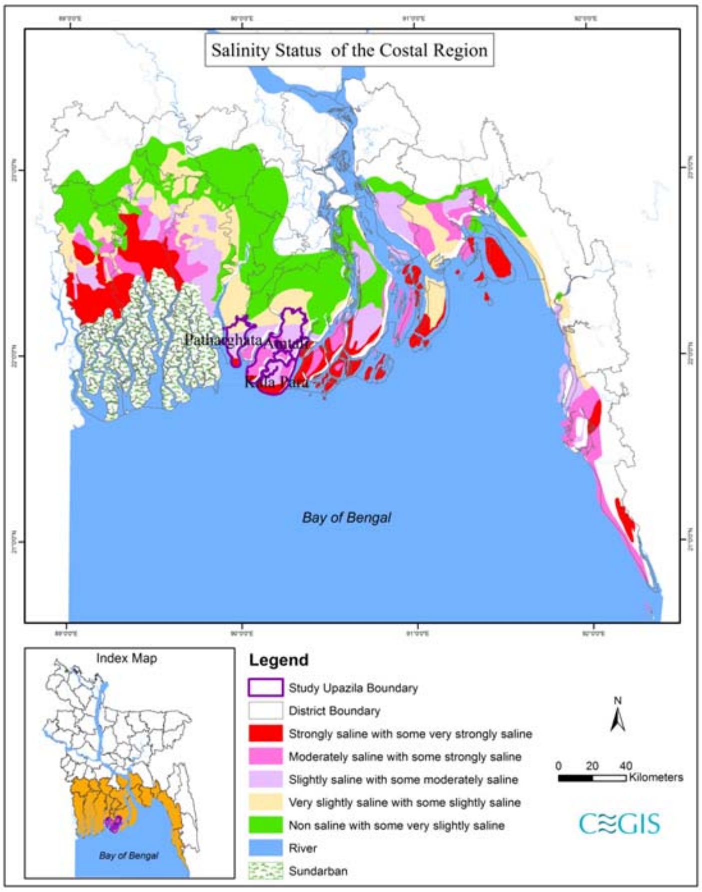


Figure 4.5 Base map and salinity status of the coastal region of Bangladesh, with the selected upazilas (Amtali, Kalapara, Patarghata) in the southern, saline prone study area near Barisal marked.

4.2 The simulation modeling framework

4.2.1 Background to simulation modeling in this project

With recent advancements in computing facilities and in the development of a range of models, simulation modeling is increasingly becoming the tool of choice when it comes to assessing the anticipated impact of certain natural or human-induced changes (Kværnø et al., 2013). The understanding of natural processes by the scientific community keeps improving, which improvement continually translates into a better ability to quantify such processes by such simulation models (Deelstra, 2011, 2013).

Signs of ongoing changes to our climate call for an evaluation and assessment of its potential impacts, but changes that can be addresses by simulation studies include a wide range of scenario and impact assessment studies driven by e.g. planned land-use or land management changes (Farkas et al., 2013), industrial, urban infrastructure and other facilities planning, etc.

The RiceClima project is concerned with the potential changes that any systematic changes to climatic factors may bring to the land based agriculture sector – and in particular to rice production – in Bangladesh. It is imperatively known that climate is the most essential driving force to land based agriculture. Precipitation provides the all essential water, sunshine allows plants and crops to photosynthesize, and the combination of temperature, humidity and wind conditions determine the rate of photosynthesis. Changes to climatic conditions are the largest scale changes that may affect crop growth, it was therefore essential to first quantitatively simulate potential changes to the climate of Bangladesh.

Given Bangladesh's unique geographical setting, terrain attributes and extremely high population density, even minor changes to its climate – and subsequently to its rice production system - may result in significant changes to both the individual's and the country's livelihood and food security. Therefore, well-based simulation studies in multiple aspects and multiple scales are desirable in order to successfully quantify anticipated changes.

The RiceClima project, in its current phase, has planned to utilize a succession of three different types and scales of simulation models to help quantitatively characterize the atmospheric and hydrological boundary conditions of crop production, as well as the expected water demand and expected yields of rice production in the different growing seasons. The following subchapters provide a brief justification and background information on the modeling steps and certain related decisions.

4.2.2 Driving forces while choosing simulation models

There are numerous considerations to be accounted for, when simulation modeling based studies are designed, and the actual simulation models or model packages are chosen (Waveren et al., 1999; Farkas and Hagyo, 2010; Deelstra et al., 2010a; Deelstra et al., 2010b). The outcome of a particular simulation based study is heavily dependent on – besides the model itself - the quality, resolution and amount of the input data available and used, the quality and extent of the expert knowledge about locally prevailing conditions, as well as the validity of any assumptions that are inevitably made while parameterizing the model (Waveren et al., 1999). For this reason, we have found it important that a balance is found between e.g. model quality and relevance to the given area, the model's resolution both spatially and temporally vs. the resolution and availability of the base data, model simplicity and ease of use and the experts' familiarity with the given simulation model(s). The potential for linkages to/with pre-existing studies as well as the capability to address issues of stakeholders' interests are also examples for considerations that point beyond the idea of choosing the 'best model' in terms of strictly its scientific complexity and acceptance.

Saloranta et al. (2003) established a set of operational and functional selection criteria for (computer) models whose application is intended to support decision making related to a particular water management issue. However, these criteria, the so-called "benchmark-criteria" can also guide potential model users in selecting the appropriate model for use in other areas as well. The benchmark criteria are presented in the form of 14 questions – with a 3-tier response system – through which each model can be evaluated.

Based on the benchmark criteria, a preliminary model evaluation has been performed to select simulation models for the Riceclima project WP1 simulation modelling tasks, namely (1) to simulate what climatic changes are expected in Bangladesh in the next 80-100 years, (2) to simulate what changes to regional water availability are expected as a result of any climatic changes, and (3) to simulate what changes are expected in terms of crop water demand under current crop production practices. Models, available for the team models have been evaluated. The list of criteria that was deemed most important is as follows:

Q1.1. How well does the model's output relate to the management task?
Q1.2. How well does the model's span and spatio-temporal resolution compare with the requirements of the task?
Q1.3. How well the model has been tested?
Q1.4. How complicated is the model in relation to the task?
Q1.5. How is the balance between the model's input data and data availability?
Q1.8. How is the peer acceptance for the model with scientific theory?
Q3.5. How is the model's flexibility for adaptation and improvements

Choosing the Climate Scenario model

The project plan called for generating regional climate scenarios according to 2 selected IPCC climate scenarios and for different time periods within the 21st century for both study areas. The research consortium decided to establish 4 different periods of study for climatic factors. Such periods represent 30 year periods that are centered on the 1990's as the "current" period, and the 2020s, 2050s and 2080s as early, mid and late 21st century periods. The current period relies on historic climate data of the 1980s to the 2000s. This time scale and the chosen periods appear easy to relate to, they present potentially noticeable changes (i.e they are distinctly far and wide enough), while they provide challenges that this generation and the next 2-3 generations will face.

Since climate modeling of the RiceClima project was advised by scientists of the Institute of Water and Flood Management of the Bangladesh University of Engineering and Technology (BUET), a lot of emphasis was placed on BUET's familiarity and experience with a particular model, and linkage to prior studies regionally, using the chosen model. The chosen PRECIS (Providing REgional Climates for Impacts Studies) model, a product of the Hadley Center in the UK, was found to be capable to provide the predictions and climatic data necessary to be used successively with the hydrological and crop models. The model is well documented and BUET has an effective work-contact with the Hadley Center, allowing effective requests for potential support. The model has previously been used in the Bangladeshi context, as cited in the project's relevant report.

A weakness to prior PRECIS simulations to Bangladesh was identified in that the resolution of prior simulations was 250km x 250km. This was found to be too coarse – the entire country of Bangladesh was represented by a few grid points; and the consequence the model was not able to well cover the apparent heterogeneity between distinctively different and geographically distant areas. As a very significant improvement to the simulations, the maximum resolution that the current version of PRECIS is capable of producing, 25km x 25km, was used for RiceClima. This is considered to be a very significant improvement, since many more distinctive features can be recognized on a 10-fold better spatial resolution of simulations.

To simulate climate change scenarios – and in fact any short or longer term climatic events – given the large degree of uncertainty in model results, a growingly accepted approach is to use multiple models (i.e. model ensembles). Using a multitude of simulation and averaging their results helps emphasize trends that are commonly predicted by several models, and helps suppress 'by-chance' findings that may only be predicted by one or very few models. However, running a model ensemble requires extended familiarity and expertise with all the applied models, as well as an abundance of resources, neither of which were available within the RiceClima project. Running a model ensemble is seen as a definite improvement for any similar studies in the region.

Choosing the model to describe watershed hydrology

It is expected that any systematic change to climatic features will also have an influence on the longer term water balance of a given watershed. The choice of a simulation model to simulate surface and subsurface water balance and water availability in the two study areas was somewhat more complex, given the overlapping expertise among (but also within) the institutions of the project partners. Figure 4.6 shows the model evaluation procedure for a similar task performed by Bioforsk (Farkas et al., 2010), evaluating seven pre-selected models, using the 7 above listed questions from Saloranta et al. (2003).

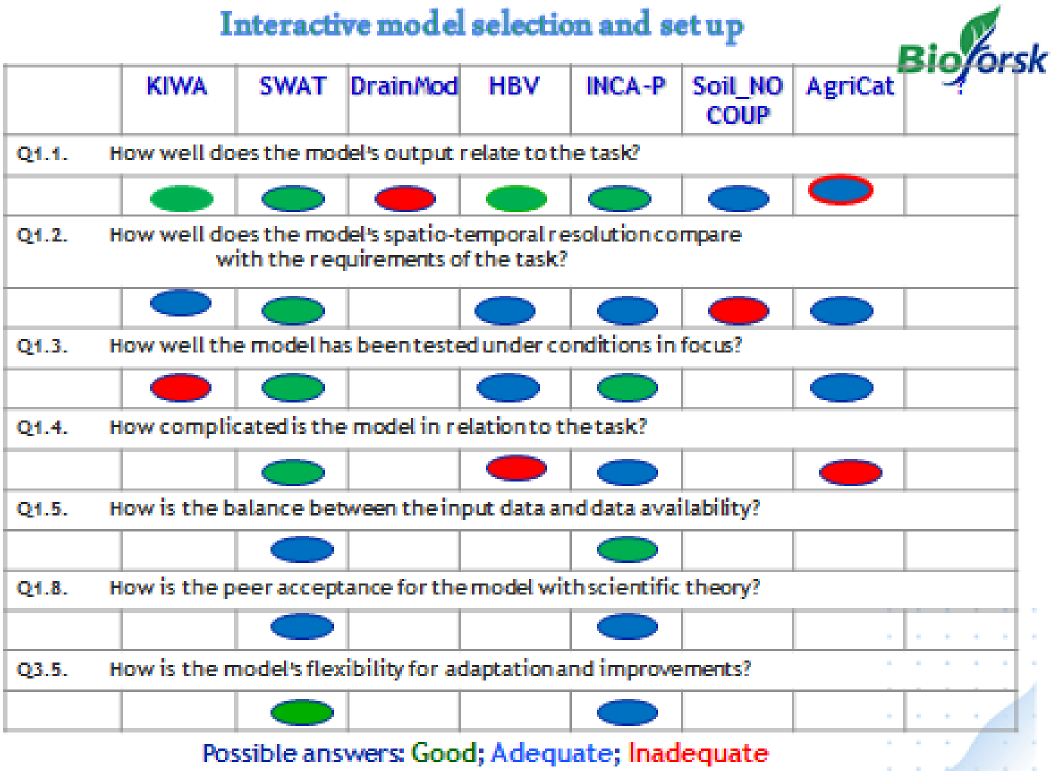


Figure 4.6 Model evaluation using the benchmark criteria of Saloranta et al. (2003)

Table 4.1 shows a somewhat similar assessment of numerous hydrological models, presented by RiceClima partner CEGIS. While their assessment was not based on the questions by Saloranta et al. (2003), but rather focusing on the models' capabilities, there is still a significant overlap between the two lists of evaluation criteria.

Table 4.1 Comparison of physically based hydrological models considered for this project, and some of their key characteristics

Model Criteria	MIKE SHE	HYDROTEL	WATFLOOD	TOPKAPI	CAS-Hydro	PRMS	SWAT	MODFLOW	WetSpa
Distributed Model	√	√	√						
Fully Distributed Model				√	√				
Semi Distributed Model						√	√	√	√
Open Source/Freely available						√	√	√	√
Flexible							√	√	√
Restricted	√	√							
Access to soil water & ground water	√								
Access to soil water							√		√
Access to ground water								√	
Easy to modify							√	√	√
Unable to modify	√	√							
Takes more time to simulate	√	√	√	√	√				
Takes less time to simulate							√	√	√
Needs MIKE 11 to couple	√								
Point & Non-point source pollution quantification							√		
Drought types, magnitude & risk quantification							√		
Water resources quantification & allocation	√						√		

From both evaluations, the SWAT model emerged as the most potent model to use for the hydrological simulations at the watershed scale. From the scientific point of view, SWAT presents a widely used and well accepted, conceptually well-established model that has the ability to be flexibly used in various environments and levels of data availability. From the practical point of view, both CEGIS and Bioforsk have voted for using SWAT because of the i) its availability, ii) having experience at both institutes in applying this model under various geographical and climatic conditions; iii) the coherence of the model weather input data with the general outputs of the climate scenario model; iv) the ease at which support is available from the developers and from the huge SWAT user group World-wide if needed; v) the already proven ability of the model to describe hydrological processes for irrigated lands under conditions similar to those in focus (e.g. research projects in India) and vi) the GIS based background of the model that greatly supports spatial representation and facilitates the direct use of input from digital spatial databases.

Choosing the crop model

With expected climatic changes, not only water availability, but the atmospheric boundary conditions - i.e. the driving forces of soil evaporation and crop transpiration - are also expected to change. The goal of the research group was to be able to show how future yields and any irrigation needs will potentially lead to change in rice production in a changing climate, and to compare those to the potential changes predicted in water availability. There is an abundance of physically based simulation models worldwide, that can simulate crop yield and irrigation needs. Since it was a more feasible goal to run a more generic but widely indicative simulation run, that was preferably representative of the entire study areas, the locally developed DRAS model was proposed for use. Since DRAS has been developed by CEGIS, there was ample existing expertise as well as help available internally, which is a great advantage in any modelling exercise. The DRAS model has already been calibrated and utilized within Bangladesh prior to the RiceClima project, which was also a great advantage of using this model. Another great advantage of using DRAS was that it is GIS-based and is readily connected with database layers of national coverage and other potential information sources that contain spatial reference. Having the support of spatial information also made the visualization and dissemination of the simulation results easy and practical.

There was concern regarding DRAS not being an internationally well-known and acknowledged model, as well as utilizing a simple field-capacity ('bucket-type') algorithm to describe soil moisture regime, rather than relying on one of the more accurate, while also more elaborate Richards-equation based finite element solutions. It was judged, however – in agreement with the general consensus in the scientific community as well as with the guidance by Saloranta et al. (2003), that using a more elaborate model would have added additional, likely unnecessary, complexity while the model results would not have been more certain. This is because of several reasons, e.g.: (i) the availability and detail of soil data that was usable for the study would not have supported the use of a more complex soil moisture module; (ii) the benefits of using a detailed, more complex soil moisture module would have been negated by the apparent uncertainty in the generated climatic data and some other inputs; (iii) the moisture regime calculations in the hydrological model (SWAT) are also based on a similarly simplified algorithm, which – together with the uncertainties in the aerial representation – expectedly only yields similar, but not better precision.

Yet another potential concern that requires discussion is the temporal resolution of the DRAS model, which works on a decadal (i.e. 10-day) resolution. This would be rather negatively seen, if the goal was e.g. advice on irrigation scheduling to particular farmers on a particular field, since models with a daily or even more detailed resolution are widely available. However, given that our research question was more aerially generic, and the data (climate) support is stochastic and uncertain, the coarse temporal resolution is unlikely to hamper the study's conclusions. Hence, our research team judged that some losses in the DRAS model's crudity and coarse temporal resolution are well compensated by the practical benefits listed earlier.

Interpretation of model results

Modeling studies are often interpreted by their face values (i.e. in absolute terms), regardless of the study's extent, scale, data support, the model's capabilities, and many other factors. Certain models and certain studies are designed to provide a very detailed simulation of various processes, and researchers are constantly working to fine tune such models (Couture et al., 2013). Other studies are not designed – or not capable – to describe all relevant processes in detail. Typically, large scale studies are such, since current modeling capabilities do not support accounting for processes at all scales in large scale studies. Nevertheless, such models are still considered to provide good approximations of natural processes at the appropriate scales.

Contrary to the traditional interpretation of modeling results, an alternative view is to interpret the results in relative terms, i.e. to focus on the change/difference between scenarios or time periods, rather than the absolute values of any prediction. This sort of interpretation has the great advantage that any systematic deviations, errors or uncertainties introduced by the model's imperfections are likely to be largely reduced when the difference of two scenarios is taken, while the derived change/difference can be equally indicative and meaningful for the particular study's needs. In RiceClima, while mostly absolute values are reported in the technical reports that report about simulation modeling results, we like to propose that the final interpretations are rather made in relative terms, (i) somewhat compensating for any known and potential unknown weaknesses in the simulations, and (ii) generalizing the effect of uncertainties in the climate data support.

4.3 Modeling results - a synthesis and discussion

4.3.1 Climate modeling

Five climatic factors, namely temperature, precipitation, sunshine hours, air humidity and wind speed, were evaluated on a seasonal and annual bases, as predicted by the selected climate model for the chosen study periods, using the A2 and A1B IPCC scenarios for each of the 3-3 upazilas in the 2 study areas. Figure 4.7 depicts the scheme of the climate modeling process from the General Circulation Model GCM) level to obtaining values for particular upazilas. In the following we summarize the findings for all five modeled factors individually.

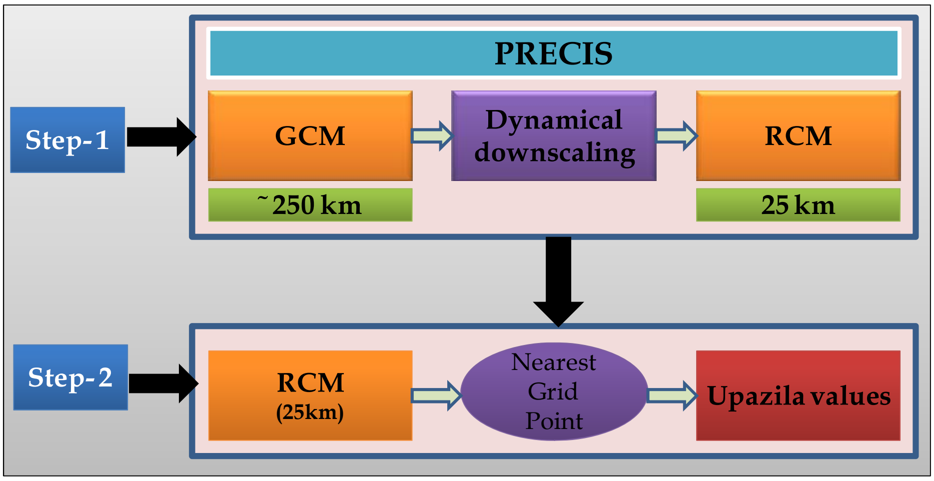


Figure 4.7 Downscaling approach followed from the GCM level to the upazila level, using the PRECIS General Circulation Model (GCM). RCM stands for Regional Circulation Model.

<u>Temperature</u>

- In terms of mean daily temperature, there appears to be a projected general temperature-rise in the southern, salinity exposed study area (Barisal division) across all distinguished seasons and all studies future periods. Such rise is projected to be continuous and very substantial according to the A1B scenario, and somewhat less substantial - and the rise somewhat interrupted around the mid-21st century according to the A2 scenario. The largest relative temperature increases are projected for the dry, winter season, which in general adds to the atmospheric water demand (potential evapotranspiration).
- The same trends are seen for the upazilas in the drought-dominant NW division of Rajshahi, the other study site, where the extent of the projected changes is even more expressed both seasonally and annually.
- While seasonal and annual mean temperature increases are projected to be in the 2.5-4°C range and 3.5°C range respectively for the Barisal area by the end of the 21st century, those are in the 3.5-4.5°C range and 4°C range respectively for the Rajshahi area, under the A1B scenario. The predicted increases are projected to be 0.5-1.5°C less under the A2 scenario.
- The results appear to be rather consistent and project to bring additional strain on agricultural production by generally increasing the atmospheric demand, i.e. the evaporative force.

Table 4.2 Cropping season-wise predicted mean temperatures (°C) in the two study areas for the period 1981-2100, using the A1B climate scenario.

Time Periods	Boro		T Aus		T Aman	
	Saline prone area	Drought prone area	Saline prone area	Drought prone area	Saline prone area	Drought prone area
Base (1981-2010)	27.04	26.16	30.39	31.44	28.65	29.11
2011-2040	28.12	26.97	31.02	31.62	29.56	30.05
2041-2070	29.44	28.07	32.05	32.64	30.64	31
2071-2100	30.51	30.39	33.16	35.57	31.54	32.51

Precipitation

The picture is somewhat more mixed in terms of predicted precipitation in the two study areas than it was for the temperature predictions. It is hard to delineate a general increase or decrease for any of the study areas either by the studied future periods, the climate scenarios, or the seasons, because of the apparent variability behind the mean predicted values. There are some indications, nevertheless:

- There is a slight indication that rainfall amounts may further decrease in the dry seasons and in the pre-monsoon period, while there may be an actual increase to the rainfall amount in the monsoon period over the examined time period. This is an unfavorable finding, since generally speaking, there is not as much need for excess amount of rain during the monsoon, while there would be definite need for every drop of rain in the dry season.
- The salinity affected Barisal area is predicted to have a larger chance for decreased annual rainfall amounts, especially in the mid-21st century. Apart from water availability concerns, this may also have effects on salinity intrusion (severity, timing) further upstream.
- The Rajshahi area, on the contrary, may see a general increase of annual rainfall by the end of the century, while in the early to mid-century the predictions are mixed.
- The amounts predicted for such changes are not too substantial in most cases – practically speaking, those are within the amount of one irrigation event for the rice crop, in both the positive and the negative direction. While projected increases of monsoon or annual rainfall amounts fluctuate, there is more indication of a chance for more significantly increasing rainfall amounts under the A2 scenario in both study areas, but mostly in the drought-prone Rajshahi area.

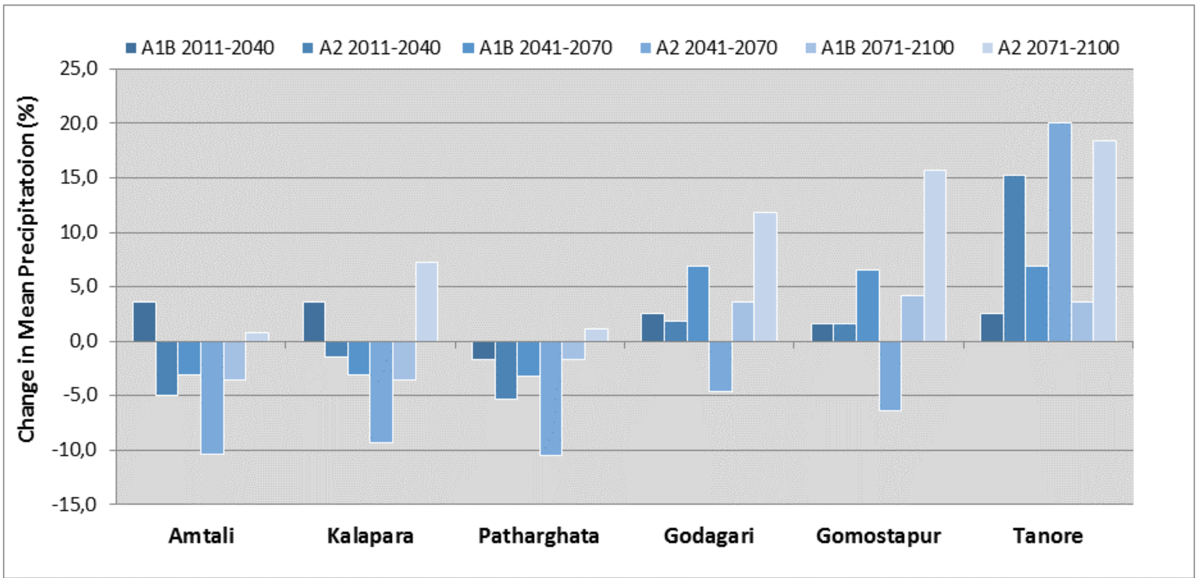


Figure 4.8 Percentage change in annual mean precipitation in Amtali, Patharghata, Kalapara, Gomastapur, Godagari and Tanore upazilas according to the A1B and A2 scenario predictions for the three studied periods of later parts of the 21st century.

Table 4.3 Cropping season-wise mean rainfall amount (mm) in the two study areas for the period 1981-2100, using the A1B climate scenario.

Time Periods	Boro		T Aus		T Aman	
	Saline prone area	Drought prone area	Saline prone area	Drought prone area	Saline prone area	Drought prone area
Base (1981-2010)	224	132	1,024	701	814	830
2011-2040	227	128	1,180	784	791	792
2041-2070	225	158	1,063	731	808	876
2071-2100	226	149	1,098	730	796	856

Air humidity

- Air humidity is predicted to decrease generally over time and in both study areas.
- The dry season decrease is predicted to be in the 3-5% range for the Barisal area, and 5-8% range for the Rajshahi area.
- The monsoon season humidity is also predicted to decrease, although to a more moderate extent: 0.5 to 2% in the Barisal area, and 2.5 to 6% in the Rajshahi area.
- Summarized annually, the Barisal area is predicted to see a gradually decreasing air humidity level by 2-3%, while the annual decrease for Rajshahi is more expressed (3.5-6%).
- For both areas, the projected decrease in air humidity is much more pronounced under the A1B scenario, coinciding with greater expected temperatures, and lesser rain.

Sunshine hours

- The amount of sunshine hours are forecasted to increase generally across all examined areas and time periods, and according to both climate scenarios.
- The extent of the increase is within 1-8% of the current amount – dominantly in the 2-5% range.
- The A1B scenario seems to signal a larger increase all across, although the A2 scenario prediction for an increase in the early century is substantially larger than that of the A1B scenario in some of the upazilas of both study areas.
- Seasonally, the sunny and dry winter season is expected to see no to only a moderate increase of sunny hours, but the most substantial increase – expressed both by hours and by % - will be seen in the monsoon and post-monsoon periods.

Wind speed

- The predicted change in wind-speed – of course excluding extreme weather events at this stage – is very moderate. Up to 12% change is predicted as the extreme changes in both directions, but the predominant change is predicted to be in the ±4% change zone across all time periods, areas and scenarios.
- While the A1B scenario predicts essentially no changes in the examined areas other than a 3-4% general increase late in the century, the A2 scenario yielded a prediction of a 6-12% drop in wind speed in the early century, gradually approaching (and exceeding in one upazila) todays wind speeds through the mid and late century.

Synthesis

A synthesis of the combined effects of the predicted climatic changes signals for more climate-driven strain on land based agriculture in the examined study areas. All examined climatic factors are logically understood (as well as have been shown) to have an influence on the “atmospheric demand”, or in other words the evaporative power of the atmosphere, that determines the demand side of soil evaporation and crop transpiration. Generally, increasing temperatures, increased sunshine hours and lower air humidity all point towards in increased demand, especially dominated by the predicted, greatly increased temperatures. Precipitation amounts could partially compensate that effect by providing an extra amount of water on the availability side of soil evaporation and crop transpiration. However, there is no significant and consistently increasing rainfall amount predicted; therefore it is very likely that the extra demand posed by the increased temperatures and sunshine hours, and decreased air humidity will not be met by extra amounts of rainfall. Figure 4.9 depicts expected trends in potential evapotranspiration during the course of the 21st century in Bangladesh. The somewhat decreasing predicted wind speeds point towards a slight reduction in atmospheric demand, but the other – more dominant – climatic factors listed above are expected to suppress that. This, altogether, will likely increase the strain on land based agriculture, materializing in potential yield losses and/or demanding extra economic and environmental resources to supply extra amounts of water in order to sustain agricultural production. Such strain and demand, according to our predictions, appears to be less significant if the A2 scenario becomes applicable. If the different seasons are examined, it is likely that the already excessive evaporative demand during the dry season will further increase, primarily driven by the increasing temperatures, rather than by the somewhat decreasing rainfall amounts. During the monsoon, the expected change is somewhat less, driven by a sustained or potentially increasing rainfall, and the lesser increase in temperature.

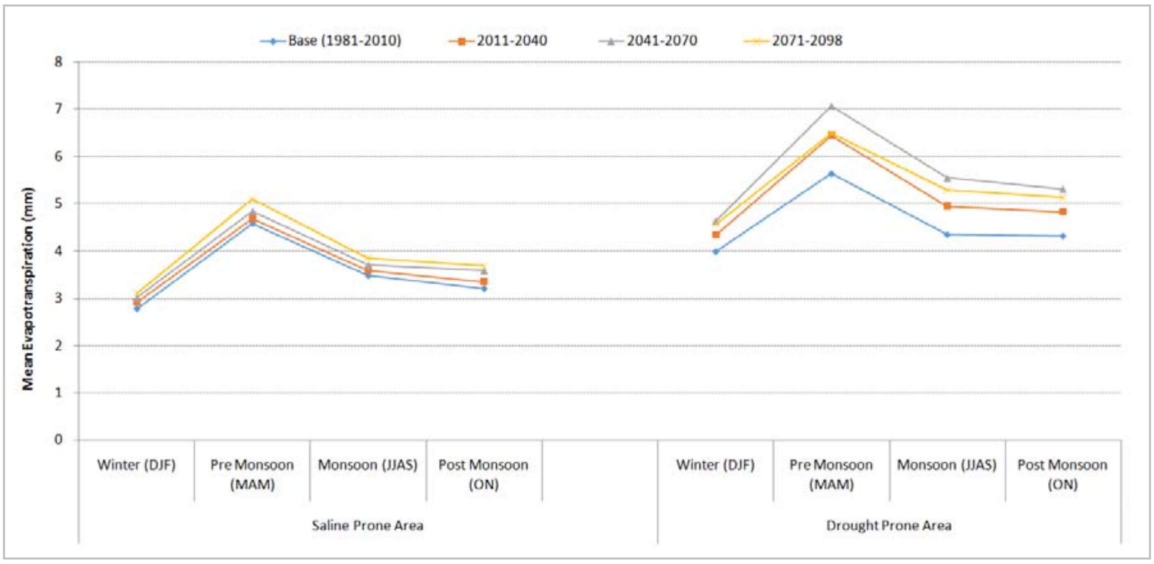


Figure 4.9 Expected trends in seasonal mean evapotranspiration (mm) for the period 1981-2100.

Table 4.4 Expected cropping season-wise daily mean evapotranspiration (mm) in the two study areas for the period 1981-2100.

Time Periods	Boro		T Aus		T Aman	
	Saline prone area	Drought prone area	Saline prone area	Drought prone area	Saline prone area	Drought prone area
Base (1981-2010)	4.00	5.19	3.75	4.77	3.38	4.34
2011-2040	4.10	5.91	3.81	5.46	3.54	4.91
2041-2070	4.24	5.79	3.97	5.95	3.65	5.29
2071-2100	4.37	6.49	4.23	6.22	3.79	5.15

4.3.2 Hydrological modeling

In order to assess the expected impact of climatic changes on land-based agriculture, it was necessary to simulate the hydrological balance of the study areas. We summarize the findings as follows.

Rajshahi study area

- In response to the climatic changes, the hydrological model predicts lesser, or a more uncertain amount of stream water flow for future periods in the drought-prone Rajshahi area in the dry season and the pre and post monsoon periods.

✓ Predicted changes in stream flow amounts are small in quantity in the dry season, but the predictions appear to indicate a consistently decreasing trend, signaling lesser available surface water for use.

✓ The pre and post monsoon water yields appear to show a rather fluctuating trend under the A1B scenario over time, but a rather a slight decreasing trend under the A2 scenario. These two periods may be the periods that provide the largest uncertainties for rice growers.

✓ Monsoon season water yields are predicted to be dominantly sustained or increasing in most areas and periods, though such predicted increase is not consistent across all areas and periods.

- Consistently with the climatic predictions, there are larger monthly water yield peaks predicted in the monsoon season under the A2 scenario. While field visits yielded information that rice production today typically needs supplementary irrigation in this area even in the monsoon season, it is not readily certain whether any extra water yield in the monsoon will have more benefits by suppressing such need than drawbacks via extra water logging and flooding.
- There is also indication that the monthly flow peaks may be shifting in future periods in all the examined upazilas.

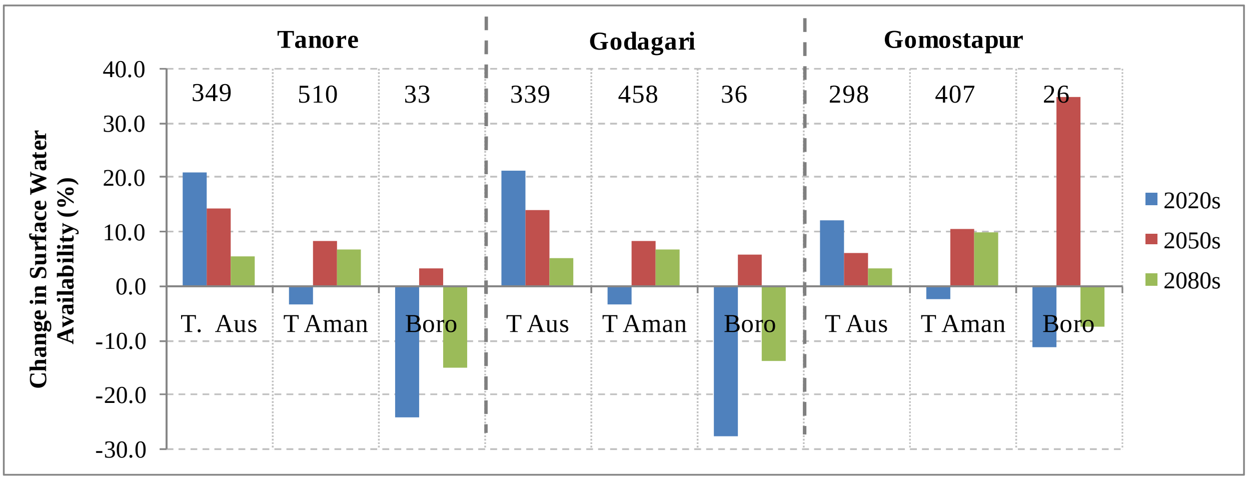


Figure 4.10 Climate change impact on surface water availability during the three cropping periods in the drought prone study area (Rajshahi) under climate change scenario A1B

Note: Cropping periods: T Aus: 1-May to 29-July; T Aman: 21-July to 28-Oct; Boro: 21-Jan to 29-Apr. The value in the upper part of the graph represents available surface water in mm during the base period (1981-2008)

Barisal study area

- The predictions for the Barisal area generally fall in line with those for the Rajshahi area in the sense that:

✓ for the dry winter season, as well as for the pre and post monsoon periods a generally decreasing surface water availability (stream flow) is predicted. This appears to be apparent under both climate scenarios, with an early monsoon increase predicted consistently only under A1B for the 2030s.

✓ Monsoon water yields are expected to be sustained or increase in the Barisal area in the course of the 21st century under the examined climate scenarios.

✓ Similarly to the Rajshahi area, most of the uncertainty for rice growers may be expected in the pre and post monsoon season.

- An additional notable impact of the predictions for this area is that a further reduction of river/stream water yield in the late winter season may create even more favorable conditions for salt-water intrusion in that season than it currently does, increasing the potential for worsening salinity conditions.

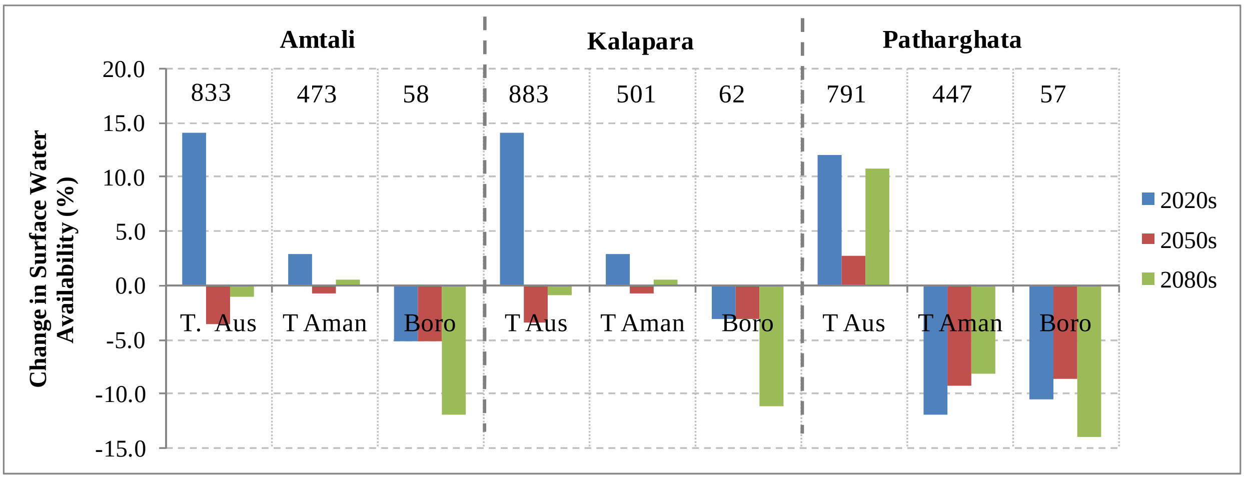


Figure 4.11 Climate change impact on surface water availability during the three cropping periods in the saline prone study area (Barisal) under climate change scenario A1B

Note: Cropping periods: T Aus: 11-May to 8-Aug; T Aman: 11-Aug to 7-Nov; Boro: 21-Jan to 29-Apr. The value in the upper part of the graph represents available surface water in mm during the base period (1981-2008)

4.3.3 Crop modeling

While hydrological balance modeling yielded information on expected changes in water availability in the study areas, crop growth/yield and irrigation demand modeling provides information on how the predicted climatic changes may influence the crop water demand. Figure 4.12 outlines the structure and data need of the DRAS model used to assess this part of the modeling framework.

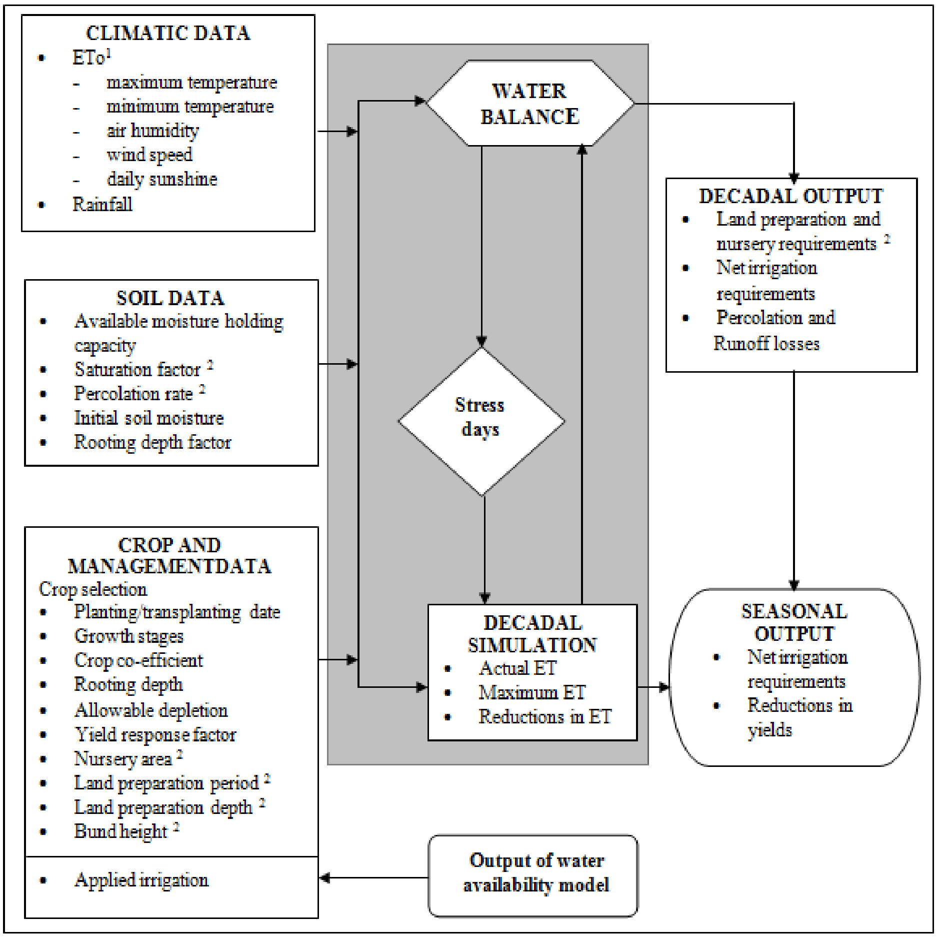


Figure 4.12 Structure and input data requirement of the DRAS model, used to evaluate crop growth, yield and net irrigation requirement

We summarize the findings of crop yield modeling as follows.

Barisal study area

- The aerial crop model predicts that - on condition that no supplementary irrigation is provided – the expected losses in yields will be somewhat less for the T Aus crop in the Barisal area, regardless of the climate scenario.
- The prediction is the opposite, however, for the monsoon – post monsoon T-Aman crop, for which additional yield losses are predicted in the future parts of the 21st century.
- While this sounds somewhat contrary to the climate and water availability predictions, it should be noted that the cropping seasons do not fall perfectly in line with the month- and season-based climatic and water yield predictions. While the T-Aus crop sees benefits from shifting patterns in the climate predictions like an earlier onset and bimodality of monsoon rains, the T-aman crop is likely negatively responding to a lessening amount of post-monsoon rains.

Rajshahi study area

- Under similar, no-irrigation conditions, the Rajshahi area sees more substantial yield losses in the T-Aus season already under current climatic conditions than the Barisal area does.
- ✓ The predication for the T-Aus season for future periods is that the water-stress conditions would ease up somewhat, and yield losses would decrease to some extent under both climate scenarios, but more so for the less hot and somewhat more rainy A2 scenario.
- ✓ Under the A1B scenario, yield losses would reduce more moderately till the late century, when the conditions would likely be more unfavorable again, signaling further yield losses.
- The difference between the two areas is much less substantial in the T-aman cropping season.
- ✓ The T-Aman crop is predicted to see more water-stress based yield losses in the future under the A1B scenario.
- ✓ The A2 scenario predictions are mixed for this crop, resulting in potentially smaller losses in the late century.

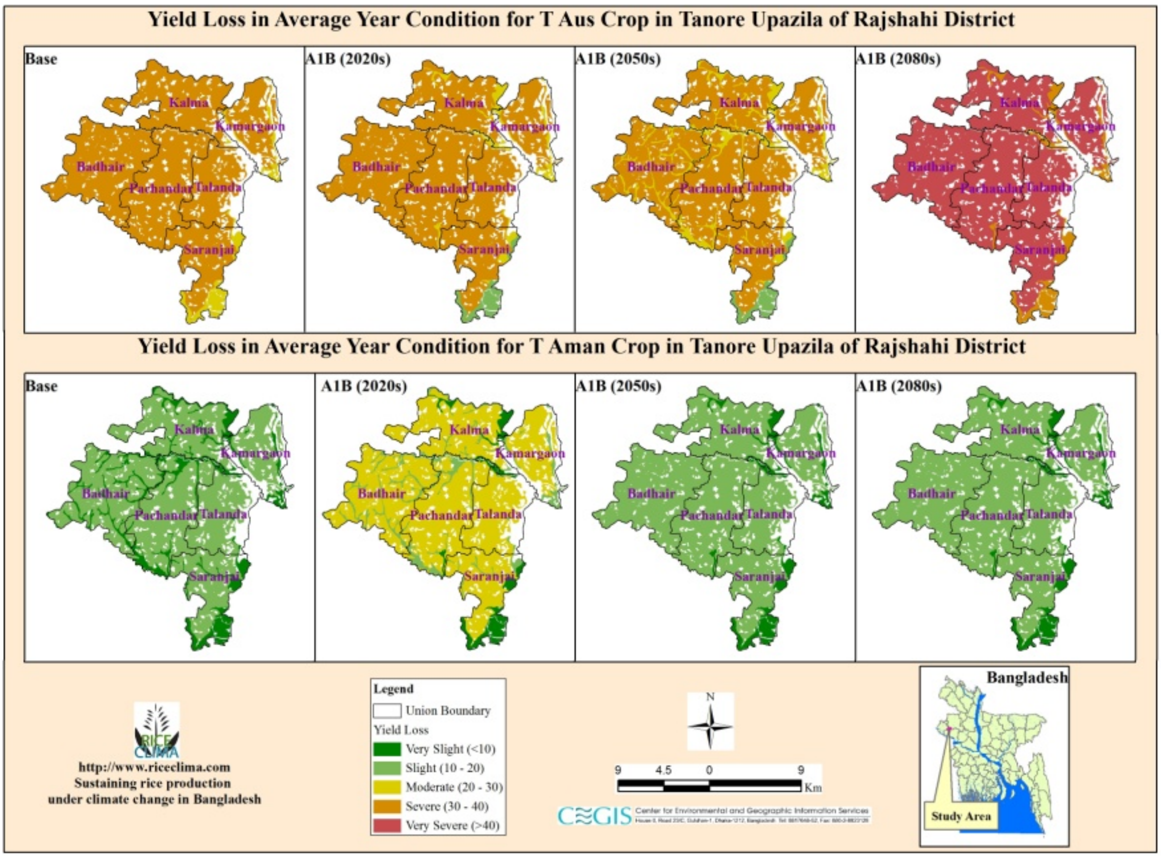


Figure 4.13 Example of average-year yield loss maps for the T Aus and T Aman cropping seasons, generated for Tanore upazila in the drought prone study area, using the DRAS model

Net irrigation requirement is defined as the amount of irrigation water needed to achieve optimal (non water-limited) crop growth. This water need is calculated by the crop growth model, under the given climatic scenarios. The simulated net irrigation requirement findings are summarized as follows:

- Net irrigation requirement trends generally follow the yield loss trends; when yield losses are expected to increase, net irrigation requirements are also expected to increase to some extent in both study areas. Their trends are not expected to match perfectly, as the timing of expected events can make a large difference for the crop.
- The expected change (extra demand) in net irrigation water requirement in the T-Aman season is predominantly in the 30-70mm range.
- The T-Aus season is expected to have a reduction in irrigation water requirement predominantly in the range of 30-70mm, depending on the location, scenario and time period considered.

Table 4.5 Status of Net Irrigation Requirement (NIR) at the drought prone study area. (+) means an increase in NIR, while (-) means a decrease

Crop Name	Base Year NIR (mm)	Change of NIR (mm) from base situation		
		2020s	2050s	2080s
T Aus	310-350	-(60 to 70)	-(75 to 90)	+(50 to 70)
T Aman	140-180	+(60 to 70)	+(35 to 40)	+(65 to 75)
Boro	1030-1120	+(20 to 40)	+(20 to 60)	+(30 to 70)

Table 4.6 Status of Net Irrigation Requirement (NIR) at the saline prone study area. (+) means an increase in NIR, while (-) means a decrease

Crop Name		Base Year NIR (mm)	Change of NIR (mm) from base situation		
			2020s	2050s	2080s
T Aus		100-120	-(60 to 80)	-(25 to 40)	-(5 to 10)
T Aman		80-125	+(20 to 30)	+(30 to 40)	+(20 to 25)
Boro		830-880	+(10 to 20)	+(10 to 30)	+(35 to 40)

Concerning the Boro season
The Boro (winter) season was not analysed in detail for yield losses, as it is well known already that a near 100% yield loss is expected in that season without irrigation. Notable, however, is that the A1B scenario simulations consistently signal a need for an additional amount of irrigation in both locations and in all future periods, while the A2 scenario indicates a reduced need (by cca. 30-100mm) compared to current conditions. Regardless, the Boro season will remain a fully irrigated cropping season.

4.4 Discussion and projections

Preliminary notes
Prior to any further discussion of the results presented in the modeling reports and chapter, it is noted that the climate scenario predictions, and the hydrological as well as crop growth simulations are all affected by significant uncertainties. The absolute predictions may not be accurate and should be interpreted with great care. Nevertheless, since the chosen models are expected to be able to combine and translate the effect of the main driving forces reasonably well, the relative evaluation of the outputs – i.e. their general direction and any substantial patterns – should be indicative of future expectations.

The study performed under this project gave indications of changes expected to individual, well defined factors. Expected changes to particular climate variables were evaluated, surface water availability was evaluated in more detail by the hydrological model, and yield losses and net irrigation requirements were evaluated by the crop model, summarized for each study upazila. It is the interpretation of their combined effect that is the main concern for the stakeholders at any scales – from the individual farmers up to the national Government level. Given the type of simulation models used and the scale of the modeling studies used in this project, we believe that the results of this study are more indicative, informative and beneficial to the various levels of Governments, policy and decision makers, than to farmers. Farmers would better benefit directly from smaller scale, more detailed studies, which was unfortunately beyond the scope of this project phase.

Discussion
From the performed simulation studies, there appears to be indication that the crop growing environment is changing for the later parts of the 21st century. While the expected change is to a different degree in the two study areas, the indication is that the sum of the climatic changes will present a mostly more demanding growing environment. **The simulations signal a drier, more climate-stressed winter season (Boro growing season), a rather unpredictable but somewhat more favorable T-Aus growing season, and a somewhat less favorable T-Aman growing season.**

While the monsoon season has its precipitation predicted to increase, the pre and post monsoon seasons are predicted to get drier, more climate-stressed. The growing seasons and the typical climatic seasons only partially overlap, therefore the crop model was needed to translate the timing of the predicted changes into the expected effects of those changes by traditional cropping seasons. It is an interesting development, that the future conditions are predicted to likely become more

favorable for crop growing in the T-Aus season, while the contribution of T-Aus rice to the national rice production has almost continually became less significant in the past 2-3 decades.
Investments by the Government and local authorities into developing irrigation facilities made the Boro season to be attractive to farmers, and in response, the contribution of the Boro season rice to the national rice production has grown very significantly over the same period. However, it is of concern that in the drier areas such as the Rajshahi area, such practice may rely on unsustainable irrigation practices. To study the water recharge conditions over the span of a whole year were not part of this study, but there is indication that the groundwater levels have been deepening in this study area over the last cca. 15-20 years (Figure 4.14). Careful evaluation of the effects of any ongoing and potential alternative practices needs to be performed: while the strictly understood water use efficiency may improve with the introduction of alternative practices, the recharge conditions may also be potentially negatively affected on a longer term.

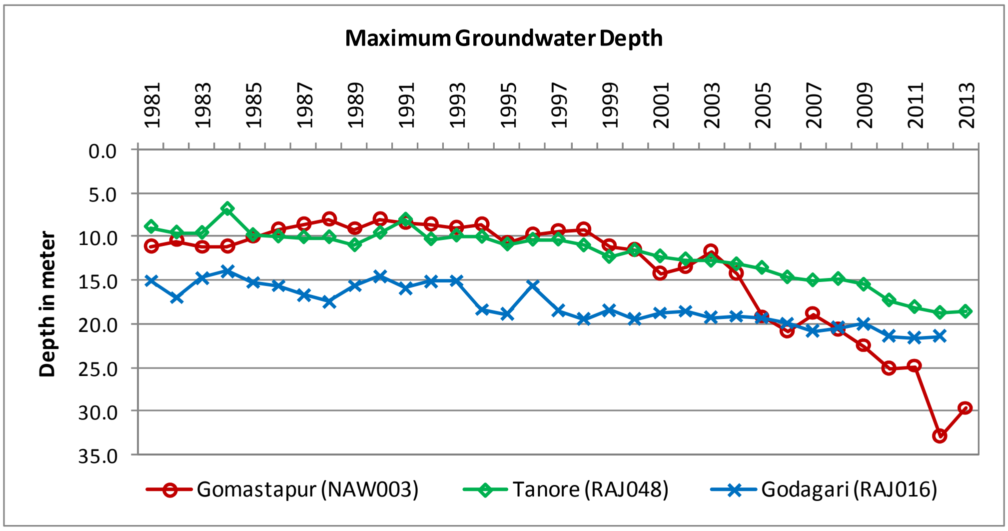


Figure 4.14 Ground water depth history of the drought prone study area

The predicted changes only show potentials in the agro-environmental changes, any deficits or benefits would still need to be realized via smart management and good policies. It is likely that new blanket policies or recommendations would not be the most efficient and feasible solution to sustain/increase rice production in Bangladesh in a sustainable manner. Rather, more differentiation by areas – as their conditions will change differently – and likely more differentiation by small farming communities – as their micro-environments are different – may be more efficient alternatives. Such alternatives would have to be studied further in the future, as it could not be a feasible part of the current project: the scale of examination and modeling was relatively large, many factors of finer differentiation (e.g. locally specific simulations, alternative timings, alternative varieties, etc.) remained unaccounted for.

The outcome of the hydrological modeling also needs to be evaluated with great care (Farkas and Hagyo, 2010; Couture et al., 2013). There are periods of time, for which some increase of surface water availability is projected. However, it has not been accounted for that any such change will also be met by a growing demand by (1) household use by the projected growing population, as well as (2) industry and other sectors will also be competing for the use of any water. Therefore, it would be more conservative to assume that there would be very limited, if any, excess water available for agricultural use over the course of the year, and sustainable agricultural growth would need to be achieved by a more efficient use and management of the available water resources.

It is also noted that the relevant parts of this study have been completed on assumption that the agricultural area remains as it stands currently. That may change in the future e.g. by utilizing new areas for agricultural production, in response to new policies. It may, however, also change in a negative direction, partly by secondary impacts of climatic changes, as well as lack of control over soil and land use. Climatic changes may negatively impact the size of land usable for agriculture by different means, e.g.:

- There is indication that in the Southern region – represented by the Barisal study area in this project – a growing size of land is impacted by a growing degree of seasonal salinity in the soil as well as the surface and subsurface waters. Those factors very clearly limit agricultural production, the extent of which would still need to be quantified. Plant breeders are in competition with time to compensate for losses to salinity with new, more tolerant genotypes.
- Projected climatic changes can also bring more extended flooding both in space and time. Inundation can affect larger areas in the future, and flooding may remain in effect for longer periods during monsoon, if predictions for rainfall increases in that period will stand.
- Climatic changes will also affect additional factors that can have a very significant influence on the overall, field-to-consumer efficiency of rice growing. Pests and diseases have their climatic niches, which – when changed – can trigger great changes in their population dynamics. Temperature and air humidity conditions are probably the two most significant factors influencing their growth dynamics, both of which are projected to change in later parts of the century. Such changes can not only influence pests and diseases in the standing crop, but also majorly influence grain storage efficiency.

Management decisions – and their control by policy – can also greatly affect what areas are usable for land-based agriculture. During field visits, we have received indication that in the areas that are bordered by sea-waters growing areas are used for shrimp farming, damaging the soil resources for rice growing, even if temporarily. In this context, it is therefore more conservative to account for a somewhat shrinking size of useful area for crop growing.

4.5 Limitations of RiceClima's modeling studies

4.5.1 General limitations and concerns regarding simulation modeling

The regionalization of models has been a recurring theme in the atmospheric and hydrological sciences over the last few decades. Such studies are an inevitable part of building a pro-active rather than re-active approach to responding to projected climatic changes. Models and modelling results in general are continually improving, but still remain limited in many ways, due to a combination of many factors, such as e.g. inadequate or unreliable environmental or other support data and limited funding available to collect more data; or limited (quantitative) knowledge of natural processes and their limited representation in simulation models.

It has long been a dilemma whether models or their support data are the limiting factor in a study. Models are being developed and fine-tuned constantly by their developers. It is generally seen that model performance will greatly depend on how well it is parameterized, how detailed support data are available for it to be calibrated on, and how efficient its calibration was. Data support in developing countries is a difficulty in general – and so was in this study. A number of modules in the simulation models had to be generically parameterized, lacking more detailed and/or local data. An example is the hydraulic characterization of the soils used. It usually yields a more efficient investment of resources to collect additional support data in such cases, than to invest in a more complex model, since the data are likely the limiting factor in the quantitative characterization of our knowledge.

Model calibration and validation is another extremely important step of the modeling process, which, unfortunately requires significant resources and effort in that detailed field data should be collected. An example of such data collection is given by Bechmann and Deelstra (2013) presenting results of an environmental monitoring program of small agricultural catchments in Norway. Data collected in such programs is extensive and at the same time costly; but of good enough quality to be used for modelling purposes. Lack of validation data is more often a problem in developing countries than in Western countries. Our study was somewhat limited in model validation terms – as it was detailed in

each of the relevant modeling reports. While some validation did take place, such efforts should be extended in the future. For the current application, the approach of interpreting the simulation results in relative terms and drawing conservative conclusions – as detailed before – should help reduce the risks posed by a lack of extensive model validation.
Data used as input to each of the simulation models have their own intrinsic uncertainties, originating from e.g. (a) their natural variability, b) the timing and sensitivity of our measurements and (c) the used techniques. These are all sources of error and uncertainty. In studies where future scenarios are generated, the uncertainty of extrapolations using imperfect models also have to be recognized. Additionally studies like this build on successive layers of simulation modeling, where the uncertainty of the output of one layer is passed on to the next layer of modeling. For example, the generated climate scenarios are used in the hydrological and crop models as if those were certain information. It takes a large effort to address, quantify and reduce such uncertainties, which is a problem that is rarely addressed sufficiently. One way of quantifying certain sources of uncertainties is to work with distributions of stochastic data, rather than to take a mean value. This can be done in e.g. a Monte-Carlo simulation scheme, but using such a technique was beyond the means of this project.

There is also a limitation introduced to simulation based scenario studies by not being able to assume a number of potential future changes. This study, for example, incorporates our current knowledge, the use of current agro-techniques, currently used rice varieties, and was applied to an area that is under agricultural use today. Changes to any of those factors may yield significant changes when their effects are upscaled to the regional or national level. Therefore, it is desirable to (re-)evaluate the effect of any such factors, when improved information becomes available.

Apart from some general limitations seen by the simulation based studies, a number of specific limitations are recognized – and partially already listed in the relevant reports – which are given an account of below.

4.5.2 Limitations recognized in the climate modeling

Global climatic changes are usually characterized by the systematic, gradual, long-term significant changes that are expectable in the form of changing annual or seasonal mean values and potential changes to the distributions. However, increased temperatures and other atmospheric changes are known to alter the conditions for rare, extreme events. It is anticipated that the generally warming trend will create more favorable conditions for extreme events in Bangladesh's area as well, potentially triggering more frequent or potentially more intensive cyclone activity, more frequent extreme flood events; or even the contrary, extreme short-term cold spells. All of these can have wide-scale sudden impacts on agricultural production. However, the types of computer models used in this project are not meant to account for the impact of such extreme phenomena.

The resolution of the climate model was not originally in par with the resolution of interest in this study. A 250 x 250 km resolution would not have yielded a fine enough resolution to describe the variability among locations of interest in our study. The model's resolution was then adjusted to 25 x 25 km, which reflected a lot more local variability. Still, some of the upazilas fell into the same grid cell, yielding identical predictions for their future climate. The obtain results can be considered valid at the given spatial resolution, but any statistical evaluations now or in the future are somewhat limited by this artefact because of the reduced variability in the predicted data.

Limitations recognized specifically in the hydrological modeling

The hydrological modeling was concerned with the watershed areas of the two chosen study areas. A substantial limitation of this part of the study for the Rajshahi area is that the area borders India, for which area climate modeling was not available, and for which area only coarse-scale land data was available to the modelers. This primarily affects Gomostapur upazila. Since the watershed and water sources expand across the border, the study could not evaluate their impact on the water availability in this region. In addition to cross-boundary streams, some areas are also affected by the Ganges/Padma river itself, which effect could not be evaluated due to the same reasons.

As cited earlier, the limited availability of measured discharge data as well as ground-water data limited the calibration and validation of the SWAP model for the water availability simulations. In the Barisal region, due to the characteristics of the river delta area, the only available indicator to calibrate the model against was the ground-water level – with only scarce data available both spatially and temporally. While potential biases were minimized to the best of the modelers' knowledge during model calibration, the resulting modeling uncertainty still has to be factored in.

Considering that the study is concerned with future periods up to nearly a century in advance, different other factors may affect river water yields. The impact of any non-environmental changes to river water yield – such as e.g. engineering solutions to limit or divert water flow in rivers within or outside the country's borders – can have significant cascading effects downstream, which of course could not be accounted for in the present study.

Limitations recognized in the crop modeling

The crop model used has its strengths in its aerial extent and its GIS connected interface. Users of a relatively large scale crop model like that have to consider that its resolution, the complexity of the underlying algorithms and the time necessary to complete the simulation run(s) are all interdependent. The DRAS model has a resolution that well supports medium to larger scale planning and policy making, but is limited in covering exact fields or plots, and it is therefore of limited benefit to individual farmers. It is a somewhat similar situation with its temporal resolution. Having a 10-day resolution will support larger scale planning more than giving fine-scale, day-to-day advice.

The model – like every model - has a few notable limitations to its built-in algorithms as well. The atmospheric concentration of carbon dioxide (CO_2) is predicted to be on the rise in the future. There is a physiological effect of atmospheric CO_2 levels on the water use and biomass production of plants via its influence on stomatal conductance. Such effects are already accounted for in small scale detailed models that simulate the growth of an individual plant, but it is not yet solved to build that effect into models like the DRAS model. This is a factor that will need re-evaluation in the future as more and more advanced models keep being developed worldwide.

There are certain limitations to the moisture regime module of the model that need to be noted. While the field-capacity approach (aka 'bucket'-type model) is not a limitation but an accepted approach the model developers followed, not being able to account for the potential benefit of capillary rise from the ground-water is a limitation. Rice growing is typically done in continuously ponded water in Bangladesh, therefore the significance of capillary rise within the growing seasons is fortunately rather limited, as capillary rise only happens when the top soil is in a drying process for a substantial amount of time. Nevertheless, this model would not be suitable to evaluate year-round water balance, as capillary rise is expected to contribute to the topsoil moisture conditions while the land is fallow and not irrigated in the dry season.

An additional limitation to the moisture regime module is that it does not account for overland flow – i.e. lateral flow on the soil surface. This is a limitation that essentially makes a model to be a 1-dimensional (1-D) model, calculating only with vertical water movement in the soil profile. In the particular case of rice production in Bangladesh, there is only one season that is affected by overland flow to any significant degree, the monsoon season. It is essentially only during monsoon that the rainfall amount – plus any added water yield from streams - exceeds the infiltration capacity of the soil, and overland flow (surface runoff) occurs. While water ponding does occur in reality, excess water that is over the amount that can be confined by the bunds that surround each field is drained as early as possible. Outside those periods, both in the field as well as in the simulation model, the amount of water available to the crop is the amount that can pond among the bunds, which limits the expected period of misrepresentation in the model to the flooded days with above bund-level floods. Such conditions are not expected outside the monsoon season; any significant rainfall amounts are likely captured by the bunded fields, and will contribute to vertical flow with a nearly 100% probability.

The DRAS model – just as the vast majority of crop production models - does not have a salinity module that can account for the physiological effect (inhibition) of soil water salinity on crop growth. In fact, it is very hard to find a simulation model that can simulate that effect quantitatively and that is calibrated for local conditions. Currently, salinity substantially impacts rice growth in the Boro season, and early into the T-Aus growing season. At this stage, we refrained from providing a quantitative evaluation of the salinity impact on crop growth. The negative impact of any substantial amount of salinity on most current rice varieties is well documented, which can likely be overcome only by engineering solutions and/or novel crop varieties. Expert opinion on and related advice towards further developing more salt-tolerant varieties are addressed in a later chapter of this monograph. Future crop growing, however, will likely involve new varieties, which we did not have a chance to model at this stage. Therefore the type of quantitative evaluation that we presented will need to be updated when such new information becomes available. Nevertheless, a model like the small-scale FAO Aquacrop simulation model – which was made part of the capacity building efforts of this project – can be used by the participating scientists in the future. The FAO Aquacrop model has the capability to provide a semi-quantitative evaluation of salinity impacts on smaller scales.

One final note on limitations of the crop modeling study is that the net irrigation requirement by the crop was calculated on the condition that the soil is kept fully wet during the crop growth period. There are indications, however, that deficit irrigation – i.e. only partially replenishing the extracted and evaporated water, and especially when that is made crop growth-stage dependent – can produce similar yields while using somewhat less water. This option was not evaluated yet at this stage because of limitations in the model and by the relatively large spatial units of interest in the presented modeling study.

4.6 Recommendations

4.6.1 Capacity building

The regionalization of models has been a recurring theme in the atmospheric and hydrological sciences over the last few decades. It is always a difficult task to develop well supported scenarios and put scientific developments in water resources management techniques in practice. However, the situation is not encouraging in developing countries often due to a combination of inadequate or unreliable data, scarce technical capacities, limited funding and limited exposure to (or awareness of) international scientific developments. At the same time practitioners are also often reluctant, or do not have the training to use new methods in place of established practices. Therefore, we recommend capacity building – at every level of the stakeholders, from the farmer to the higher offices in the Government - via proper training in and dissemination of novel tools and information, extension, and field demonstration activities.

4.6.2 Field data collection and the reduction of uncertainties

Upon cataloging the necessary data for the modeling studies, it has become clear that significant data and knowledge gaps exist, which would needed to be filled in for desirable future improvements to similar studies. Such knowledge gaps are sources of extra uncertainty, which would both be possible and necessary to eliminate by an investment in extra data collection and additional model validation against field data. Some of the desirable data types would not necessarily require expensive and extensive field data collection campaigns, but rather the collection of simple data time series by relatively inexpensive tools or equipment. For example, the knowledge of water height in a river throughout the year, the knowledge of groundwater depth at a nearby location would help better validate the hydrological model. The laboratory characterization of even a few soil types may help prove the estimation technique that is currently used to generate the hydraulic properties that the simulation models use, hence somewhat reducing the extent of uncertainties. Knowing the dynamics of salinity intrusion - by quick, seasonal measurements of river water salinity, soil and groundwater salinity would help build a salinity model that can better characterize the progression of salinity, and help make irrigation and management decisions.

Multi-model approaches – i.e. the parallel use of several models – can also greatly enhance simulation studies by reducing the potential effect of biases and uncertainties linked to particular models. While the use of such technology is growing worldwide, it requires substantial extra resources as well as expertise to perform such an analysis.

4.6.3 Small scale simulation modeling

In our view, one extra layer of simulation modeling – a small scale, detailed crop growth modeling is necessary to fully explore the benefits of simulation modeling for the range of stakeholders. The currently used crop modeling does not have the spatial or temporal resolution to assist local farmers in their decision making. A simulation model like the FAO Aquacrop model can help in making daily decisions even on short notice, when it is properly pre-parameterized, daily weather data are available, and the model is used and interpreted by trained experts. Results can be easily interpreted and translated into simple language for dissemination among small or larger groups of farmers as necessary. Providing season-specific crop variety scenarios or irrigation scenarios, giving soil-specific irrigation advice are all among the potential options, helping the local farming community, rather than only providing larger scale and more generic policy assistance. This is seen as one potential way to comprehensively assess the effects of potential adaptation options from very small up to approximately upazila scales. Preparations have been made for any such an extra step by the project's participants by organizing training for nearly 20 local scientists and students in using the named model, and by inquiring about potential channels of wide dissemination during our field visits.

5. Adaptation to Changing Climate:

The Drought Prone Areas, Rajshahi province

5.1 Introduction

Climate change is the reality now- its impacts in Bangladesh will mean gradual changes in temperature, rainfall amounts and patterns and sea level rise, etc. Additionally, increased climate variability and extreme events including more intense floods, droughts and storms. However, apart from extreme temperatures and erratic rainfall patterns, over-exploitation of groundwater resources threaten current and future crop production and livelihoods in Rajshahi province. In some locations, groundwater tables depleted by cca. 20feet in just over 20 years (i.e. 1985 to 2007) earlier, but the depletion has progressed by the alarming rate of cca. 30ft in just 4 years (2008 to 2012) more recently – presenting major concerns regarding the sustainability of irrigation projects in this region. Frequent droughts - moderate to severe in nature - and general soil nutrient depletions add more pressure on natural sources for a sustainable crop production.

The Rajshahi region is one of the hottest and driest parts of Bangladesh, therefore any additional variation in rainfall and temperature patterns could significantly influence rice production and thus jeopardize livelihood, and both regional and national food security. In order to address such challenges pro-actively, it is essential that the status of agriculture is assessed and appropriate response tools are identified. The main objective of this chapter is to present a short, partly interpretive, summary of the climate scenarios for Rajshahi, analyze its implications for regional hydrology and vulnerability of rice crop production, and suggest sustainable crop growing technologies for extendedly drought prone areas of Bangladesh.

5.1.1 Summary of climatic factors, climatic scenarios and drought analysis

The mean annual temperature in the Rajshahi region is around 25.9^{0}C and the mean daily minimum and maximum temperatures vary from 10.9^{0}C to 36.1^{0}C. Highest temperatures are generally observed in April and May and the lowest in January. The highest temperature on record is 45.1^{0}C and the lowest is 3.4^{0}C (CEGIS, 2013a). Climate change predictions performed in this study suggest that the annual mean temperature, as a whole, is likely to increase in all seasons during all three examined periods (2011 to 2040, 2041 to 2070 and 2071 to 2100) according to both the A1B and A2 scenarios, with respect to the base period (1971-2010). Its rate of predicted change variesa likely increase of 1 to 4^{0}C under the A1B scenario and 1 to 3^{0}C under the A2 scenario is predicted. Historic data indicate that maximum temperatures over 35^{o}C occur in April, which temperatures are likely to increase further with any systematic change. The specific significance of such temperature rise is that not only other crops, but even the existing rice varieties can develop sterility if extreme high temperature hit the crop during the flowering period - resulting in potentially severe yield reduction (BRRI, 2011). Other crops can develop such sterility even at lower maximum temperatures, as indicated in the previous subchapter and Table 5.1 therein.

According to current records, annual total rainfall varies from 1377 to 1487 mm in Rajshahi region. Dry season rainfall is only 16-18% of the annual rainfall total (CEGIS, 2013a). Annual mean precipitation is expected to increase in the later parts of the century between 3 to 7% under the A1B scenario, before declining again by the end of the century by cca. 4% compared to the base period (1971-2010). Under the A2 scenario, the future change in precipitation is projected to show greater heterogeneity among the examined upazilas, signaling a slight decline being followed by increase in rainfall by the end of the century. The patterns can, however, be considered rather uncertain, since an examined range of other studies strongly disagree with each other.

It is likely that pre-monsoon rainfall will decrease, indicating increased supplemental irrigation water requirement for the Aus rice and other crops in this season. However, monsoon rainfall is expected to increase, which may not only help agriculture by potentially lessening irrigation water needs, but may potentially cause more damaging flooding or water-logging in certain parts of the study area, and thereby hamper monsoon rice (T. Aman) production.

Correspondingly, water availability studies performed by the SWAT hydrological indicate less surface water to be available in the dry season, and more being available in the wet season – according to both scenarios – compared to the base period. This further expands the uneven distribution of rainfall, and may further enhance climatic extremes.

5.1.2 Water scarcity considerations

As also noted in the previous subchapter on the saline prone areas, water scarcity, a known phenomenon in Bangladesh, originates not only from the physical constraints of fresh water resources, but also due to its inefficient use and often poor management. The ever increasing demand on one hand and the inefficient use and general lack of storage capabilities are likely to widen the gap between water supply and demand in the foreseeable future, especially in the Rajshahi area. This is one of the hottest and driest areas of Bangladesh, while it is intensively utilized in agriculture.

In Bangladesh, the area coverage, on average, for Aus (pre-monsoon), T. Aman (wet season) and Boro (dry season) rice is 0.9, 5.05 and 4.6 Mha, respectively. The corresponding paddy production is 2.29, 14.69 and 27.00 MMT, respectively (BBS, 2011). Growing rice in the dry, Boro season is considered to be safe practice, athough it nearly entirely depends on irrigation water. Boro rice growing area is on the rise, the area used for T. Aman rice is not changing considerably, whereas the Aus rice area is generally shrinking over the years. This pattern suggests an increasing dependence on irrigation water. In many areas, like in the Rajshahi area, centrally coordinated projects have developed irrigation facilities in the recent past. Such facilities have provided improved access to irrigation water to farmers, but the irrigation costs during the Boro season are nearly one-third of the total cost of rice production.

Overexploitation of groundwater resources is, however, a severe, ongoing phenomenon, which needs to be evaluated and addressed in order to keep ongoing agricultural practices sustainable. As cited already, records show a continuous – and recently accelerated - decline of groundwater levels in the area. This will not only further increase the price of pumping (via the need for extra energy), but if the process continues, groundwater resources may be beyond reach for the current technology. In that case, without a major investment in equipment upgrade, groundwater resources would become insufficient to further support dry season irrigated agriculture up to its potential. Changes to climatic conditions may also increase the evaporative demand, i.e. the water need for the crop. Therefore, other technologies – surface water storage, changed practices, etc. - need to be evaluated in order to reduce the pressure on groundwater resources.

5.1.3 Main constraints of agricultural development in the drought prone study area

Data from focus group discussions (FGDs) and field surveys indicate that farmers are already adopting some alternative cropping patterns (Table 5.1).

Table 5.1 Major cropping patterns and percent area coverage in selected study site

Locations	Cropping patterns	Coverage (%)
Godagari	Tomato/Mustard+Boro-Fallow-T.Aman	42
	Boro- Fallow-T.Aman	38
	Fallow-T. Aus-T.Aman	10
	Wheat – Fallow – T. Aman	5
	Others	5
Tanore	Potato/Mustard+Boro-Fallow-T.Aman	40
	Boro- Fallow-T.Aman	35
	Wheat/Maize-Fallow-T.Aman	20
	Others	5
Gomostapur	Boro-Fallow-T.Aman	40
	Mustard+Boro-Fallow-T. Aman	34
	Fallow-T. Aus-T. Aman	11
	Others	5

The yields and area coverage of currently cultivated main crops in the project sites are shown in Table 5.2, and soil nutrient status in the areas is presented in Table 5.3.

Table 5.2 Major crops grown area (ha) and yield under different study sites

Crops	Popular varieties	Area (ha)	Average yield (t/ha)	Yield range (t/ha)
Godagari, Rajshahi				
Local T. Aus	Pariza	12.20	4.28	3.90 - 4.85
HYV T. Aus	BRRIdhan48	1.33	4.80	4.25 - 4.90
Sawrna (aman)	Guti Sawrna, Ranjit Sawrna and Lal Sawrna	35.20	5.13	4.80 - 5.55
Chickpea		5.53	1.16	0.90 - 1.80
Mustard		6.33	1.07	0.90 - 1.31
Tomato		5.94	21.16	16.50 - 30.00
Wheat		12.20	3.66	3.08 - 4.80
Total cropped area		**95.07**		
Tanore, Rajshahi				
Sawrna (aman)	Guti Sawrna, Ranjit Sawrna and Lal Sawrna	25.93	5.26	4.50 - 5.63
Chickpea		0.53	1.80	1.3 - 2.00
Maize		4.20	5.40	4.90 - 6.10
Mustard		6.20	1.04	0.90 - 1.20
Potato		6.20	17.84	16.05 – 18.00
Wheat		4.13	3.53	3.15 - 4.80
Total		**80.20**		
Gomastapur, Chapai Nawabgonj				
Local T. Aus	Pariza	12.40	4.34	4.19 - 4.70
Local Aman	Fine and aromatic variety	5.87	2.25	1.95 - 2.55
HYV T. Aman	BRRI dhan34	0.27	3.62	3.40 - 3.85
Sawrna (aman)	Guti Sawrna, Ranjit Sawrna and Lal Sawrna	38.80	4.86	4.50 - 5.10
Chickpea		1.07	1.65	1.05 - 1.80
Mustard		4.00	1.11	1.05 - 1.80
Wheat		12.80	3.51	3.00 - 3.60
Total		**78.67**		

Table 5.3 Initial soil nutrient status at Rajshahi project sites

Locations	pH	OM	Total N	K	P	S	Zn
	-	%		Meq/100 gm soil	Microgram/gm		
Godagari	5.5-7.3	0.56-2.55	0.05-0.12	0.12-0.42	7.6-30.0	10.3-36.0	0.35-1.59
Tanore	4.9-7.2	0.39-3.22	0.02-0.18	0.08-0.43	4.3-29.6	11.0-38.2	0.47-1.63
Gomastapur	5.3-7.3	1.80-3.41	0.10-0.18	0.14-0.72	4.0-29.2	13.8-39.7	0.44-2.97
Critical values	-	-	0.12	0.12	5.0	10.0	0.60

Most of the soils are acidic in nature with low organic matter content and general nutrient deficiencies: low total nitrogen contents, along with a widespread deficiency of phosphorus. Application of organic matter and balanced fertilizers are needed for satisfactory crop production. As cited above, access to groundwater-based irrigation water is at risk for the future, due to continuous depletion of groundwater level in the Rajshahi region.

A number of additional and intertwining constraints for agricultural development in Rajshahi region were revealed through the FGDs, which are summarized as follows:

I. Crop production related factors
- Lack of improved and quality seeds;
- Lack of proper production technologies;
- Lack of drought tolerant and short duration varieties;
- Incidence of pests and diseases; and
- Low soil fertility due to low organic matter content and wide-spread nutrient deficiency.

II. Water resources and water management related factors
- Lack of available irrigation water;
- Groundwater table decline, resulting in further increaing pumping costs;
- Lack of surface water access and storage (ponds and ditches) for irrigation purposes;
- Electricity failure during irrigation time; and
- High irrigation costs.

III. Climate and environment related concerns
- High daily temperatures, especially during the dry period;
- Low night temperatures during the winter period;
- Short winder period; and
- Uneven distribution of rainfall

IV. Socio-economic factors
- High input prices and low output prices of agricultural commodities;
- Lack of individual/community storage facilities;
- Lack of availability of direct sell markets, the need to use middlemen;
- Lack of a formal agricultural credit system;
- Discrimination of wages between male and female agricultural workers; and
- Women's role in decision making in crop production processes and family management is low.

5.2 Field trials performed

Sites for field trials were selected based on feedback and preferences of different stakeholders. Information on particular localities was also gathered through interviews with farmers, via focus group discussions, field visits and literature search. Field demonstrations of selected technologies were carried during the project, while several farmers' training and field days were also conducted for capacity building and awareness development of farmers. The presented results are supported by Tables 5.4-5.7 and Figures 5.2 and 5.3 – also referred to in later sections of this chapter.

During the trials, initiatives were taken to grow low water demanding crops in the dry season, along with the dissemination of stress tolerant rice varieties for the pre-monsoon and the wet seasons. Aus rice was grown as rainfed crop (rainfall 324 mm) with 2-3 supplemental irrigations (120 to 180 mm). The water used for direct seeded rice was slightly less compared to that of transplanted rice: supplemental irrigation took place in the amount of 100 to 150 mm, with 316 mm rainfall. Grain yield of T. Aus and T. Aman rice under researcher's management (RM) varied from 3.50 to 4.10 t/ha and 3.20 to 4.90 t/ha, respectively. Under farmer's management (FM) it was 3.35 to 3.84 t/ha and 3.34 to 4.64 t/ha for T. Aus and T. Aman growing seasons, respectively. Water productivity for transplanted and direct seeded Aus rice varied from 7.88-9.20 and 7.98-9.68 kg/ha-mm, respectively. In transplanted conditions, water productivity for medium duration and short duration varieties were 5.76 to 6.83 and 5.71 to 7.23 kg/ha-mm, respectively. In direct seeded conditions, water productivity was 4.00 to 5.71 kg/ha-mm for medium duration and 4.26 to 5.09 kg/ha-mm for short duration rice varieties, respectively. Most of the farmers in this study area adopted BRRI dhan48 in the Aus and BRRI dhan56 in the Aman season. Field performance of non-rice crops was very good and farmers' gladly adopted BARI Gom26, BARI Sarisha15 and BARI Chola9 varieties. Water productivity for wheat varied from 16.55 to 18.06 kg/ha-mm; for mustard 5.83 to 7.70 kg/ha-mm; whereas it varied from 6.55 to 11.21 kg/ha-mm for chickpea.

5.2.1 A tool box of adaptation measures for the Rajshahi region

Based on existing climatic situations, future projections and existing and the projected shortage of water resources, we summarize generally recommendable – or in some cases already observed - ways of adaptation as follows.

1. One of the simplest adaptation options is to cultivate low water demanding and drought tolerant or drought escaping crops like wheat, mustard, legume based cropping systems (chickpea, mungbean) linseed etc. Many farmers are growing long duration old rice varieties that can be replaced by stress tolerant, short duration ones, depending on land suitability in the different seasons (crop rotations and crop diversity).
2. In areas with medium to extreme water shortage and having no irrigation facilities, direct seeded Aus and Aman rice may be a better option for sustaining staple food production.
3. Construction of small sized mini-ponds and any other storage technologies for rainwater-harvesting is another option to facilitate supplemental irrigation in the T. Aman season (if needed) as well as for Rabi crops. However, farmers should have easy access to good quality seeds at the beginning of the season, in order to take advantage of improved irrigation facilities efficiently.
4. Field demonstrations were made in different seasons for testing the performance of new varieties along with improved crop husbandry. In the T. Aus season, BRRI dhan48 and BRRI dhan55 were tested, whereas in extreme water shortage areas BRRI dhan42 was grown as dry seeded crop. Results are shown in Table 5.4, and the varieties should be considered for wider use.

Table 5.4 Field performance of Aus varieties during 2012-13, Rajshahi site

Crop*	Mgt.	RF (mm)	RFe (mm)	Supplemental irrigation (No.)	Irrigation water (mm)	Total water use (mm)	Yield (t/ha)	Water productivity (kg/ha-mm)
TP rice	RM	586	324	2-3 (2)	120-180 (120)	444-504 (444)	3.50-4.10 (3.91)	7.88-9.20 (8.81)
	FM	586	324	2-3 (2)	120-180 (120)	444-504 (444)	3.35-3.84 (3.56)	7.54-8,64 (8.02)
DS rice	RM	556	316	1	70	386	1.72	4.46

RM = Researchers management, FM = Farmers management
* TP rice = transplanted rice, DS rice = direct seeded rice

5. In the T. Aman season, BRRI dhan56 and BINA dhan7 were cultivated to avoid the potential drought at later stages of the crop. BRRI dhan49 was also introduced as high yielding variety. In

extreme dry areas like Kalma and Tanore, BRRI dhan56 was grown as dry seeded crop (Table 5.5) with success. Characteristics of different rice varieties are shown in Table 5.6. During the Rabi/Boro season, farmers were encouraged to grow low water demanding crops like wheat, mustard, chickpea etc. in order to cope with the apparent over use of ground water resources (Table 5.7).

Table 5.5 Field level water use, crop yield and water productivity of Aman rice at Rajshahi site during 2013

Crop duration	Mgt.	RF (mm)	RFe (mm)	Supplemental irrigation (no.)	Irrigation water (mm)	Total water use (mm)	Yield (t/ha)	Water productivity (kg/ha-mm)
Medium (132-137 day) TP	RM	888	537	3-4 (3)	180-240 (180)	717-777 (717)	4.13-4.90 (4.58)	5.76-6.83 (6.39)
	FM	888	537	3-4 (3)	180-240 (180)	717-777 (717)	3.34-4.64 (4.22)	4.66-6.47 (5.88)
Short (105-112 day) TP	RM	788	440	2-3 (2)	120-160 (120)	560-620 (560)	3.20-4.05 (3.55)	5.71-7.23 (6.34)
Medium DS (132-137 day)	RM	888	537	-	-	537	2.15-3.07 (2.58)	4.00-5.71 (4.80)
Short DS (105-112 day)	RM	788	440	-	-	440	1.80-2.24 (1.95)	4.26-5.09 (4.43)

Table 5.6 Characteristics of cultivated variety in different seasons

Season	Variety	Growth duration (days)	Average yield (t/ha)	Characteristics
Aus (TP)	BRRI dhan48	110	5.0-5.5	T. Aus
Aus (TP)	BRRI dhan55	105	4.5-5.0	Salinity, drought and cold tolerance
Aus (DS)	BRRI dhan42	100	3.0-3.5	Upland, drought tolerant
Aman (TP)	BRRI dhan49	135	5.0-5.5	High yielding
Aman (TP)	BRRI dhan56	110	3.5-5.0	Drought tolerant, short duration
Aman (TP)	BINA dhan7	115	3.5-5.0	Drought tolerant, short tolerant
Wheat	BARI Gom26 BARI Gom28	104-110	3.5-4.5	Suitable for late planting, heat tolerant
Mustard	BARI Sarisha14 BARI Sarisha15	75-80 80-85	1.4-1.6 1.55-1.65	Short duration, high yielding
Chola	BARI Chola5 BARI Chola9	125-130 125-130	1.8-2.0 2.3-2.7	- High yielding, Suitable for barind tract

Table 5.7 Water use, crop yield and water productivity of some Rabi crops at Rajshahi site during 2012-2013

Crop	Mgt.	RF (mm)	Supplemental irrigation (no.)	Amount of irrigation (mm)	Total water use (mm)	Yield (t/ha)	Water productivity (kg/ha-mm)
Wheat	RM	132	2-3 (2)	120-160 (120)	252-292 (252)	4.17-4.55 (4.40)	16.55-18.06 (17.46)
	FM	132	2-3 (2)	120-160 (120)	252-292 (252)	3.18-4.09 (3.96)	12.62-16.23 (15.71)
Mustard	RM	132	1	60	192	1.12-1.44 (1.25)	5.83-7.50 (6.51)
	FM	132	1	60	192	0.95-1.21 (1.03)	4.95-6.28 (5.35)
Chickpea	RM	132	-	-	132	0.87-1.48 (1.09)	6.55-11.21 (8.22)
	FM	132	-	-	132	0.68-1.24 (1052)	5.15-9.41 (7.97)

6. In the T. Aman season, farmers of the Rajshahi region mostly grow HYVs and prefer early transplanting for the establishment of dry season crops. There is a tendency of these farmers to apply high doses of N fertilizer (200 kg Urea/ha) which can be reduced without having any impact on yield. T. Aman establishment of this area mostly depends on rain and irrigation water.

7. Rainfall during the flowering stage was one of the major factors of FS outbreak at the Rajshahi region during the T. Aman season (2013). Higher disease incidence and severity was found from those plots which received rain during flowering compared with those plots which received rain after flowering (Table 5.8). Differences in varietal reactions to FS were also significant. BRRI dhan49 was found highly susceptible to FS (Figure 5.1). Application of high doses of N fertilizer was another factor responsible for FS outbreak in the region. Farmers should reduce the amount of N fertilizer and potentially adjust planting dates to control FS, while more tolerant rice varieties should also be identified or developed.

Table 5.8 False smut disease incidence and severity at Rajshahi region

Variety	Rain during flowering		Rain after flowering	
	Panicle infection (%)	**Grain infection (%)**	**Panicle infection (%)**	**Grain infection (%)**
BRRI dhan49	50-60	4-5	5-10	0.3-0.5
BINA dhan7	10-15	0.1-0.5	2-3	0.03-0.05
Swarna	40-45	1.0-1.5	3-4	0.05-0.08

8. The project study also suggested the adoption of an existing disease forecasting model to prepare for FS disease management. An epidemiological study is also needed on FS disease. Finally, disease control measures of FS need to be developed and farmers should be trained for control of the disease.
9. Capacity building is important and government should allocate resources to train farmers on selected adaptation measures and general awareness about climate change impacts. Farmers in general showed interest in trainings and gaining knowledge. As a start, about 360 farmers were trained within this project through three large workshops in the three selected upazilas in both the T. Aman and Rabi seasons on cropping systems, efficient fertilizer and water management and pest management.
10. Among the tested T. Aman varieties, BRRI dhan56 was preferable because of its short duration and drought tolerance, and was also preferred by farmers (Figure 5.2). They also adopted BINA dhan7 for the same reasons.
11. In extreme water shortage areas farmers showed interest in growing dry seeded rice in both the Aus and Aman seasons. Among the tested Rabi crops, the cropping area of mustard expanded faster compared to other crops (Figure 5.3). For all crops and varieties, the area increased by 3 fold to 7 fold, of which 60% expansion is own land and 40% is the neighboring farmers.
12. In some areas, farmers grow linseed and other less water demanding crops and they are transforming the land of field crops to mango, guava and jujube orchards, either for the purposes of addressing drought or for greater profits. In mango orchards, rice, wheat, and mustard can be cultivated in an intercropping system for the first 10-12 years.

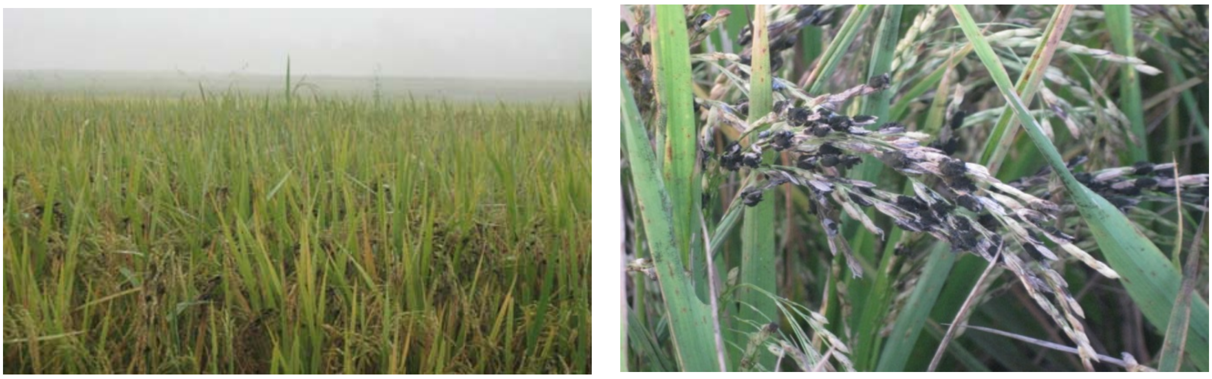


Figure 5.1 False smut infected plot at Rajshahi during T. Aman season (2013)

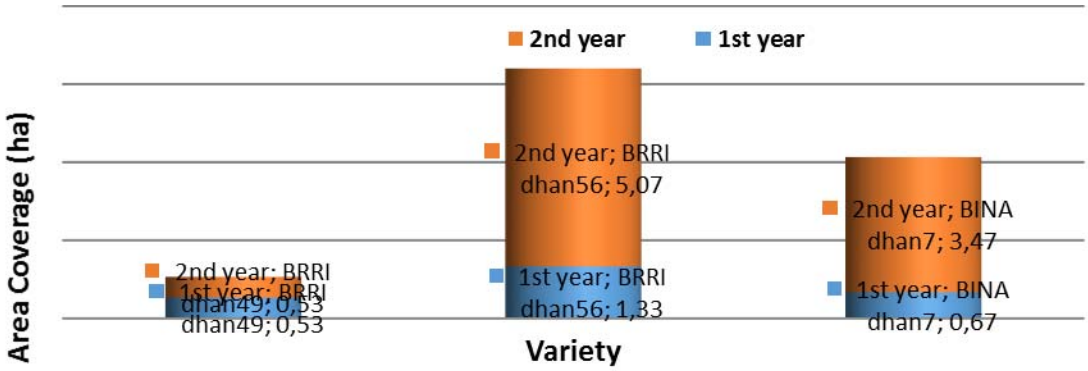


Figure 5.2 Adoption of different T.Aman varieties during 2013.

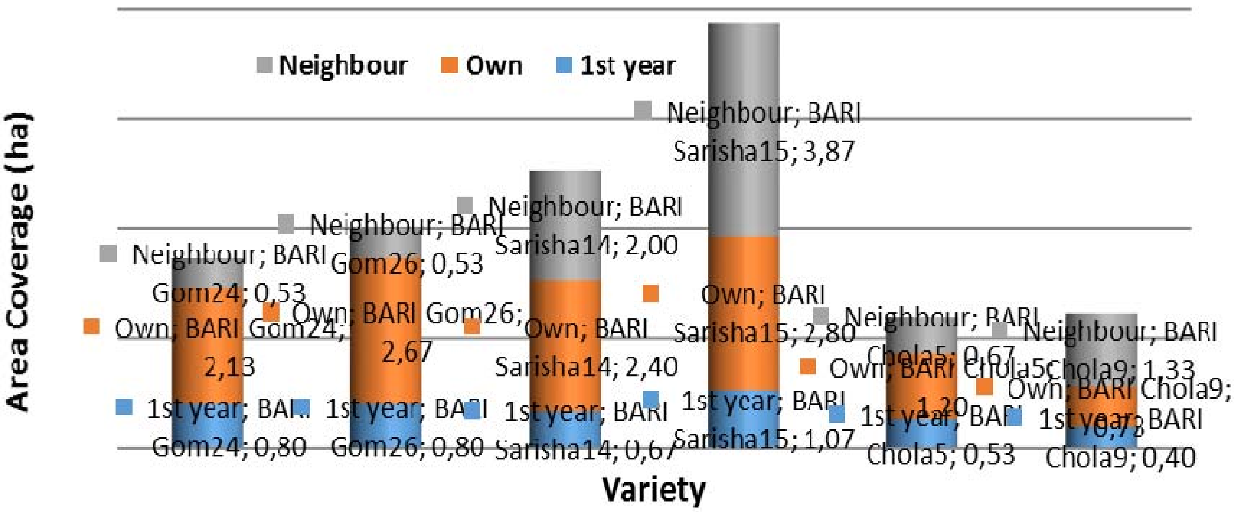


Figure 5.3 Adoption of different Rabi crops during 2012-13.

5.3 Conclusions

- Rajshahi region experiences moderate to severe droughts frequently. Different non-rice crops are suitable for growing under such conditions.
- Annual mean temperature is likely to increase in the future by various amounts, but in all seasons of crop growth. Under climate change situations, the frequency of reaching 35°C and above during March to May may increase the risk of crop sterility even for the rice crop – and more so for many other alternative crops- making the development and distribution of heat tolerant varieties desirable.
- The availability of surface water would get worse in the T.Aus season, but may improve for the T. Aman season, while also increasing the potential for more floods. Groundwater availability will likely be increasingly insufficient for Boro rice cultivation in the future. Rainwater-harvesting and the expansion of water storage facilities seem essential for any future agronomic growth in this area.
- Low water demanding, short duration, drought tolerant and heat tolerant crops should be cultivated for sustainable food production in Bangladesh.
- T. Aman rice is preferable as rainfed crop but 2-4 supplemental irrigations may be needed. In transplanted conditions, water productivity varied from 5.71 to 7.23 kg/ha-mm depending on growth duration of rice varieties. Water productivity was 4.00 to 5.71 kg/ha-mm under direct seeded conditions.
- Under water deficit conditions, direct seeded Aus and Aman crop establishment can become more suitable under a changed climate.
- The field performance of non-rice crops was very good, and farmers showed eagerness to adopt modern varieties because of their higher yield. Water productivity of wheat varied from 16.55 to 18.06 kg/ha-mm; mustard from 5.83 to 7.70 kg/ha-mm and it was 6.55 to 11.21 kg/ha-mm for chickpea and other legumes.
- Shifts in climatic patterns also affect patterns and severity of pest and disease prevalence, which needs to be controlled. A disease forecast system with proper distribution of resulting information is desirable.

5.4 General recommendations

- Weather forecasting with wide access to its predictions would be desirable for the proper utilization of rainwater, and better management of irrigation water.
- Re-excavation of natural canals and ponds and construction of on-farm reservoirs for rainwater harvesting and storage would be desirable.
- Cultivation of low water demanding and high value crops along with the establishment of direct marketing channels would be desirable.
- Coordinated joint use of ponds for fish and crop culture would be desirable for better profits as well as food security locally. There should be provision of pond water withdrawal beyond 1.5 m for irrigation purposes.
- Adoption of conservation agriculture- minimum tillage, cover crop, mulching, would be desirable.
- More field demonstrations on direct-seeded crop establishment technique would be desirable to enhance the potential for conserving and the efficient utilization of water resources.
- Minimization of groundwater withdrawal would be desirable, and potentially assisted by an increasing cultivation of non-rice crops in the dry season.
- Installation of surface water conveyance and distribution systems for the high Barind Tract, 10-20 km away from river water sources, would be desirable for better use of available surface waters.
- Drought escaping technologies should be further developed.
- Soil nutrient depletion and plant nutrient uptake patterns should be examined in relation to higher temperatures and increased CO_2 concentrations.
- Drought and heat tolerant crop varieties should be developed and disseminated among the farmers.

- Concerted efforts of all regional research and extension organizations can play a vital role in the future of this area, and thus al such activities should be enhanced in a coordinated way.

6. Adaptation for Crop Production:

In a Changing Climate of Barisal: Saline Prone Areas

6.1 Introduction

There are a variety of problems seriously affecting crop production in the saline prone Barisal area. Increasing temperatures, erratic rainfall, cyclones, tidal surges, sea level rise and salinity intrusion threaten crop production and livelihoods in this area. Siltation of natural canals, intrusion of saline water towards inland and its intrusion into aquifers are reducing freshwater availability, which adversely affects agriculture as a whole in southern Bangladesh. Several cyclones have devastated the coastal areas in the recent past, and the frequency of cyclones, severe flood and droughts are expected to increase in the coming years. Moreover, IPCC Report 5 (2013) indicated that temperature is likely to increase by 1.8-3.4^{o}C at the end of this century along with a sea level rise of 0.26-0.82 m. Sea level rise may claim almost 17% of its land, extending from the coastal periphery towards inland of the country (Dewan and Nizamuddin, 1998 and SRDI, 1997). An approximately 10612 sq. km sized area is expected to be affected by salinity if sea levels rise according to existing predictions, i.e. by 32 cm by 2050, and the size of the affected area is expected to be 14468 sq. km if there is a 88 cm sea level rise by the end of 21st century. Moderate droughts and soil nutrient depletions along with climate change impacts are adding more pressure on natural resources for sustainable crop production. These imply that crop production and small farmers' livelihoods will be more vulnerable in coastal areas of Bangladesh.

Any further variations in seasonal rainfall patterns and amounts, temperatures and cyclonic storms could significantly influence rice production and thus jeopardize food security. Development of strategies and identification of appropriate response tools is essential in order to face such challenges and sustain crop production. Therefore, this chapter aims to look at the vulnerability of rice crop production and provide a tool box of adaptation technologies to address climate change impacts and sustain rice production in the saline prone areas of Bangladesh.

6.1.1 Summary of climate change predictions

This subchapter provides a short summary of climate, hydrology and crop growth modeling results from the project's relevant reports, as well as the earlier chapter in this compendium in order to provide context to some of the adaptation recommendations.

In this study area, mean annual temperatures are likely to increase during the course of the rest of the 21st century by 1 to 3^{0}C under the A1B scenario and 0.6 to 2.5^{0}C under the A2 scenario, compared to the base period (1971-2010). Based on observations in the last 30 years (1983-2012), daily maximum temperatures recorded were above 32^{o}C in April. The significance of maximum temperatures for crops is in that crops can become sterile – resulting in yield reduction - if high temperatures occur during flowering Such temperatures are already critical for certain crops (e.g. wheat, pea, mustard and tomato), and projected further increases will make the situation worse. Table 6.1 presents a list of crops with their critical temperatures for sterility. Different reports exist that report on annual precipitation rates. Annual mean precipitation in the study areas is expected to increase by more than 3% in the next three decades of the 21st century compared to the base period (1970-2010). However, in the periods of 2041-2070 and 2071-2100, mean annual precipitation is likely to decrease by about 3% compared to the base period under A1B scenario. Under the A2 scenario, mean annual precipitation is expected to decline by about 9-11% during 2041-2070. However, by the end of 21st century, precipitation is expected to increase by more than 3% compared to the base period. According to another prediction, dry season rainfall (December-February) may increase countrywide by 107% in 2050 and pre-monsoon rainfall may decrease by as much as 67%, indicating an increased need for supplemental irrigation water for pre-monsoon crops. It is noted, however, that these large percentages refer to only small amounts of water in absolute amounts, given the small amount of base period rainfall in those respective periods.

Table 6.1 Critical temperature for sterility in some selected field crops

Name of crop	Critical temperature for sterility (°C)	Reference
Rice (*Oryza sativa* L.)	35	BRRI, 2011
Wheat (*Tritichum aestivum* L.)	30	Saini and Aspinal, 1982
Chickpea (*Cicer arietinum* L.)	35	Devasirvatham et al, 2012
Pea (*Pisum sativum*)	30	McDonald and Paulsen, 1997
Groundnut (*Arachis hypogaea* L.)	35	Prasad et al, 1999
Mustard (*Brassica juncea* L.)	27	Chauhan et al, 2013
Mung bean (*Vigna radiata* L.)	40	Tickoo et al, 19996
Tomato (*Lycopersicon esculentum* L.)	32	Peet et al, 1998

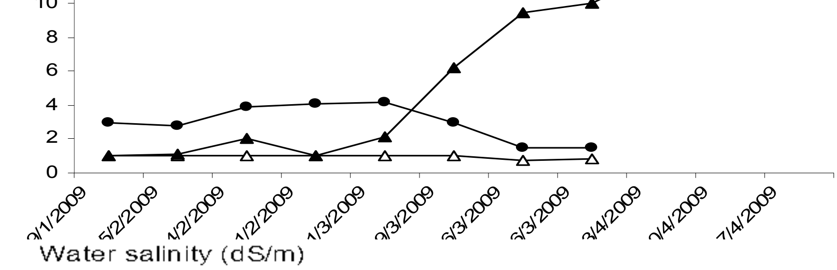
Water availability, as predicted by the SWAT model, is likely to be reduced by 12-30% during pre-monsoon (April-May) except in the 2030s according to the A1B scenario and the 2080s according to the A2 scenario. There is indication, however, of an expected increase in the monsoon (Jun-Sep) period and annual flow of water rainfed T. Aus yield, as predicted by the DRAS model, may increase by 3-7% by the 2050s and 1-7% by the 2080s under both the A1B and A2 scenarios compared to the base period. In the same periods, T. Aman yield is predicted to decrease by 3-19% and 2-12%, respectively, without supplementary irrigation. Irrigation water demand of the T. Aus as well as T. Aman crops may be affected by predicted changes to rainfall (increase for T. Aus, decrease for T. Aman)under both the A1B and A2 scenarios, but such changes can only be interpreted in the bigger context of other climatic changes (e.g. temperature change, change to sunshine hours). An earlier chapter provides more information on such changes and their interpretation. Water demand would increase somewhat under the A1B scenario but is expected to decrease under the A2 scenario for the Boro crop. Nevertheless, the Boro crop will remain a fully irrigated crop. Estimated net irrigation requirement (NIR) – i.e. irrigation needed to keep the soil constantly wet - for the T. Aus, T. Aman and Boro crops is evaluated to be 100-120 mm, 80-125 mm and 830-880 mm, respectively on average in the base period. Irrigation water requirement is predicted to decrease for the T. Aus crop and increase for the T. Aman crop in the study areas under both scenarios, although the pattern of expected rainfall is rather uncertain, especially in terms of its timing.

6.1.2 Water scarcity considerations in quantity and quality

Water scarcity, a known phenomenon in Bangladesh, originates not only from the physical constraints of fresh water resources, but also due to its inefficient use and often poor management. An increasing demand on one hand and the inefficient use on the other are likely to widen the gap between water supply and demand in the foreseeable future. Besides, unpredictable rainfall and the general shortage of facilities for storage of surface runoff are all negatively affecting water availability in Bangladesh.

Although there is plenty of surface water in the Barisal region during the wet season, farmers are often reluctant to utilize supplemental irrigation systems and thus the rice crop suffers from drought occasionally. Our analyses for drought indicated that the Barisal region experienced moderate to severe droughts for several years although its rainfall amount is substantially greater than that of the Rajshahi region. The moderate drought (SPI ≤ -1) was observed in most of the years and extreme drought (SPI ≤ -2) was detected during five of the last 30 examined years (1983-2012).

There are a large number of natural canals and khals criss-crossing the Barisal region, which give the opportunity to use surface water. Tidal water also flows into the canals twice a day, therefore, surface water availability for crop production is sufficient in the Barisal region, if properly managed.



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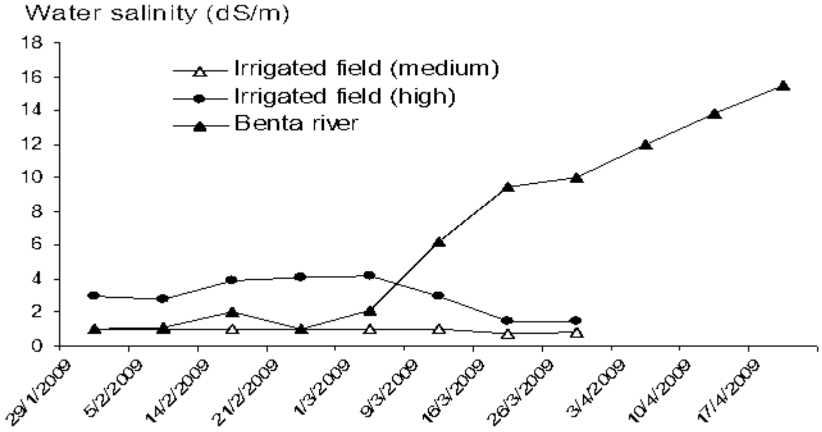

Figure 6.1 Field and river water salinity in the Barisal region

6.1.3 Main constraints for agricultural development in the Barisal region

Some of the main constraints observed for agricultural development in the Barisal region are summarized as:

I. Crop production related factors
- Lack of improved and quality seeds of crop, especially salinity tolerant crops;
- Lack of salinity tolerant and short duration varieties;
- Incidence of pest and disease; and
- No modern rice varieties available, having taller seedling height for planting in stagnant water conditions.

II. Water resources and water management related factors
- Seasonal lack of availability of suitable (non-saline) irrigation water;
- Faulty and damaged polder systems;
- Weak management of sluice gates and water reservoirs for irrigation purposes; and
- Frequency of electricity failure during irrigation time.

III. Climate and environment related factors
- High maximum temperatures during the dry period;
- Low minimum temperatures during the winter period;
- Short winter period; and
- Unpredictable cyclone activity and surges from sea.

IV. Socio-economic factors
- High input costs and low product prices of agricultural commodities;
- Lack of individual/community storage facilities;
- Lack of availability of direct-sale centers and the existence of middleman;
- Lack of a formal agricultural credit system;
- Discrimination of wages between male and female agricultural workers; and
- Women's marginal role in decision making related to crop production processes

6.1.4 Current crop production systems and gaps in the Barisal region

The following information on the ongoing crop production systems is based on focus group discussions (FGDs) and field surveys:

- The dominant crop rotation in Kalapara was Pulses-Fallow-T. Aman, practiced in 55% of the cropped area (Table 6.2)

- Pulses-T. Aus-T. Aman in Amtali (56%) and Fallow-Fallow-T. Aman was most common in Patharghata (45%) upazilas (Table 6.2).

Table 6.2 Major cropping patterns and area coverage in the Barisal region

Locations	Cropping patterns	Coverage (%)
Kalapara	Pulses-Fallow-T. Aman	55
	Rabi crops-Fallow-T.Aman	20
	Fallow-T. Aus-T.Aman	10
	Others	15
Amtali	Pulses-T. Aus-T.Aman	56
	Fallow-T.Aus-T.Aman	34
	Others	10
Patharghata	Fallow-Fallow-T.Aman	45
	Fallow-T.Aus-T.Aman	25
	Potato/Sunflower-Fallow-T.Aman	20
	Others	10

- Many of the farmers preferred to grow local T. Aman varieties because of taller seedlings that facilitated planting in stagnant water, yielding 2.4-4.5 t/ha grain yields (Table 6.3).

Table 6.3. Major crops grown and yield under different seasons

Crops	Popular varieties	Area (ha)	Average yield (t/ha)	Yield range (t/ha)
Kalapara				
Local T. Aman	Sadamota, Lalmota, Vojan,Tepu	36.27	2.81	2.40 – 3.60
HYV T. Aman	BR11 and BRRIdan41	15.20	3.37	3.00 – 3.60
Pulses	Felon, Kheshari	1.80	1.09	0.98– 1.20
Vegetables	Ash gourd, Sweet gourd, etc	2.53	12.18	10.75 – 13.50
Total		**67.53**		
Amtali				
Local T. Aus	Mala China	9.60	3.30	3.00-3.60
Local T. Aman	Sadamota, Lalmota	27.33	2.70	2.40-3.00
HYV T. Aman	BR11, BRRI dhan40/53	16.37	3.80	3.10-4.50
Pulses	Felon, Kheshari	6.40	1.18	1.00-1.75
Vegetables	Ash gourd, Sweet gourd, etc	1.00	12.08	11.05– 13.25
Total		**63.00**		
Patharghata				
Local T. Aman	Kajalsail, Sadamota, Lalmota	32.53	3.45	2.40-4.50
HYV T. Aman	BR11, BR22 and BRRI dhan44	4.33	4.60	3.40-5.80
Potato	Cardinal	2.47	9.75	9.00-10.50
Sunflower		1.20	1.80	1.65-1.95
Pulses	Felon, Kheshari	19.87	1.24	0.98-1.50
Vegetables	Bitter gourd, Water gourd, etc	1.27	10.75	9.50-12.00
Total		**61.67**		

- A few BRRI varieties are gaining popularities in these three project sites because of better grain yield. Mala China is very popular in the Amtali site, however this variety is not similar to BR2.
- Most of the soils are acidic to neutral in nature having quite satisfactory organic matter content but widespread deficiencies of nitrogen and phosphorus exist (Table 6.4).

Table 6.4 Initial soil nutrient status of Barisal project sites

Locations	EC	pH	OM	Total N	Mg	K	P	B	Zn
	dS/m	-	%		Meq/100 gm soil		Microgram/gm		
Amtali	1.44-6.85	4.3-7.1	0.93-2.63	0.05-0.14	5.09-8.08	0.21-0.72	0.42-5.76	0.22-1.10	0.54-1.60
Kalapara	1.66-5.86	4.7-5.4	0.76-2.16	0.04-0.12	4.97-7.99	0.20-0.34	0.85-8.76	0.50-0.95	0.69-1.28
Patharghata	1.91-11.51	4.5-7.2	.83-4.17	0.05-0.24	3.32-6.56	.20-0.61	1.27-11.78	0.33-0.98	0.52-2.77
Critical values	-	-	-	0.12	0.50	0.12	8.00	0.20	0.60

- Application of balanced fertilizers is needed for satisfactory crop production in such soils.
- Soil salinity is highly variable (1.5 -11.5 dS/m) and is a major constraint for crop production, especially in the dry season.

BRRI dhan47 was grown during the dry season in 2013-14 at Amtali and Borguna to compare the performance under both fresh water and saline water (about 3 dS/m) irrigation conditions. The crop failed to survive under saline conditions (Figure 6.2).

Figure 6.2 Performance of BRRI dhan47 depending on irrigation water salinity at Amtali, Boro 2013-14.

6.2 Field trials performed

Apart from awareness and capacity building through field days and training, as part of this project, pilot demonstrations were conducted to test the suitability of low water demanding crops in the dry season along with stress tolerant rice varieties for pre-monsoon, the wet season and the dry season. The project sites were selected based on the needs and preferences of different stakeholders. Pilot demonstrations took place in each of the three upazilas (Amtali and Patharghata of Barguna district and Kalapara of Patuakhali district). Discussions with farmers and stakeholders on suitable adaptation strategies, BRRI's experience from the area and results from other projects helped in identifying and selecting different varieties for pilot testing under controlled conditions as well as on farmer fields. The presented results are supported by Tables 6.5-6.7 and Figures 6.7-6.8 – also referred to in later sections of this chapter.

Aus and Aman rice were grown as rainfed crops that received benefits from tidal water. Grain yield of T. Aus and T. Aman crops within the pilot demonstrations (i.e. researcher plots) varied from 3.70 to 4.15 t/ha and 4.32 to 4.91 t/ha, respectively. Under farmer's management (FM), the obtained yield was 3.26 to 3.75 t/ha and 4.19 to 4.50 t/ha for T. Aus and T. Aman, respectively. Water productivity for Aus and Aman rice varied from 7.49-9.54 and 9.56-11.21 kg/ha-mm, respectively. Grain yield of Boro rice within the pilot demonstrations and farmers management varied from 4.47 to 5.20 t/ha and 4.13 to 4.68 t/ha, whereas water productivity varied from 4.70 to 5.46 kg/ha-mm and

3.96 to 4.50 kg/ha-mm, respectively. Wheat and mustard production became poor due to late sowing and the negative effects of salinity. Based on the performance of different varieties that were tried, the majority of the farmers in the study areas preferred to use BRRI dhan48 in the Aus and BRRI dhan46, BR22 and BRRI dhan40 in the Aman season. During the Boro season, BRRI dhan47 was more preferred than BRRI dhan55 and farmers showed interest to grow BARI shahrisha16 and BARI Gom25.

6.3 Tool box of adaptation measures for the Barisal region

In response to climatic projections, existing and predicted shortage of fresh water resources, and salinity problems, suitable adaptation measures have been identified through the RiceClima project:

- One of the first adaptation options that was identified was to cultivate salt tolerant rice and non-rice crops. Many farmers were observed to be growing long duration, old varieties that can be replaced by salinity tolerant, short duration, modern ones depending on land suitability in different seasons. The river water salinity normally increases after February, indicating suitability for short duration dry season crops. Additionally, trapping of fresh water in natural canals and its subsequent use for irrigation would be beneficial for the expansion of dry season cropped areas.
- Based on the field pilot demonstrations that were conducted in different seasons for testing the performance of new stress tolerant varieties, along with improved crop husbandry, some recommendations were provided to farmers. (In the T. Aus season, BRRI dhan48 and BRRI dhan55 were tested (Table 6.5), and in the T. Aman season, BR22, BR23, BRRI dhan40, BRRI dhan41, BRRI dhan44, BRRI dhan46, BRRI dhan53 and BRRI dhan54 were tested (Table 6.6).

Table 6.5 Field performance of Aus varieties during 2013, Barisal site

Crop*	Mgt.	RF (mm)	RFe (mm)	Total water use (mm)	Yield (t/ha)	Water productivity (kg/ha-mm)
TP rice	RM	645	435	435	3.70-4.15 (3.85)	8.51-9.54 (8.85)
	FM	645	435	435	3.26-3.75 (3.42)	7.49-8.62 (7.86)

RM = Researchers management, FM = Farmers management
* TP rice = transplanted rice

Table 6.6 Field level water use, crop yield and water productivity of Aman rice at Barisal site during 2013

Crop duration	Mgt.	RF (mm)	RFe (mm)	Total water use (mm)	Yield (t/ha)	Water productivity (kg/ha-mm)
Long duration TP rice (145-154 days)	RM	879	438	438	4.32-4.91 (4.58)	9.86-11.21 (10.46)
	FM	879	438	438	4.19-4.50 (4.25)	9.56-10.27 (9.70)

RM = Researchers management, FM = Farmers management

- In elevated areas, growing early maturing T. Aman rice followed by mustard and wheat cultivation may be a suitable rotation, if extreme high temperatures can be avoided during flowering.

Table 6.7 Field level water use, crop yield and water productivity in Boro/Rabi season at Barisal region, 2012-2013

Crop	Mgt.	RF (mm)	No. of irrigation	Amount of irrigation (mm)	Total water use (mm)	Yield (t/ha)	Water productivity (kg/ha-mm)
Boro Rice	RM	132	14-16 (15)	780-860 (820)	912-992 (952)	4.47-5.20 (4.90)	4.70-5.46 (5.15)
	FM	132	15-18 (17)	850-976 (910)	982-1108 (1042)	4.13-4.68 (4.35)	3.96-4.50 (4.17)
Wheat	RM	30	2	120	150	2.00-2.50 (2.30)	13.33-16.67 (15.33)
Mustard	RM	30	0	0	30	1.20-1.50 (1.30)	40.00-50.00 (43.33)

RM = Researchers management, FM = Farmers management

Table 6.8 Characteristics of cultivated variety in different seasons

Season	Variety	Growth duration (days)	Average yield (t/ha)	Characteristics
Aus	BRRI dhan48	110	5.5	HYV T. Aus
	BRRI dhan55	105	5.0	Salinity, drought and cold tolerance
Aman	BR22	150	5.0	High yielding, suitable for late planting and photoperiod sensitive
	BR23	150	5.5	
	BRRI dhan40	145	4.5	HYV, salt tolerant, photoperiod sensitive
	BRRI dhan41	148	4.5	
	BRRI dhan44	145	5.5	HYV, photoperiod sensitive
	BRRI dhan46	150	4.7	High yielding, suitable for late planting and photoperiod sensitive
	BRRI dhan53	125	4.5	Short duration, salt tolerant (8-10 dS/m)
	BRRI dhan54	135	4.5	Medium duration, salt tolerant (8-10 dS/m)
Boro	BRRI dhan47	152	6.0	HYV, salt tolerant
	BRRI dhan55	145	7.0	HYV, salt, drought and cold tolerant
Wheat	BARI Gom25	102-110	4.6	Suitable for late planting, heat and salt tolerant
Mustard	BARI Sarisha16	105-115	2.5	HYV, suitable for late planting, drought and salt tolerant

- Farmers were given recommendations to grow salt tolerant Boro rice varieties, like BRRI dhan47 using trapped fresh water (Table 6.7). Stress tolerant Boro rice, wheat and mustard crops are also suitable for late sowing (Table 6.8).
- Farmers usually grow local varieties and a few HYV varieties by using tidal water with delayed transplanting in the Aus (pre-monsoon) season. In the wet season, these areas were found to be dominated by local varieties like Sadamota, Kachaomota, Morichsail etc due to water stagnation and tidal inundation of the cropland. Taller local rice varieties with taller seedlings are required for transplanting in tidal areas (Figure 6.3).

Figure 6.3 Tall rice seedlings and its transplanting.

- Fish rearing in low lying water bodies (waterlogged areas) or gher areas with vegetables on the raised bank during wet season is already being practiced by farmers and could be expanded with more support in terms of investments, training and inputs (Figure 6.4),

Figure 6.4 Fish in gher in the wet season

- In the dry season, some farmers cultivate Boro rice in gher areas (Figure 6.5), also using trapped canal water. Growing rice in the dry season is safe, though it depends on irrigation water, which is becoming more limited. Moreover, seeding must be completed within the 3rd week of November for a good harvest of Boro rice (Mondal et al., 2004).

Figure 6.5 Rice cultivation in gher during the dry season

- Within the polders, farmers grow Felon as a relay crop with T. Aman, sunflower, water melon and chili. Beyond the polder areas, farmers cultivate vegetables, banana, fruits like guava by creating raised beds called ‘sorjan’ to protect the crops from tidal submergence and salinity (Figure 6.6). This is becoming popular as an adaptation measure to address flooding.

Figure 6.6 Fruits and vegetables cultivation in Sorjan system.

- We also tested modern, stress tolerant crop varieties to replace local ones. Among the tested T. Aman varieties, most of the farmers adopted BRRI dhan46 because of higher yield and suitability
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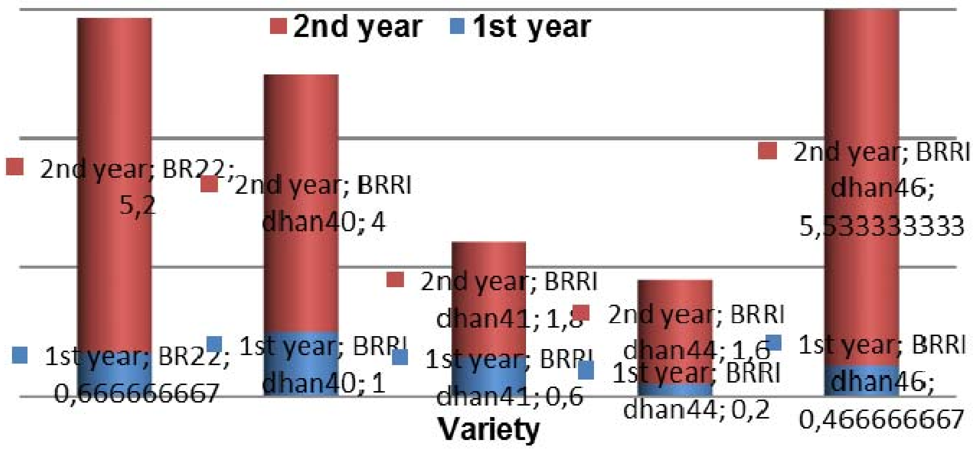


Figure 6.7 Adoption of different T.Aman varieties during 2013

- Sunflower, Felon and pulses (e.g., mungbean) are more suitable to adapt to salt and drought conditions. During the Boro season, among suitable rice varieties, farmers mostly adopted BRRI dhan47 due to its salt tolerance (Figure 6.8).

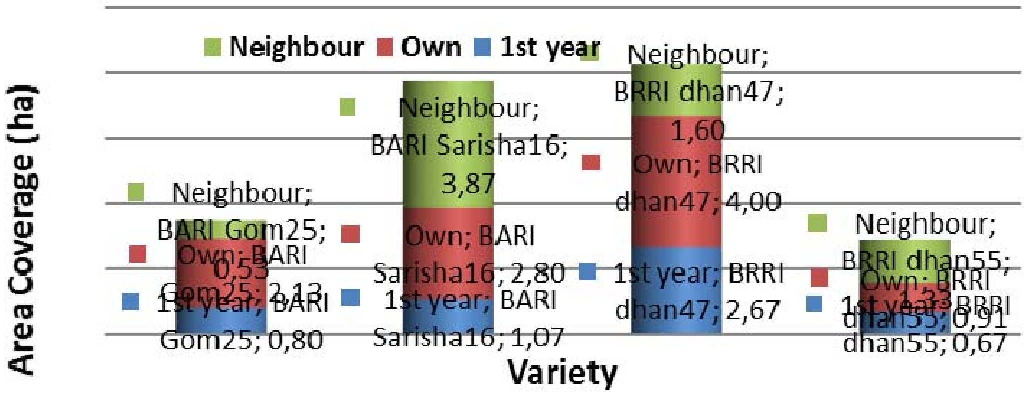


Figure 6.8 Adoption of different Rabi crops during 2012-13

- Training and capacity building is very important in order to increase awareness and provide new knowledge to farmers about new and alternative adaptation technologies. About 360 farmers were trained in three training workshops within the three selected upazilas in both the T. Aman and the dry seasons on crop cultivation, efficient fertilizer and water management, pest management etc. About 300-350 farmers and local officials and leaders also participated in three field days organized in the three selected upazilas.
-

6.4 Conclusions

- The Barisal study region mostly experiences salinity problems and lack of fresh water during the dry season. Selected salt tolerant rice and non-rice crops are suitable for growing under such conditions.
- Salinity affected areas (up to about 14468 sq. km) in Bangladesh may be affected by further inundation due to sea level rise by the end of the 21st century.
- Mean annual temperature is likely to increase by 1 to 3^{0}C under the A1B climate change scenario and 0.6 to 2.5^{0}C under the A2 scenario. Climate change scenarios indicate that 32^{o}C and much higher temperatures will likely occur during the period from March to May, making it critical for wheat, mustard and some other crops cultivation, unless heat tolerant varieties are bred and disseminated among the farmers.
- Low water demanding, short duration, salt and heat tolerant rice and non-rice crops may be desirable in general.
- In pilot areas established in this project, T. Aus and T. Aman rice were mainly grown as rainfed crop along with the use and support of tidal water. Water productivity varied from 7.49 to 9.54 kg/ha-mm and 9.56 to 11.21 kg/ha-mm depending on growth duration of rice varieties.
- The field performance of Boro rice and non-rice crops was very good in dry season field trials. Farmers showed eagerness to adopt new varieties, depending on land suitability. The water productivity of Boro rice varied from 3.96 to 5.46 kg/ha-mm depending on growth duration.
- We found that awareness and capacity building through trainings and field days was well attended and effective.

6.5 Recommendations

- Farmers should be supplied with improved quality seeds.

- Investments to revive drainage systems in order to increase the availability of fresh water will be critical in the Barisal region.
- Farmers should be trained to measure salinity, and helped to be capable to trap fresh water and use it for irrigation.
- Timely establishment of Aus rice is necessary to avoid tidal flood damage during the reproductive stage.
- Fresh water availability should be increased through better sluice gate management. The Bangladesh Water Development Board (BWDB) should take the initiative regarding water management through e.g. a sluice gate operating committee. A sluice gate operating committee can be comprised of e.g. DAE and BWDB personnel along with local administration and farmers.
- Development of a water delivery system should be considered to help the cultivation of crops further away from fresh water sources.
- Community based seedbeds for the Aus rice could be useful to small farmers.
- Improvement is necessary in technology dissemination systems targeting the end users.
- Programs to develop and distribute short duration and salt tolerant varieties should be taken up on a large scale.

7. Socio-ecological vulnerability assessment for:

Flood and saline-prone region in rural Bangladesh

7.1 Summary

The current study attempted to quantitatively measure the vulnerability status of selected regions in Bangladesh impacted by climate change. Three upazilas were selected in the drought prone region of Rajshahi, while another three upazilas were assessed in the saline-flood prone Barisal region. The Exposure, Sensitivity and Adaptive capacity of each upazila was measured through socio-demographic, agro-economic and infrastructural indicators inspired by the literature, RiceClima reports but also elicited from a household survey in the examined areas. The technique of Principal Component Analysis was used for the assessment of the indicators while descriptive statistics also helped for a better understanding of the current situation in the two regions. The findings indicated that the drought prone Rajshahi upazilas (North Bangladesh) are more exposed to inefficient irrigation management and lack of access to household's utilities (water, electricity). The flood and saline prone upazilas of the Barisal region in South Bangladesh lack transportation, agricultural, education and health infrastructure on a regional level. In both regions, the introduction of cash crops and the improvement of market conditions in agriculture are deemed as necessary actions.

7.2 Introduction

It is predicted that climate change will aggravate the presence of sudden (e.g. cyclones, floods etc.) and chronic (e.g. erosion) hazards to agrarian communities in developing countries. The degree of exposure, sensitivity and adaptive capacity to climate change determines the vulnerability level of a community (Nelson et al., 2010a). The agrarian population in Bangladesh is ranked by many studies to be of the most vulnerable in the world due to the poor socio-economic features, the unique geophysical location and the high exposure to climate change effects (Ramamasy and Bass, 2007).

However, the measurement and interpretation of vulnerability indices is argued to be a rather difficult undertaking (O'Brien et al., 2004). First, it is rather arduous to define the vulnerability of an agrarian community within some administrative boundaries only. The climate change impacts affect larger scale areas - geographical regions (Fussel, 2007) and thus it is difficult to tell the differences between administrative units. Further, there can be multiple threats at various scales occurring simultaneously in social and natural aspects, which make the identification and impact-value assessment quite dubious. Additionally, an impact from climate change can be instantaneous or may develop slowly over time, and thus the vulnerability assessment may become a rather puzzling process.

Although there may be difficulties in determining the assessment parameters of vulnerability, the biophysical and socioeconomic disciplines seem to adopt two distinctively different approaches. The "end-point" approach is more welcomed among biophysicists while the "start-point" notion prevails in socio-economics. The "end-point" approach may, for example examine future climate scenarios by evaluating - through modeling - its biophysical impacts and suggesting potential adaptive options. The "start-point" deploys the existing inequalities within a society, which are deemed to further exacerbate when exposed to climate change (Smit and Wandel, 2006).

In our study, we attempted to borrow elements from both domains for the development of a socio-ecological vulnerability assessment in flood-saline and drought prone areas of Bangladesh. The northern drought prone Rajshahi and the southern flood-saline prone Barisal regions were selected as study areas and three sub-regions (upazilas) were adopted in each region. Demographic, agro-economic and infrastructure related indicators were introduced as assumed signals of social vulnerability, along with the results of climatic and hydrological models as biophysical indicators. Principal component analysis (PCA) was employed for the valuation of the vulnerability levels in each of the examined upazilas. Also, farmers' preferences were elicited for a better clarification of potential adaptation measures to be taken against climate change.

7.3 Methodology

7.3.1 Defining the vulnerability concept in a changing climate

According to the definition of the Intergovernmental Panel on Climate Change (IPCC), the leading international body for the assessment of climate change, the vulnerability to climate change could be synopsized as the "degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes" (IPCC, 2001, Glossary).

The vulnerability concept is highly dependent on the exposure, sensitivity and adaptive capacity of a system to cope with weather extremes. There is a multitude of interpretations pertaining to the affecting parameters of vulnerability but we currently borrow the definitions given by the IPCC which stipulates that the *exposure* relates to ―"the nature and degree to which a system is exposed to significant climatic variations"‖ (IPCC, 2001, Glossary). The *sensitivity* on the other hand, reveals the "degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise) (IPCC, 2001, Glossary)". Finally, the *adaptive capacity* is dictated as " the ability (or potential) of a system to successfully adjust to climate change (including climate variability and extremes) to (i) moderate potential damages, (ii) to take advantage of opportunities, and/or (iii) to cope with the consequences (IPCC, 2001, Glossary).

Although the components of vulnerability are well described in IPCC it still remains difficult to define the multifaceted nature of vulnerability. Both natural and social scientists agree that the vulnerability is *multi-dimensional and differential* which means that it is perceived differently across physical space and between various social groups (Cardona et al., 2012). It is also *scale* and *time-dependent* because various socioeconomic and biophysical impacts unequal in magnitude, may appear at the same time. Moreover, it is highly *dynamic* because the impacts may appear instantaneously or aggregated within the years (Vogel and O'Brien, 2004, Devisscher et al., 2012). Although the fuzzy nature of vulnerability is highly acknowledged there is a strong effort to define the boundaries of a vulnerable system. In this report, we have adopted the following diagrammatic concept of vulnerability as presented below:

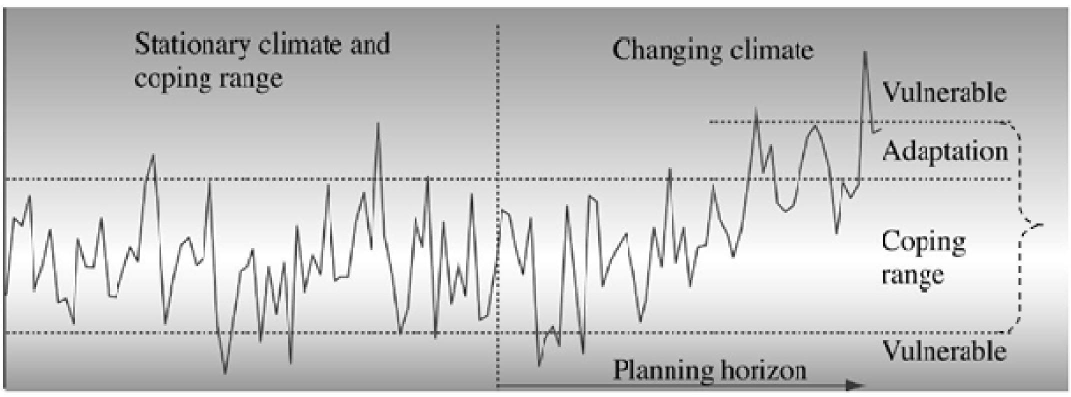


Figure 7.1 Boundaries of vulnerability and climate change, Source: Fellman, 2012

As shown in Figure 7.1, when the climate is in a stationary mode (left part of the figure), there are still some weather abnormalities which could be however managed within the coping range of an agrarian community. For example, higher temperatures or heavier rainfalls could be observed for some days in rural Bangladesh even when there is a stationary climate. The farmers have developed the relevant mechanisms to cope with weather fluctuations and overcome the relevant problems occurring from such weather events.

In the case of climate change however, the weather extremes may become more frequent and with higher intensity (right part of figure 7.1). In this case, the coping rage of a socio-ecological system becomes more limited and it is much dependent on the *exposure* and *sensitivity* to the changing climate. It is then that the *adaptive capacity* should be enhanced which actually represents the potential of a system to better adapt in climate change. In other words, the higher the adaptive capacity, the lower the vulnerability is. On the contrary, the synergy between exposure and sensitivity will augment the vulnerability levels.

In simple mathematical terms, the vulnerability of climate change can be expressed as below:

$$V = A - (E + S) \qquad (1)$$

Where V = Vulnerability, A= Adaptive Capacity, E = Exposure, S = Sensitivity

The operational dimensions of vulnerability often depend on the biophysical and socio-economic perspectives attributed in each case.

7.3.2 The operational dimensions of vulnerability

The ''starting'' and ''ending'' points of operational vulnerability

The operational dimensions of vulnerability are differently interpreted by social and biophysical sciences. The social sciences mostly perceive vulnerability as a situation where the existent inequalities between developed and developing regions will further exacerbate (O'Brien et al., 2004). The inherent social and economic differences will make it very hard for communities in developing countries to cope with the external pressures and climate change. As a result, the people from developing regions will be further marginalized and restrained from economic wealth. This vulnerability dimension is mostly acknowledged as a ''starting point'' and as such is nowadays acknowledged from all scientific disciplines. The input data for the ''starting point" perception are mostly indicators pertaining to the areas of socio-demographics, economic wealth, infrastructural facilities and information access.

It is frequent that in developing regions the indicators are processed with operational tools used for poverty analysis. The reason is that a given set of adverse phenomena such as weather extremes could decrease consumption below a minimum poverty level. Hence, a poverty analysis could somehow reflect the vulnerability aspects as well the distributional effects and inequality aspects of an agrarian community in Bangladesh for instance, which is hampered from extensive droughts or floods. It is however noted that the poverty analysis is mostly focused on the consumption levels which can hardly represent the socio-ecological vulnerability by climate change (Brouwer et al., 2007). Instead, statistical exploratory techniques such as components and factor analysis, generalized linear and non-linear models are nowadays introduced to this purpose.

The biophysical disciplines put much emphasis on the physical affects while the socio-economic aspects tend to be of secondary importance. Future emissions coupled with projected population trends and other technological aspects generate different climate change scenarios (Eakin and Luers, 2006). The adaptive capacity of an ecosystem is determined through the robustness and resilience conditions of an ecosystem to cope with the magnitude of the climate change impacts (Anderies et al., 2004). The biophysical perspective is mostly acknowledged as the ''end point'' approach.

The operational tools applied in such cases are - more often than not - different climatic models. The current models have been much evolved so as to forecast climate change on regional and global scales with a degree of uncertainty (Gallopin, 2006). The most frequent parameters examined are the temperature, precipitation, wind speed, sunshine exposure and humidity. However, there are considerable limitations in our understanding of the climate system and the precision of biophysical parameters especially on a regional level. This becomes more distinctive in the case of developing countries where the biophysical indicators for the regions are scarce and often unreliable (Basak, 2011).

Our study introduces a mixture of theory and data-driven approaches for the development of a quantitative regional assessment in two regions of rural Bangladesh. In particular, we borrow elements from both the socio-economic and biophysical perspectives for the construction of a vulnerability assessment. To this end, we introduced indicators already applied in a multitude of biophysical and socio-economic studies for the development of vulnerability indexes (Abson et al., 2012; Deressa et al., 2008; Fellman 2012; Piya et al. 2012). These indicators were sourced from published sources of similar projects, RiceClima reports and individual research papers. A household survey was conducted for this data-driven approach as it is presented in details in the following Section. Overall, we introduced three groups of vulnerability indicators corresponding to the areas of exposure, sensitivity and adaptive capacity, respectively. The exposure group in Table 7.1 represents a set of various biophysical and technical indicators originated from RiceClima reports. It should be mentioned that the values of the Exposure indicators represent the weighted mean of a 30-years observations in the selected upazilas.

Table 7.1 Exposure Indicators

EXPOSURE INDICATORS				
Code	**Abbreviation**	**Unit**	**Explanatory Note**	**TD.-DD**
1	T_annual	Celcius	Mean Temperature for All year	TD
2	P_annual	mm	Mean Precipitation for All year	
3	Yloss_Aus	%	Yield Loss compared to the potential yield without irrigation for T.Aus period	DD
4	Yloss_aman		Yield Loss compared to the potential yield without irrigation for T.Aman period	
5	YL_slight_aus		Indicated level of slight loss in % of years for T.Aus period	
6	YL_mod_aus		Indicated level of moderate loss in % of years for T.Aus period	
7	YL_severe_aus		Indicated level of severe loss in % of years for T.Aus period	
8	YL_slight_aman		Indicated level of slight loss in % of years for T.Aman period	
9	YL_mod_aman		Indicated level of moderate loss in % of years for T.Aman period	
10	YL_severe_aman		Indicated level of severe loss in % of years for T.Aman period	
11	NIR_Aus	mm	Net irrigation requirements for T.Aus period	
12	NIR_Aman		Net irrigation requirements for T.Aman period	
13	NIR_Boro		Net irrigation requirements for Boro period	

Note: TD= Theory-Driven Indicators; DD=Data-Driven Indicators

In Table 7.2, the sensitivity indicators suggested for our study are displayed. As advised by the Bangladesh Rice Research Institute (BRRI), the growing of winter rice (boro) or keeping fallow land in winter time are considered as more sensitive practices to drought conditions than cultivating water resistant crops. Also the small and tenant farmers are suggested by literature reviews to be suitable sensitivity indicators for agricultural vulnerability assessments (Biswas et al., 2009).

Table 7.2 Sensitivity Indicators

Code	Abbreviation	Unit	Explanatory Note	TD-DD.
1	Cropping Pattern 1	%	Boro- Fallow-T.Aman	
2	Cropping Pattern 2	%	Fallow-T. Aus-T.Aman	DD
3	HYV Boro	tn/ha	Rice variety for dry (winter)period	
4	Small Farm	%	Small Farmers	TD
5	Tenant Farm	%	Tenancy Farming	

Note: Tn/ha= Tonnes per hectare, HYV= High Yield Variety

It is noted that the biophysical indicators used for the sensitivity and exposure measurements are not related to any future climate change predictions but to past observations. Finally, the adaptive capacity indicators are displayed in Table 7.3 as below:

As presented in Table 7.3, 6 indicators are attributed to the socio-demographic situation (1-5, 21), 5 indicators describe agro-economic activities (6-10) and 14 (11-20, 22-25) indicators refer to infrastructure access. The relatively small number of agro-economic indicators is due to the summation of individual indicators in some cases. For instance, the Benefit-Cost Ratio of crops per hectare represents the average ratio of all the cultivated crops (e.g. different rice varieties, vegetables etc.) on a per hectare basis. Similarly, the Livestock indicator represents the total amount of livestock (i.e. cows, goat, poultry) given different weights for each animal due to the various economic importance.

It is noted that there were additional meaningful indicators, like the irrigation management, the insect and disease frequency and others to be introduced in the vulnerability assessment. However, the absence of sufficient and appropriate data obstructed their use in the vulnerability assessment. A description of these indicators is presented in Annex 1.

Table 7.3 Indicators of Adaptive Capacity

C.	Indicator	Unit	Explanatory Note	TD-DD	C.	Indicator	Unit	Explanatory Note	TD-DD
	SOCIO-DEMOGRAPHIC INDICATORS				12	Access b. house-Electr.		Access to brick-made housing-electricity	DD
1	Age		Mean age of adult family members		13	Infr.Health		Community clinics per population	
2	Schooling years	Years	Mean schooling years of adult family members		14	Infr.post.		Post services per population	
3	Farm Exp.		Mean Farm experience		15	Infr.veter.		Veterinary centers per population	
4	Family Size	Nos.	Mean Family Size	TD	16	Infr.coop		Cooperatives per population	
5	Own Farm	%	Owning Farmland		17	Infr.agr.ext.	Nos.	Agricultural extensions per population	
	AGRO-ECONOMIC INDICATORS				18	Infr.finan.		Financial schemes per population	
6	Farm Size	Ha	Mean Farm size per household		19	Infr.school		Schools per population	TD
7	Crop Intens.	%	Ratio between the gross cropped area and cultivated land	DD	20	Infr.coll.		Colleges per population	
8	BCR All		Benefit Cost Ratio crops/ha		21	In-migrat.		People migrating to the upazila per population	
9	Livestock	Nos.	Livestock amount with weighted averages	TD	22	Local m.	Km	Distance from local markets	
10	Inc. Av.	Tk/hsd	Mean income per household		23	Bigger m.	km	Distance from bigger markets	
	INFRASTRUCTURE INDICATORS				24	Hosp. Km	KM	Distance from Hospitals	
11	Access Tub.-Latr.	Nos.	Access to tubewell and Latrine	DD	25	Town km	km	Distance from towns	

Note : C. = Code; Nos.= Number; TD= Theory-Driven Indicators; DD=Data-Driven Indicators

7.3.3 Principal Component Analysis and Farmer's preferences

We employ the Principal Component Analysis (PCA) to identify the potential significance of the adaptive capacity, sensitivity and exposure indicators for the assessment of vulnerability in selected drought and saline-flood prone areas of Bangladesh. The PCA is a technique presented in many applications of statistical and econometric inference. PCA has been also extensively applied in socioeconomic and biophysical vulnerability assessments in regional, national and global level (Deressa et al., 2008; Abson et al., 2012, Piya et al. 2012; Borja-Vega and De la Fuente, 2013). The objective of PCA is to explain potential relations between a large set of independent variables (in our case indicators) with a latent dependent variable, which in our case is the vulnerability level of each upazila. The comparative advantage of PCA over other exploratory techniques is that it can rearrange the independent variables for the simplification of the analysis without losing significant information. This is achieved by lowering the dimensions of the original data to few principal components.

The components are tested for potential correlations with each independent variable (indicator), known as factor loadings, which are equivalent to standardized regression coefficients (ß weights) in multiple regressions. The higher values of the factor loadings (correlation), mean a closer relationship with the principal components. The correlation threshold for a variable to remain as a loading factor is not quite precise. As a rule of thumb though, the correlations, positive or negative, presenting a loading factor lower than +/- 0.7 are often discarded from the analysis. The remaining correlations represent the variables needed to develop the scoring index for the vulnerability assessment.

Also, the number of principal components to interpret the relevant variables is debatable and it mainly depends on the grading of eigenvalues associated with each component. In practical terms, the components presenting eigenvalue higher than 1 are approved for explaining the independent variables (indicators) (Everitt and Hothorn, 2011). More often than not, the principal components should be as many as to explain 60-70% of the variables (Abson et al., 2012). PCA gives also the potential to understand the overall importance of an independent variable across all the principal components. This is named as Communality for PCA and it is equal to the sum of all the squared factor loadings for all the principal components related to the independent variable (indicator). This value is the same as the R^2 in multiple regression. The value ranges from zero to 1 where 1 indicates that the variable can be fully defined by the factors. The higher the value, the higher the importance of the relevant indicator. The data to be used in PCA should be initially standardized and checked for potential multicollinearity between the independent variables for the avoidance of biased results.

A potential limitation of the PCA method is the weighting importance in the selected variables. Some authors claim that the PCA may not reflect the higher significance that each variable may possess, by failing to attribute the actual results of a vulnerability assessment. The PCA can run stepwise for each group of the indicators of exposure, sensitivity and adaptive capacity as presented in Tables 7.1, 7.2 and 7.3 or by merging all the indicators of the three groups in one. We have selected the stepwise approach with slight modification in an attempt to better implement Eq.1 in our analysis. To this end, we have run PCA model for adaptive capacity indicators while the sensitivity and exposure indicators were merged in one group since they are represented by a negative signalling in Eq.1.

Below, we present an indicative example of PCA assessment for the case of the Adaptive Capacity Assessment in Godagari upazila (Rajshahi region). As shown in Table 7.4, all the Adaptive Indicators have been initially standardized. We then run the PCA analysis to identify which of the proposed indicators present a loading factor higher than +/- 0.7 and would be eligible for the vulnerability assessment. In the example, the eligible indicators are highlighted with greyish colour.

Table 7.4 Example of Standardized Adaptive Indicators

Age	Schooling years	Farm Exp.	Family Size	Own Farm	Farm Size	Crop Intens.	BCR All	Livestock Score	Inc. Av.	Acc. Tubwl. Latrine	Acc. b house Elect.	Acc. health
0.81	-0.41	-0.10	-0.18	-1	1	1	0.02	-1	1	1	1	-1
Infr. post	**infr. health**	**infr.vet**	**Infr.coop**	**Infr.agr.ext.**	**Infr.finan**	**infr.school**	**infr.college**	**in-migrat**	**Local m.**	**bigger m.**	**hosp. Km**	**town km**
1	-0.11	1	-1	-0.17	1	1	0.26	0.17	1	-1	0.14	0.33

In turn, the factor loadings of these indicators are multiplied with the standardized values for the calculation of the Adaptive Capacity levels as below: = -0.416 (Schooling years) * 0.821 (Loading) + (-

0.18)(Family Size)* (-0.862) (Loading)+ (-1) (Own Farm)* 0.876 (Loading) + 1 (Farm Size) * (-0.761) (Loading) + 1 (Crop Intens.)* 0.93 (Loading) + 1 (Invc.Av.)* (-0.9) (Loading) + 1 (Acc.Tubwl- Latrine)* 0.965 (Loading) + 1 (Acc.b.house-Electr.)* 0.967 (Loading) + (-1) (Acc. Health)* (-0.967) (Loading) + (-0.11) (infr.health) * (-0.764) (Loading)+ 1 (infr.vet) * 0.892(Loading) + (-1) (Infr.coop)* (-0.91303)(Loading) +(-0.17) (Infr.agr.ext)* (0.809) (Loading) + 1 (Infr.finan)* (-0.943)(Loading) + 0.267 (infr.college)* (-0.823) (Loading) + 0.178 (in-migrat)* (- 0.816)(Loading) = **1.546,** which is the Adaptive Capacity Score for Godagari upazila in our example.

In the case of indicator's significance as represented through Communality value, we present an example of the Schooling Year's indicator by considering that we have only two principal components (PC) as below:

Schooling Years = $(0.821)^2$ (PC 1) + $(0.499)^2$(PC 2)= **0.924,** Communality Value
It is underlined that the PCA assessment can measure the relative vulnerability between the examined areas and does not suggest some absolute vulnerability grades based upon a global vulnerability index.

For a better clarification of PCA results, we have also attempted to elicit farmers' preferences with regards to the confrontation of weather extremes and improvement of their adaptive capacity. The farmers were not asked to assess the performance of the same adaptive indicators introduced in PCA but to express in a non-determined context their suggestions for a better adaptation to a changing climate.

7.3.4 Vulnerability of Bangladesh

Bangladesh has been repeatedly threatened by natural disasters like flood, salinity and droughts mainly influenced by the country's unique geophysical and climatic conditions (Nienke et al, 2006). In particular, the mountainous ranging of the Tibetan Plateau is drained through a massive river network spreading all over Bangladesh and finally ending up in the Bay of Bengal. The occurrence of intense monsoonal periods often augments the drainage effects by leading to floods mainly in the southern lowland areas (World Bank, 2010). Additionally, saline intrusions are noticed in the south downstream areas, which are attributed to the higher sea level elevation in the coastlands. On the other hand, less rainfall and high evaporating losses in the northwest Bangladesh have entailed seasonal drought events with severe impacts on local communities (Ramamasy and Bass, 2007).

The extreme events are anticipated to get aggravated by climate change as repeatedly noted in the literature (Nguyen, 2006; Biswas et al, 2009; Winston et al, 2010). The snow melting in the mountainous areas of the Tibetan Plateau coupled with erratic and intense monsoons are expected to constitute the driver for increased flooding. Also, the delayed monsoon conditions and the higher sea level intrusion are probable to lead in more frequent drought and salinization effects (MoEF, 2009; Winston et al, 2010). To this end, Bangladesh is struggling to cope with the current adverse weather conditions while national plans and strategies to respond to the impacts caused by climate change are developed.

The threatening situation and the efforts undergone by Bangladesh are well quoted in a recent report by the International Institute for Environmental Development (2013) "…Bangladesh is the most climate vulnerable country in the world and has consistently been a leader in developing solutions around community-based adaptation to climate change, national adaptation planning and offering political leadership as part of the Least Developed Country (LDC) group, which represents the least developed countries at the climate change negotiations."

We have selected the regions of Rajshahi and Barisal in the northern and southern parts of the country, as the most representative areas suffering from drought and flood-saline occurrences respectively. Within each province, three sub-regions (upazilas) were chosen which could best ascribe these opposite weather patterns' impact on a regional level.

7.3.5 Drought (Rajshahi Region) and flood-saline (Barisal) regions

General Description

In Rajshahi region, the study sites are located in Godagari and Tanore upazilas (lowest administrative unit) under Rajshahi district and Gomostapur upazila under Chapai Nawabganj district. The area is characterized by severe drought and is located in north-western Bangladesh between 88.10^0 to 88.40^0 longitudes and 24.20^0 to 25.00^0 latitudes (Figure 7.2).

The site area receives lower amount of precipitation (1500 mm) than the rest of Bangladesh, while its cropping intensity of 191-262% is more than the national average (180%). The higher cropping intensity may be attributed to the improved and more widely available irrigation facilities (deep tubewells) developed by the Barind Multipurpose Development Authority (BMDA). The number of deep tubewells (DTW) seems to be proportionate with the cropping intensity in the study location; however, the groundwater table is declining alarmingly due to over exploitation (CEGIS, 2013).

The government's rules and regulations for irrigation are seldom followed at the field level in Rajshahi. Lack of groundwater reserves, poor quality seeds, high pest prevalence, low soil organic matter content, and extreme temperatures are the major problems for agricultural development. Also, grazing land has decreased tremendously because of increased cropping intensity while insect pests and diseases have made their appearance more frequently. Of late, brick fields have also been established in place of crop fields. The removal of top soil for making bricks is a great concern regarding future agricultural productivity.

In Barisal region, the study sites are located in Amtoli and Patharghata Upazila (lowest administrative unit) under Barguna disrtict and Kalapara Upazila under Patharghata district. The study area lies between 89.50^0 to 90.24^0 longitudes and 21.46^0 to 22.18^0 latitudes (Figure 7.3). The study areas are mainly bounded by the Bay of Bengal in the South side, Tetulia river in the eastern side of Kalapara upazila, Buriswar river in the western side of the Amtoli upazila, Biskhali and Baleswar river in the eastern and western side of Patharghata upazila, respectively.

The area is characterized by an intermediate amount of rainfall (about 2000 mm) and with a cropping intensity of 173-199%, which is around the national average (180%). The land type of this area is medium low to medium high land, where maximum flooding depth is about 90 cm during the monsoon season.

The study areas are within a polder system, which was constructed mainly for flood protection and to prevent the area from saline water intrusion as presented in Figure 7.4. At present, the sluice gates are not properly maintained and many of them are out of order. Moreover, sedimentation near the sluice gates is increasing day by day, which causes drainage congestion in the study areas.

Seasonal intrusion of saline water is damaging the ecological and hydrological balance of the studied upazilas. Additionally, inadequate saline tolerant varieties, high pest prevalence, lack of farm machinery, and lack of training on modern crop production technologies are some of the other bottlenecks of agricultural development (Biswas, 2009).

7.3.6 Agricultural practices in Rajshahi and Barisal regions

The major crops grown in Rajshahi are rice and wheat. However, currently increasing areas of rice fields are being replaced by mango orchards due to the lower water demand and higher profitability of the mango fruit. This may have significant implications for the future rice production in Bangladesh. The minor crops are potato, tomato, gram, maize, and eggplant.

The major cropping patterns in Godagari was the Boro – Fallow – T. Aman (42%) followed by Boro – T. Aus – T. Aman (38%). Similar patterns were also observed in Tanore area. However, in Gomostapur area the highest coverage was the Boro – Fallow – T. Aman pattern (40%) followed by Boro – fallow – T. Aman (34%).

During the last 15 years, the amount of rainfall and its distribution pattern, temperature and drought duration, has changed unfavorably to growing traditional rice variaties. In the mid-90s farmers mostly cultivated Kalokuchi, Shaitta, Dharial, Sonasail, Mugi, Raghusail, Magusail, Jhingasail, BR10, BR11 and IR20 rice varieties. At present, Pariza, Sada Sawrna, Guti Sawrna, BINA dhan7, BRRI dhan28, BRRI dhan36 and BRRI dhan39 are mostly grown.

Farmers also grow short duration rice varieties in attempt to reduce the effect of drought conditions. Moreover, they are growing tomato, mustard, and potato to minimize the need for irrigation water in the dry season.

In the case of Barisal, rice is the major crop. The minor crops are pulses, potato, chili, mustard, sunflower, watermelon, groundnut and spices, etc. Pulse-Fallow-T. Aman (55%) is the major cropping pattern followed by Winter Crops-Fallow-T. Aman (20%) in Kalapara upazila. In the case of Amtoli upazila, Grass pea-T. Aus-T. Aman (48%) is the major pattern followed by Fallow-T. Aus-T. Aman (24%). The dominant cropping pattern in Patharghata upazila is Fallow-Fallow-T. Aman (40%) followed by Grass pea-Fallow/T. Aus-T. Aman pattern (25%).

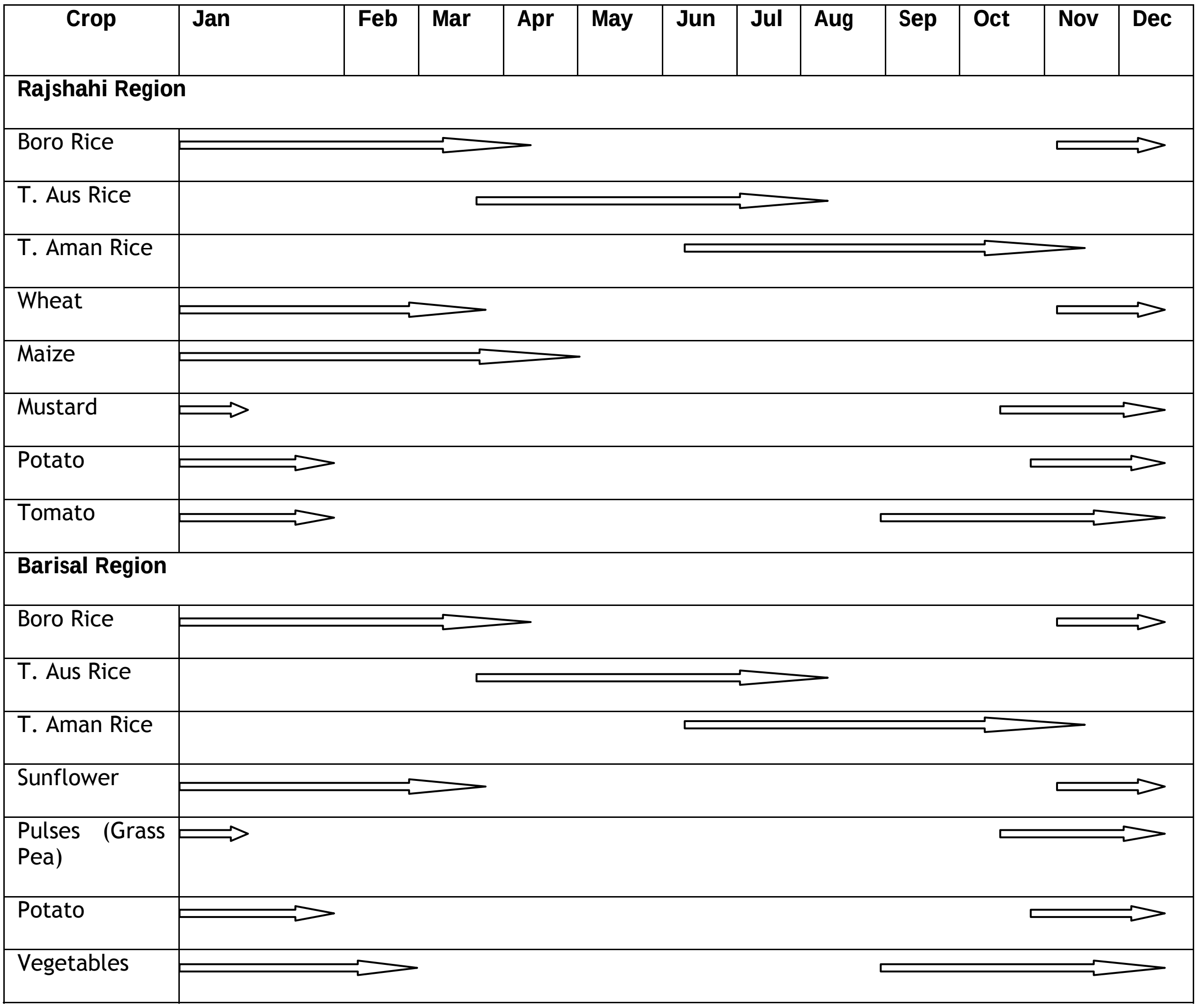


Figure 7.2 The growth period of cultivated crops in Rajshahi and Barisal regions

Alike Rajshahi, change in climate conditions in the past few years have adversely affected rice growing via changes to the rainfall and its distribution pattern, temperature, and drought duration.

Farmers earlier cultivated rice varieties such as Kajalsail, Sadamota, Lalmota, Laxmibilash, Rajasail, Shaitta, Brindamoni, Rangalaxmi, Shitabhog, Kutiagni, Betichikon, Jhingasail, Matichak etc and a few HYV rice varieties such as BR11, BR22. At present, Sadamota, Vajan, BR11, BR22, BR23, BRRI dhan27, BRRI dhan40, BRRI dhan41 and BRRI dhan49 are commonly grown, which cover 60-99% of the land in the T. Aman season and about 90% of the land in the T. Aus season.

The growth periods of different rice and non-rice crops in Rajshahi and Barisal are shown in Figure 7.2. As presented, the boro rice needs longer growth period than the T. Aman rice. Mustard, potato and tomato need comparatively short growth duration. It is further presented that not exactly the same crops are cultivated in both regions due to different geophysical and weather conditions.

7.3.7 Primary and Secondary Data

The primary data was elicited from a household survey analysis conducted in the two regions. In each region, 100 farmers from different farm sizes (small, medium and large) were queried through a random sampling method. The collection of the survey responses was carried out from February to March 2013.

The survey period covered 3 agricultural crop seasons. These are: i) Kharif-I: 16 March to 30 June); ii) Kharif-II: 01 July to 15 October and iii) Rabi: 16 October to 15 March. The survey data covered Rabi/Boro, 2011; Kharif-I, 2012 and Kharif-II, 2012 seasons. The crops cultivated in these seasons are boro rice in October-November to harvesting time April-May, then the aus rice during March-April to July-August and lastly the aman rice in July-August to November-December.

The secondary data was originated from the following sources:

- Scientific publications on socioeconomic and biophysical indicators.
- Bangladesh Meteorological Office (BMO), the Directorate of Agricultural Extension (DAE) and other government publications.
- Internal project reports of the RiceClima project on climate change scenarios, hydrological and crop modelling.

7.4 Results

7.4.1 Crop profitability

The profitability of crop production was examined through the Benefit-Cost ratio indicator as presented in Tables 7.5 and 7.6. In Rajshahi region, non-rice crops were more profitable (BCR ranged from 1.37 to 2.28) than rice crops (BCR ranged from 1.15 to 1.25). Among rice crops HYV boro rice were less profitable than aus or T.Aman rice due to the high irrigation and fertilizer costs associated with boro rice production (Table 7.6).

Table 7.5 Location wise crops grown and gross margin (Tk/ha) in Rajshahi region

Crops	Yield (t/ha)	Sale price (Tk/kg)	Total Variable cost (TVC) (Tk/ha)	Gross return (GR) (Tk/ha)	Gross Margin (GM = GR-TVC) (Tk/ha)	Undiscoun-ted BCR = GR/TVC
Godagari site						
T. Aus (Pariza)	4.28	16.25	61,525	73,830	12,305	1.20
T. Aman	5.13	16.25	70,794	88,493	17,699	1.25
HYV Boro	5.30	16.12	77,552	90,736	13,184	1.17
Mustard	1.07	45.06	33,756	49,284	15,528	1.46
Tomato	21.16	8.25	76,566	1,74,570	98,004	2.28
Wheat	3.66	18.80	52,896	72,468	19,572	1.37
Tanore site						
T. Aman	5.45	16.25	77,060	94,013	16,953	1.22
HYV Boro	5.70	16.12	84,856	97,584	12,728	1.15
Maize	5.40	12.50	41,657	72,900	31,243	1.75
Mustard	1.04	45.06	31,935	47,902	15,967	1.50
Potato	17.84	9.40	78,362	1,67,696	89,334	2.14
Wheat	3.53	18.80	49,924	69,894	19,970	1.40
Gomastapur site						
T. Aus (Pariza)	5.24	16.25	73,488	90,390	16,902	1.23
T. Aman	5.42	16.25	74,202	93,495	19,293	1.26
HYV Boro	5.60	16.12	85,600	95,872	10,272	1.12
Mustard	1.11	45.06	35,753	51,127	15,374	1.43
Wheat	3.51	18.80	47,930	69,498	21,568	1.45

Source: Field Survey, 2013.

In Barisal region, non-rice crops were also more profitable (BCR ranged from 2.10 to 2.75) than rice crops (BCR ranged from 1.18 to 1.30). Among rice crops HYV T. Aman rice was more profitable (BCR1.30) than aus rice (BCR 1.20) or boro rice (BCR 1.8) (Table 7.6). This was happened due to rain fed cultivation practice and use of low doses of fertilizer, which incurred low costs associated with T. Aman rice production.

Table 7.6 Location wise crops grown and gross margin (Tk/ha) in Barisal region

Crops	Yield (t/ha)	Sale price (Tk/kg)	Total Variable cost (TVC) (Tk/ha)	Gross return (GR) (Tk/ha)	Gross Margin (GM = GR-TVC) (Tk/ha)	Undiscoun-ted BCR = GR/TVC
Kalapara site						
Local T. Aman	2.81	16.15	39,502	48,192	8,690	1.22
HYV T. Aman	3.37	15.75	43,422	56,448	13,026	1.30
HYV Boro	4.20	15.50	58,729	69,300	10,571	1.18
Pulses	1.09	35.42	18,385	38,608	20,223	2.10
Vegetables	12.18	10.14	44,911	1,23,505	78,594	2.75
Amtoli site						
Local T. Aus	3.30	16.10	47,025	56,430	9,405	1.20
Local T. Aman	2.70	16.15	37,646	46,305	8,659	1.23
HYV T. Aman	3.80	15.75	50,516	63,650	13,134	1.26
HYV Boro	4.27	15.50	58,713	70,455	11,742	1.20
Pulses	1.18	36.30	19,122	42,834	23,712	2.24
Vegetables	12.08	11.50	52,423	1,38,920	86,497	2.65
Patharghata site						
Local T. Aman	3.45	16.25	48,385	59,513	11,128	1.23
HYV T. Aman	4.60	16.50	64,919	80,500	15,581	1.24
Potato	9.75	12.10	49,989	1,17,975	67,986	2.36
Sunflower	1.80	30.50	22,941	58,500	35,559	2.55
Pulses	1.24	38.67	19,572	47,951	28,379	2.45
Vegetables	10.75	10.75	44,108	1,15,563	71,455	2.62

Source: Field Survey, 2013

7.4.2 Irrigation management

The main source of irrigation water along with the common type of distribution systems. In Rajshahi, groundwater is the main sources for crop irrigation and the supply is conducted with buried pipe systems. Both Deep Tube wells (DTW) and Mini DTW are used for irrigation. In few cases, surface water is used for irrigation purpose in some areas adjacent to the pond and canals.

Conversely, in Barisal surface water is the main sources for crop irrigation. Irrigation water is distributed with open canal systems. However, recently the irrigated agriculture has not become a common practice. The sea intrusion has increased the salinity of the surface waters to that extend that is not suitable for irrigation purposes. Low lift pumps (LLP) are used for pumping surface water usually from small ponds where the salinity is rather low.

7.4.3 Rice diseases and insects

The respondents were also asked about the impact of rice diseases and its incidence level. In both Rajshahi and Barisal regions sheath blight was the most common disease followed by blast. The present incidence level of rice blast was almost similar compared to last 15 years incidence but presently, sheath blight emerged as a major disease for rice because of climatic and ecological variations occurred over this time period.

The respondents were also asked about the rice insects and its incidence level. The farmers' views were almost identical between the two regions. Brown plant hopper (BPH) was the most common insect followed by goll midge. The incidence level of rice hispa was higher in the past but nowadays has been drastically reduced because of unfavourable ecosystem for its development.

7.4.4 PCA Results

The results of PCA suggest that a large amount of the indicators enclosed in the Adaptive Capacity group are satisfactorily explained (66.4%). In particular, 16 out of the 25 adaptive variables are statistically significant and can be identified as potential drivers for the vulnerability levels of each upazila . The crop intensity, the access to housing facilities and the presence of financial institutions are given the highest importance.

In the case of the Exposure and Sensitivity indicators, 14 out of the 19 variables could be well explained (84%) by the PCA analysis as potential determinants. Also, the standardized values of all the variables from each group are presented in Annex 3.

We then assess the overall significance of each indicator through the communality values as presented in Table 7.7. The five most important ones are presented for the Adaptive capacity group while an equal amount is also denoted for the Exposure and Sensitivity groups. For the case of Adaptive indicators, the household's livelihood conditions are most noticeable. It is then, the health and veterinary access as of almost equal importance while the farm ownership is also signified. In the case of Exposure and Sensitivity group, an almost equal merit of significance is attributed to the five most important indicators. Particularly, the indicators related to the yield loss and the irrigation requirements of T.Aus rice crop season are noticed while the annual precipitation and temperature indicators are hinted.

Table 7.7 Significance of Vulnerability Indicators

Adaptive Capacity	Communality Value	Exposure-Sensitivity	Communality Value
Access Tubewell_Lartrine	0.986	Yloss_Aus	0.999
Access Pacca_Electricity	0.986	YL_severe_aus	0.997
Access health	0.986	NIR_Aus	0.997
infr.vet	0.976	P_annual	0.997
Own Farm	0.965	T_annual	0.995

The scoring of the vulnerability levels for each upazilla is derived by the subtraction of the exposure and sensitivity indicators from the adaptive capacity as presented in Figure 7.6. When each group of indicators is separately examined for each upazila, the lowest adaptive capacity is given to **Amtoli** while further aside follows the **Kalapara**, both situated in Barisal region. This could be probably attributed to the **low mean annual income** and the **poor performance of infrastructural indicators** in these two upazilas which seem to hamper the adaptive potential. The **poor infrastructure** could be also in part responsible for the low adaptive capacity score in **Patharghata** upazila while also the **small farm experience** seems to be a contributor. However, the other demographic and agro-economic indicators perform much better in Patharghata than in the two other upazilas of Barisal region and thus there is a better adaptive capacity scoring.

In the case of adaptive capacity indicators in Rajshahi region, **Godagari** upazila seem to score remarkably lower than the other two upazilas but still in higher levels than the Barisal region. This low score seems to be rendered on the **limited access to household facilities (latrine, water, electricity)** while also the **education and crop intensity indicators** perform comparatively lower than the two other Rajshahi upazilas. The high scoring of Tanore and more distinctively Gomastapur appears to be the result of a satisfactory performance in most of the **demographic and agro-economic indicators.**

Reversely, all the **Rajshahi** upazilas attain a remarkably low scoring in the exposure and sensitivity indicators which counterbalances the positive performance of the adaptive capacity. This is much attributed to the **unfavorable climatic conditions for irrigated agriculture** recorded for the last 30 years in Rajshahi which have hindered the potential of higher agricultural production. On the

contrary, the **milder climatic conditions** in **Barisal** region and the much lower need on irrigation have resulted in lower production loss.
Overall, the less vulnerable areas are shown in Barisal firstly by **Patharghata** while closely behind follows **Kalapara** upazila. Unlikely, **Amtoli** upazila although belonging to Barisal region, seems to perform worse than **Tanore** and **Gomastapur** in Rajshahi**.** The scoring of **Godagari** vulnerability is noticeably the lowest among all other upazilas.

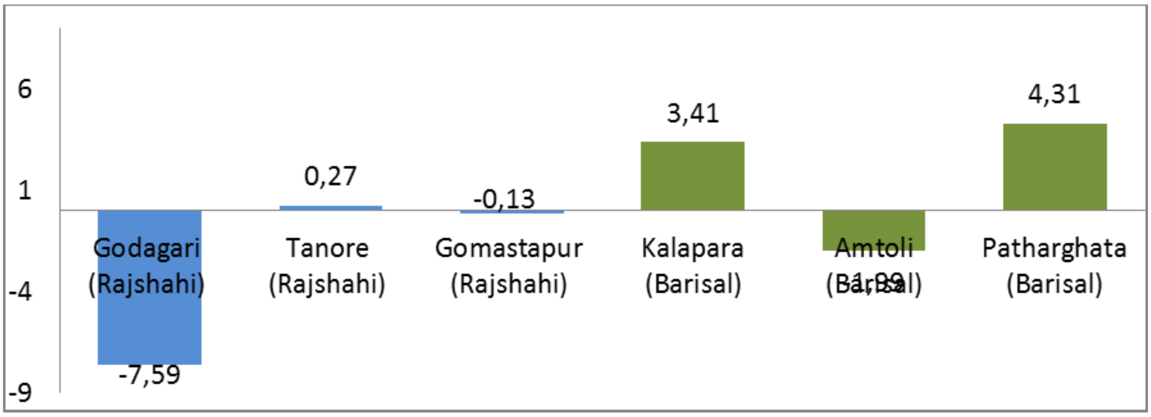


Figure 7.3 PCA Assessment Results.

It is mentioned that the vulnerability scoring between upazilas does not represent an absolute value index but the relevant performance between the areas.

7.4.5 Farmers' preferences

The farmers' preferences for the improvement of their adaptive capacity indicate a strong inclination to the agricultural activities. As presented in Table 7.8, there is a clear indication of intertwinement between the need for farming improvement and the concept of adaptation in a changing climate. Most of the suggestions pertaining to the pricing of agricultural inputs and products while the technological support is also of major importance. Another area of interest is the improvement of infrastructure in irrigation systems on surface water conservation and provision of better groundwater systems. Finally, the access to better seeds and the arrangement of educational seminars in technologies are also suggested as priorities for a better adaptation to climate change.
When the preferences are allocated on an upazila level, it appears that the respondents of Patharghata upazila are in the highest desire of the suggested initiatives and especially the freshwater conservation measures. Broadly, the upazilas belonging to Barisal region are much more interested than Rajshahi in participating to all the relevant suggestions but for water infrastructure. The highest grades amongst upazilas are shaded with greyish color.

Table 7.8 Suggestions for improvement of adaptive capacity

Areas	Suggestions	Rajshahi Region (%)				Barisal Region (%)			
		God.	Tan.	Gom.	Mean Values	Kal.	Amt.	Path.	Mean Values
Market	Availability of agricultural inputs at reasonable / subsidized price (seed, fertilizer, water, pesticides etc.)	65	68	63	**65**	75	68	70	**71**
Market	Ensure reasonable output prices and profitability of agricultural commodities	82	78	84	**81**	82	80	84	**82**
Market	Availability of farm machineries at subsidized price or on rental basis (power tillers, pumps, sprayer, reaper, thresher etc.)	60	63	58	**60**	60	62	68	**63**
Water Facilities	Irrigation infrastructure development (setting of pumps, ensure electricity, improved canal system etc,)	85	82	90	**86**	75	78	80	**78**
Water Facilities	Conservation of water (rain water harvest, embankment, sluice gate, canals etc.)	55	52	65	**57**	95	92	96	**94**
Seeds	Availability of new high yielding and short duration rice varieties	75	72	78	**75**	85	82	88	**85**
Education	Intensive farmers' training on agricultural production technologies	75	78	72	**75**	75	88	72	**78**

7.5 Dicussion

The descriptive statistics gave an overall impression of the agricultural conditions in both regions. Not major differences are presented between the two sites except for the irrigation practices. The irrigation factor appears to play a major role in the production costs of Rajshahi region which is anticipated to get more important in the future because of the decreasing water reserves and the higher drought frequency. Further, the need to confront with the emerging disease and insects' incidences seems to be commonly shared between the two regions.

The PCA results have demonstrated the significance of the adaptive capacity, sensitivity and exposure indicators for the attribution of the vulnerability assessment. In particular, the higher scoring of Rajshahi in adaptive indicators seemed incapable of signifying a better vulnerability status of Rajshahi over Barisal region. The average production loss of Rajshahi in the last 30 years has offset any comparative advantage emerging from the adaptive capacity performance.

There are some methodological limitations of PCA use in the current study. Initially, there is a considerable uncertainty on the appropriateness and relevance of the suggested indicators. This is a broader issue standing on most of the vulnerability assessments irrelevantly to the suggested measurement approach. There is a common understanding that many indicators might enclose a degree of subjectivity in an effort to portray case-specific conditions of vulnerability. We acknowledge these potential biases and as a mitigation effort, we have introduced indicators spotted in other similar vulnerability assessments by attempting to reduce the case-specific ones.

It is also argued that the vulnerability is a dynamic concept and a static assessment like PCA could hardly explain any future changes. To this end, it is firmly explained that we have estimated the present vulnerability levels in each upazila based on the current demographic, agro-economic and infrastructural indicators and past observations of biophysical parameters. Although it is understood that any future observations may not highly deviate from the assessed ones, it is explicitly mentioned that the vulnerability assessment does not represent any future status of the selected upazilas.

However, there is the potential to provide some future vulnerability scenarios based on the performance of the examined indicators. For instance, we have tried to increase the performance of three out of the five most significant indicators for Barisal region only. Namely, the performance of Access to Health, Veterinary and the farm ownership was improved by 30% for each of the three Barisal upazilas. As presented in Figure 7.7, the Vulnerability has been now slightly to moderately improved in the three Barisal upazilas. Such scenario analyses could greatly help the policy makers to understand in which particular indicators should pay attention and invest for a better vulnerability performance.

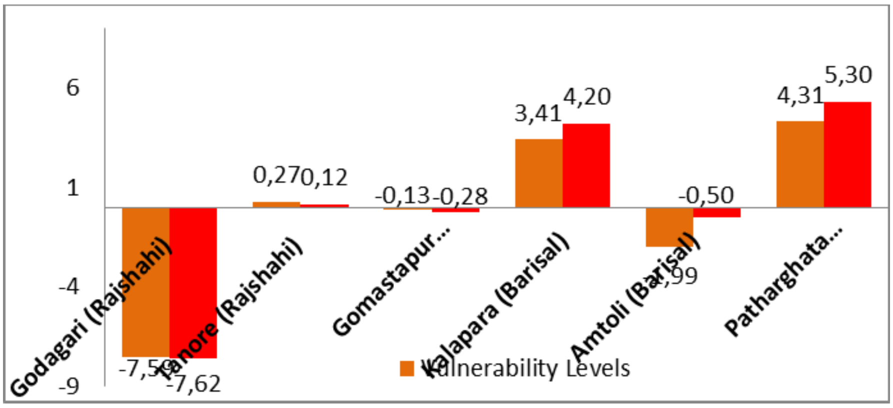


Figure 7.4 Vulnerability Scenarios for Barisal region.

The aforementioned methodological and policy relevant concerns were also met in many similar vulnerability assessment studies. A regional vulnerability assessment in Ethiopia notes the lack and unreliability of primary data (Deressa, 2008). Another vulnerability analysis of rural households in Nepal signifies the importance of scenarios for the identification of agro-economic and infrastructural areas to be improved (Pyia et al., 2012). Other applications of PCA in national trans-national level were enriched with Geographical Information Systems (GIS) in an attempt to overcome the static nature of the results (Abson et al. 2012; Borja-Vega and De la Fuente, 2013).

The farmers' preferences came to signify the need of both regions to invest on agricultural market mechanisms, irrigation facilities, seeds and educational seminars for a better adaptation to climate change. These elements were coincidentally also represented as statistically significant indicators in PCA analysis. For instance, the Mean Annual Income indicator is highly related and affected by the market mechanisms which are suggested by farmers. In turn, the suggested improvements in irrigation facilities are well represented by the Net Irrigation requirements in the Exposure group of indicators. It is mainly that the farmers pointed out some broader interventions that could help in better adaptation while the PCA indicators were focused on specific aspects of these interventions.
It is noted that the suggested improvements by farmers on market conditions seem to mostly target on the increase of their welfare, an objective which is better viewed through a poverty analysis.

7.6 Conclusions

Climate change impacts are already occurring in Bangladesh and is likely to continue with greater severity in future. Those who are most vulnerable to the adverse impacts of climate change are generally the agrarian regions. Therefore, the development of tools to assess socio-ecological vulnerability, such as in this report, could help to identify measures to create resilience and mitigate the impacts of climatic vagaries.

The current study attempted to describe in a quantitative manner the vulnerability status of the drought and saline-flood prone selected upazilas in Bangladesh. Also, some descriptive results and farmers' preferences attempted to better clarify and cross-check the vulnerability assessment.

The findings for the drought prone regions in Rajshshi signified the need to improve the access to household facilities and moreover the urgency for better groundwater management so as to meet the current production loss. In particular, as the groundwater availability is gradually diminishing, HYV boro rice cultivation could be hardly irrigated in the following years. More efficient irrigation schemes should be developed to meet the current demand while better water resistant rice varieties should be introduced. Also, cash crops like wheat, maize, mustard, potato, tomato should be better promoted as a promising response to water scarcity and a more profitable alternative to rice cultivation.

The introduction of cash crop is also encouraged in Barisal region for the improvement of the agricultural income. Moreover, the need for better infrastructure and sound water conservation measures are also prioritized in Barisal region. Also, the education on new technologies in cultivation through training, demonstration and field days is highly desired.

The current vulnerability assessment is a context-specific approach and the data, methods and results cannot be transferred without any proper adjustments to other similar studies.

8. Agricultural interventions and investment options for:

Climate change in drought and saline-flood prone regions of Bangladesh

8.1 Summary

Rice is the staple food in Bangladesh and crucial for the food security in the country. The alluvial soil deposits, through an extensive river network across Bangladesh, have contributed to a fertile land with high rice productivity potential. However, the frequent occurrence of floods, salinity and drought has repeatedly threatened the food security especially in the rural areas. Climate change is anticipated to aggravate the frequency and intensity of extreme weather events in Bangladesh by significantly impacting rice production. Noteworthy studies have proposed potential responsive measures by concentrating either on the technical or economic efficiency of the suggested interventions. To this end, the current report presents an outranking multicriteria approach enriched with a Geometrical Analysis for Interactive Assistance for a better reflection of the appropriate interventions to improve rice production on a farm basis. Further, the investment options needed to implement these interventions are explored. The drought prone areas of Rajshahi and saline prone areas of Barisal regions were chosen for the study. The results indicated that water storage systems were prioritized in Rajshahi whereas the introduction of improved varieties in Barisal was of the highest importance. Also, the training seminars for farmers were deemed as a rather significant intervention for both regions.

8.2 Introduction

Recent studies indicate that Bangladesh is undergoing a rapid economic growth, which is mainly attributed to the manufacturing sector (FAO, 2012). However, 80% of rural population in the country is heavily dependent on agriculture while rice is the staple crop particularly for marginal and small farmers (Islam, 2008). It is estimated that rice occupies almost 77% of the cropped areas, employs 65% of the country's labor force and provides around 95% of the whole food grain production and consumption. The continuous technological and institutional advancements in rice cultivation have contributed to almost a threefold increase in the production during the last four decades (BBS, 2011).

Rice production has been repeatedly threatened by natural disasters like flood, salinity and droughts mainly influenced by the country's unique geophysical and climatic conditions (Nienke et al. 2006). The mountainous range of the Tibetan Plateau is drained through a massive river network spreading all over Bangladesh and finally ending up in the Bay of Bengal. The occurrence of intense monsoonal periods often augments the drainage effects leading to floods mainly in the southern lowland areas (World Bank, 2010). Additionally, saline intrusions are noticed in the south downstream areas, which are attributed to the higher sea level elevation in the coastlands. On the other hand, erratic rainfall along with its uneven spatial and temporal distribution and high evaporating losses in the northwest Bangladesh have entailed seasonal drought events with severe impacts on marginal rice farmers (Ramamasy and Bass, 2007).

The extreme events are anticipated to get aggravated by climate change as repeatedly noted in the literature (Nguyen, 2006; Biswas et al. 2009; Winston et al. 2010). The snow melting in the mountainous areas of the Tibetan Plateau coupled with erratic and intense monsoons are expected to contribute towards increased flooding. Also, the delayed monsoon conditions and the higher sea level intrusion are probable to lead in more frequent drought and salinization effects (MoEF, 2009; Winston et al, 2010). The rice production will inevitably incur significant losses from the extreme weather by threatening the food security status of the country.

The current study proposes a multi-criteria outranking based approach for the assessment of interventions needed to tackle climate change impacts in Bangladesh. The assessment was done through an on-line survey of experts. The study sites of Rajshahi and Barisal divisions were selected as representatives of drought and saline prone conditions, respectively.

8.2.1 Interventions and Criteria

The proposed methodology initially classified the most significant interventions according to the relevant literature, local experts and field visits in the study areas[1]. The interventions suggested were based on already applied measures, which were deemed to improve agricultural productivity against climate change in Bangladesh when adopted at the farm level. Six different interventions were classified namely the land and water mechanization, the introduction of water storage schemes, improved/hybrid varieties, pest and disease control systems and training seminars (Table 8.1).

Table 8.1 Groups and attributes of the Suggested Interventions

<table>
<tr><th colspan="7">Intervention Groups</th></tr>
<tr><td rowspan="2">Water Mech.</td><td rowspan="2">Land Mech.</td><td rowspan="2">Water Stor.Sch.</td><td rowspan="2">Pest and Dis. Contr. Systems</td><td colspan="2">Improved/Hybrid Seeds</td><td rowspan="2">Training Seminars</td></tr>
<tr><td>Barisal</td><td>Rajshahi</td></tr>
<tr><th colspan="7">Individual Interventions</th></tr>
<tr><td>Sprinkle irrigation</td><td rowspan="2">Power Tiller (hand tractor)</td><td rowspan="2">Deep Tubewell</td><td>Physical Pest and Disease Control</td><td>BR22</td><td>BINA dhan 7</td><td>Transplanting and Direct Sowing</td></tr>
<tr><td>Drip Irrigation</td><td rowspan="2">Biological Pest and Disease Control</td><td>BRRI dhan40</td><td>BRRI dhan49</td><td rowspan="2">Surface and Groundwater management</td></tr>
<tr><td rowspan="2">High lift mechanical pump</td><td>Thresher</td><td rowspan="2">Shallow Tubewell</td><td>BRRI dhan41</td><td>BRRI dhan56</td></tr>
<tr><td>Weeding Machine</td><td rowspan="2">Chemical Pest and Disease Control</td><td>BRRI dhan44</td><td>BRRI dhan57</td><td rowspan="2">Early Forecasting for pest and disease control</td></tr>
<tr><td rowspan="2">Low lift mechanical pump</td><td>Seeding Machine</td><td rowspan="2">Blocked Canal*</td><td>BRRI dhan46</td><td>Sawrna</td></tr>
<tr><td rowspan="2">Transplanting machine</td><td rowspan="2">Integrated Pest and Disease Management</td><td>BRRI dhan53</td><td rowspan="2">Guti Sawrna</td><td>Insurance Schemes</td></tr>
<tr><td>Hand-Pump</td><td>Pond</td><td>BRRI dhan54</td><td>Trading and Selling skills</td></tr>
</table>

**Blocked canal is the practice where farmers attempt to store fresh water (either rain or river depending on time suitability) for irrigation in dry periods. The canal blocking is made through natural items (i.e. soil, wood, rocks etc.). Note: Water Mech.=Water Mechanization Systems, Land Mech.=Land Mechanization Systems, Water Stor.Sch.=Water Storage Schemes, Pest and Dis. Contr. Systems= Pest and Diseases Control Systems, Impr./ hyb.= Improved/Hybrid varieties*

Then, a number of agronomic and socio-economic criteria were established, based on a study by Wassman (et al. 2009) as shown in Table 8.2.

[1] The authors have conducted a field visit to selected saline prone districts in Barisal Division in February 2012, while another field visit was arranged in October 2012 to Rajshahi division in drought prone districts.

Table 8.2 Criteria for the assessment of the suggested interventions

Criteria	**Explanatory Note**
Marginal Profits per kilo of rice (Tk/kg)	The marginal profit is the additional amount of net revenues earned by a farmer for one more kilo of rice production, e.g. USD 0.25 $ / kg
Marginal Water Productivity (kg/m^3)	The marginal water productivity is the additional amount of rice produced by one more cubic meter of water e.g. 0.3 kg/m^3
Marginal Land Productivity (kg/ha)	The marginal land productivity is the additional amount of rice produced by one more hectare of land e.g. 3,500 kg/ha
Sense of food security	The sense of food security is interpreted as that the farmer can earn at least daily income equal to the poverty threshold in Bangladesh (USD 1.25$/day) through the use of the suggested farming intervention


Experts' views for Climate change adaptation measures in rice farming

Dear Expert,

Before entering the survey, we present the **representative farming features** for **rice farms in Barisal and Rajshahi Divisions** as stated by the **Bangladesh Bureau of Statistics** for the year **2010** which may help you to better judge the **proposed measures** of the survey.

Rice Farm Features	Barisal Division	Rajshahi Division
Land Farm (in acres)	1,23	1,38
Irrigated area (% of land)	20%	83%
Cropping Intensity (in %)	180%	191%
Total Rice cultivated (% in farm)	Aus 22%, Aman 51%, Boro 27%	Aus 18%, Aman 39%, Boro 43%
Total seeds (% in farm)	Local 71%, HYV16%, Hybrid 13%	Local 21%, HYV 68%, Hybrid 11%
Total Fertilizers (in kg/ha)	UREA 132kg/ha, TSP 92 kg/ha, MP 56 kg/ha	UREA 149kg/ha, TSP 99 kg/ha, MP 62 kg/ha
Land Machinery Used (% of land)	1%	2%
Soil Types	Acid sulphate-Clay Loam	Silty Clay Loam

Please **proceed** with the survey by clicking the **"Next"** button below

Load unfinished survey Next Exit and clear survey

Figure 8.1 Data provided to experts in the on-line survey.

A number of experts were invited to participate in an online survey, where they were asked to evaluate the group of interventions on each of the criteria selected. **Before entering the survey,** representative farming features for rice farms in Barisal and Rajshahi divisions were presented as **stated by the** Bangladesh Bureau of Statistics **for the year** 2010 (Figure 8.1). These features were deemed to help in a better judgment of the proposed measures.

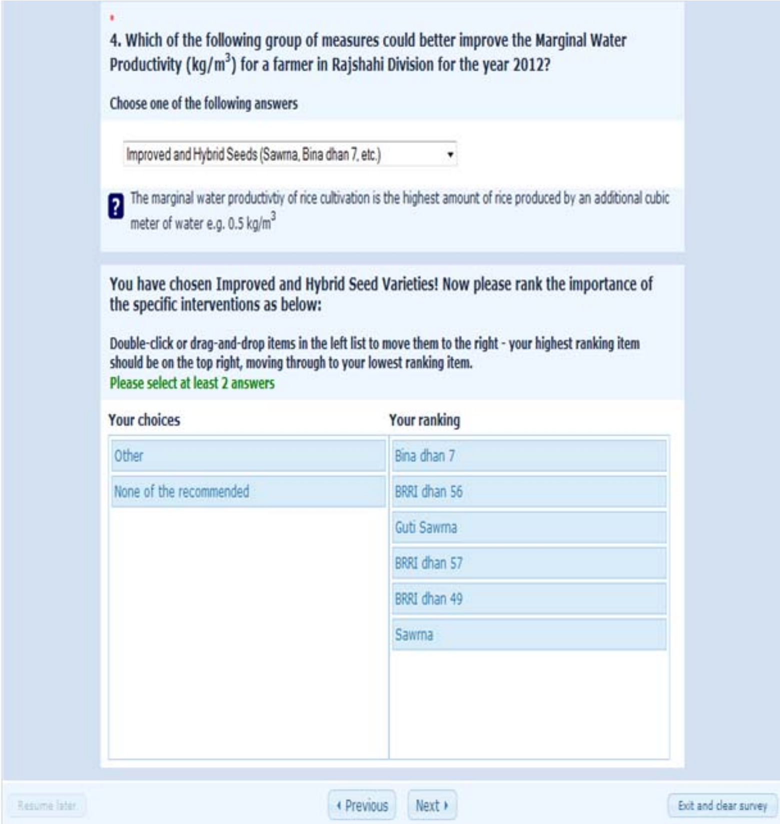


Figure 8.2 Example of agricultural intervention selection for Rajshahi region.

For each criterion, the respondents were asked to make a dual selection. First, the most suitable intervention group to improve the relevant criterion was chosen. Once the group was selected, a follow-up question appeared in which the respondents should rank the particular interventions within the chosen group to improve each criterion's performance. An example of the Improved/Hybrid Seeds group and Water Productivity criterion is presented in Figure 8.2 for the drought prone Rajshahi region.

8.2.2 Visual Promethee structure

The assessment of the suggested interventions was conducted through the Visual Promethee software which constitutes a combination of PROMETHEE outranking method with Geometrical Analysis for Interactive Assistance (GAIA). The Visual Promethee encourages the introduction of weighting coefficient for a better attribution of the significance of each criterion. In the current analysis, the weights are introduced by the respondents through the on-line survey. We suppose that the weights are normalized in such a way that their sum is equal to 1 (100%) as occurs in Promethee outranking methods (Mareschal, 2013). The introduction of GAIA in Visual Promethee was added as a diagrammatic component for the identification of potential conflicts and alliances between criteria. The GAIA is based on the Principal Component Analysis, which is a mathematical tool from applied linear algebra (Shlens, 2003; Farag and Elhabian, 2009). The analysis is a relatively simple non-parametric method for extracting relevant information from complicated data sets. The approach followed is the simplification of the data to a lower dimension analysis through a covariance or correlation computation depending on the nature of the data sets. The GAIA is based on covariance analysis for the identification of the relations between the criteria and the interventions selected in each case. The data for the assessment of the selected interventions were elicited through an on-line survey to experts on rice farming in Bangladesh with considerable knowledge on the anticipated climate change effects in the country (Table 8.3).

Table 8.3 Professional background of Survey respondents (about here**)**

Respondents	Percent (%)	Respondents	Percent (%)
International Organizations & NGOs	31	National - International Universities	22
National Research Institutes & NGOs	34	National Public Administration	13

8.3 Results

8.3.1 Weights, Performance matrix and Ranking results

The weights attributed to each criterion by the surveyed respondents point out the higher significance of the marginal profits for rice farmer as presented in Figure 8.3.

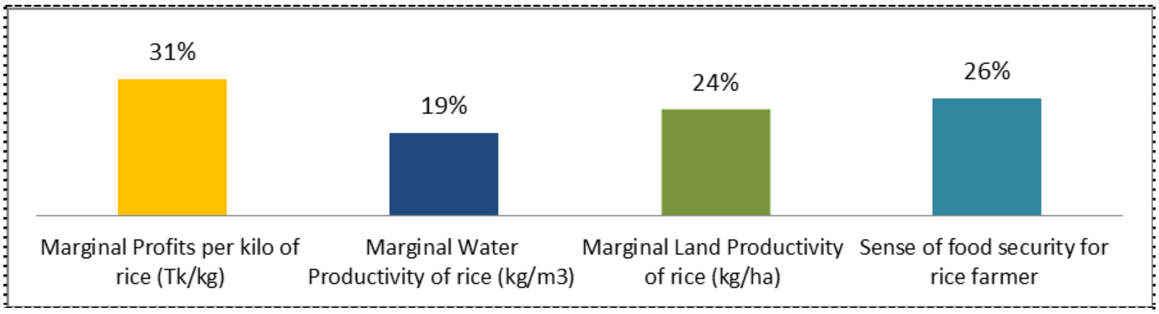


Figure 8.3 Suggested weighting coefficients for the four criteria.

The experts' preferences for the four criteria are presented in the following figures 8.4 to 8.7.

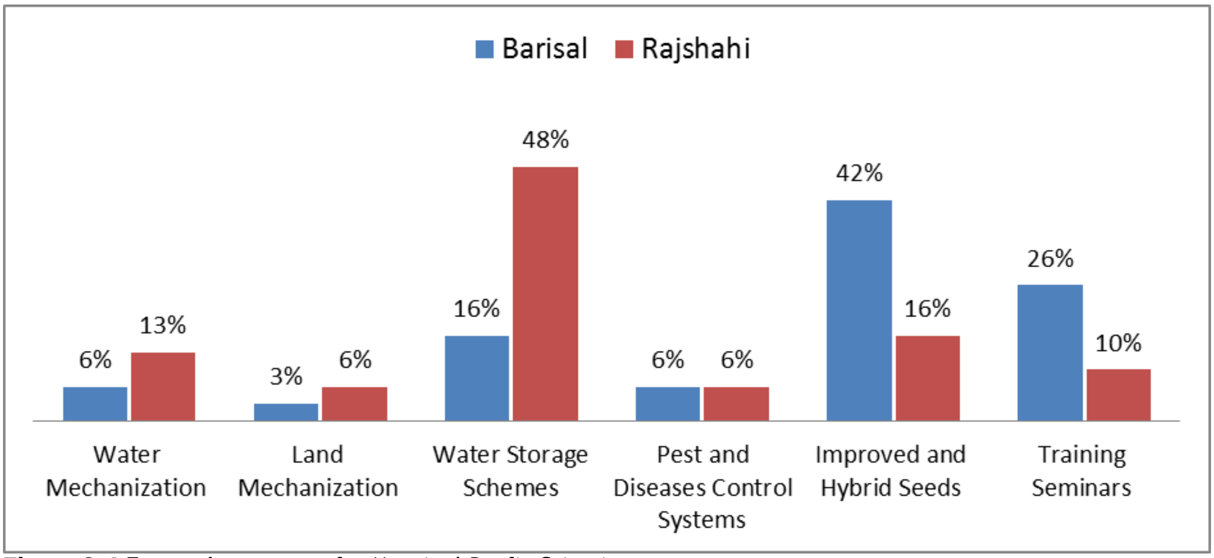


Figure 8.4 Experts' responses for Marginal Profit Criterion.

The support on Water Storage interventions is again discerned for Rajshahi region for the water productivity criterion as presented in Figure 8.5. For the case of saline-flood Barisal, the Training Seminars are now emerging as the most prominent solution with slight difference from the water storage group.

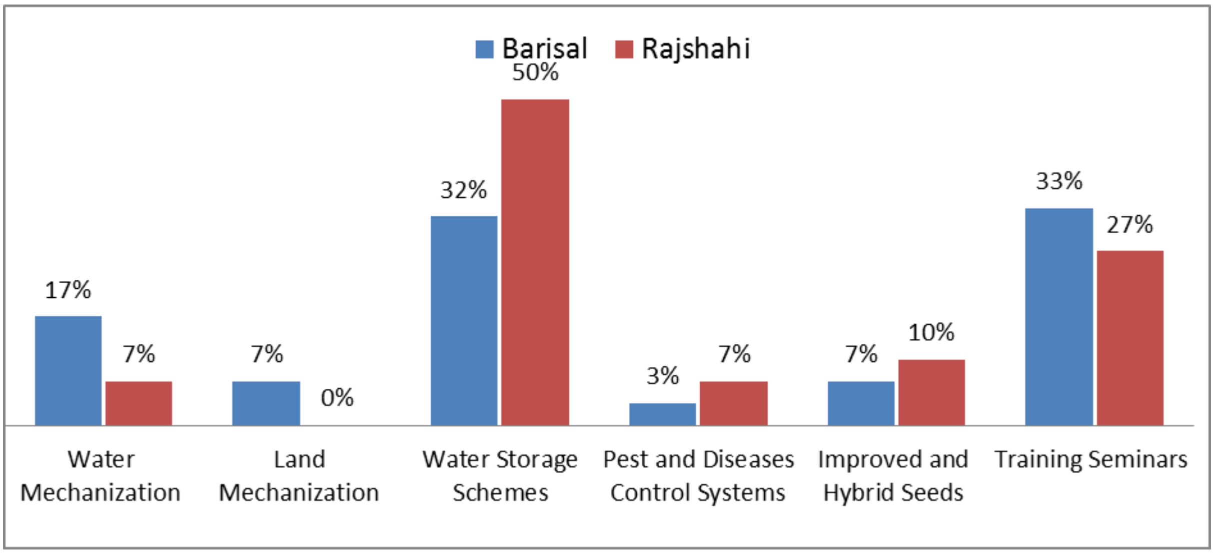


Figure 8.5 Experts' responses for Water Productivity Criterion.

The steady preference of experts on water storage in drought prone Rajshahi is also reflected for the case of land productivity criterion as presented in Figure 8.6. It is noteworthy though that the Improved/Hybrid seeds also take a high share for the Rajshahi region. The Improved/Hybrid seeds also constitute the most favorable intervention group for Barisal region while the land mechanization group is further behind.

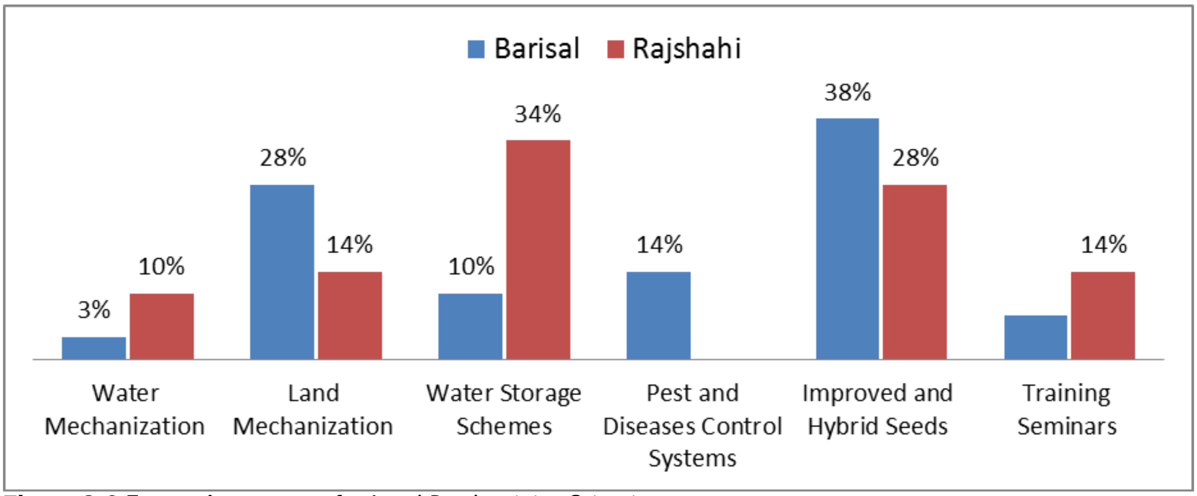


Figure 8.6 Experts' responses for Land Productivity Criterion.

The leading role of Water Storage group in Rajshahi is also well kept in the case of the Sense of Security Criterion as presented in Figure 8.7. However, an almost equal also voting for the Training Seminar groups is noticed for Rajshahi region. In Barisal region, the adherence to Improved/Hybrid Seeds groups is quite apparent since more than half of the experts are in favor of this option.

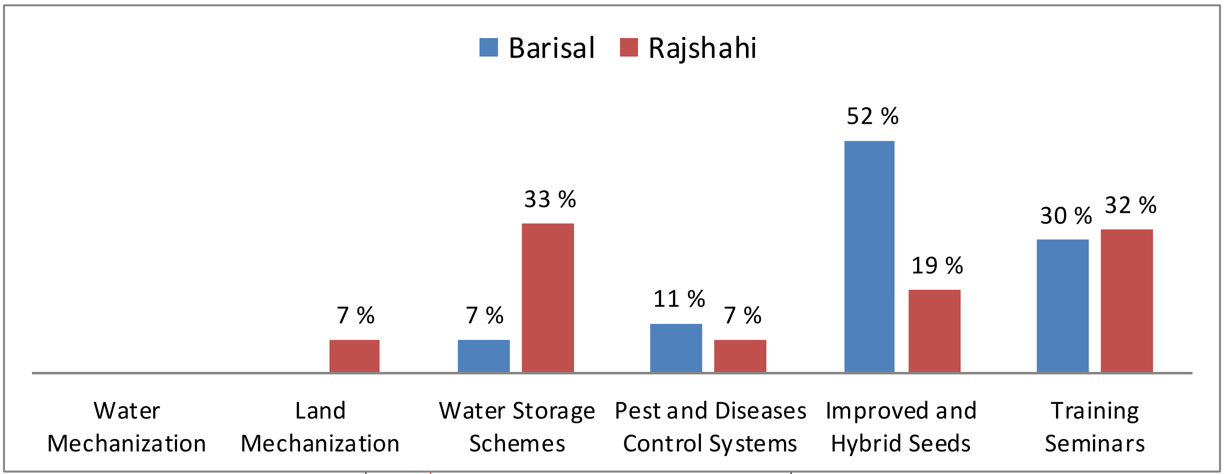
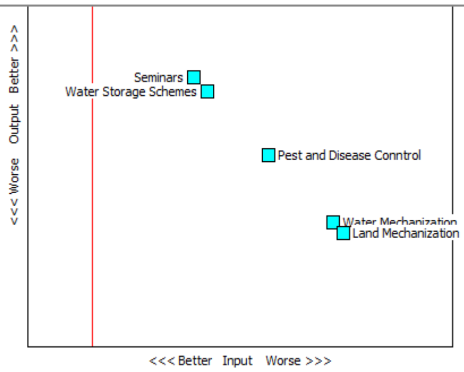


Figure 8.7 Experts' responses



8.3.2 Ranking results c

The Visual Promethee resu ... ed for Barisal and Rasjhahi regions. Visual Promethee ... ent conducted through the pairwise comparisons as i ... e 8.8. The dominance of Improved/Hybrid seeds is ı ... l Water Storage groups are almost sharing the second ... sease Control intervention group while the Water anc ... favorable by the sampled experts.

In the case of Rajshahi region, the Water Storage indicator is suggested as the most prominent option, followed by Improved/Hybrid Seeds and Training. Mechnanization of water management is preferred in Rajshahi than in the case of Barisal.

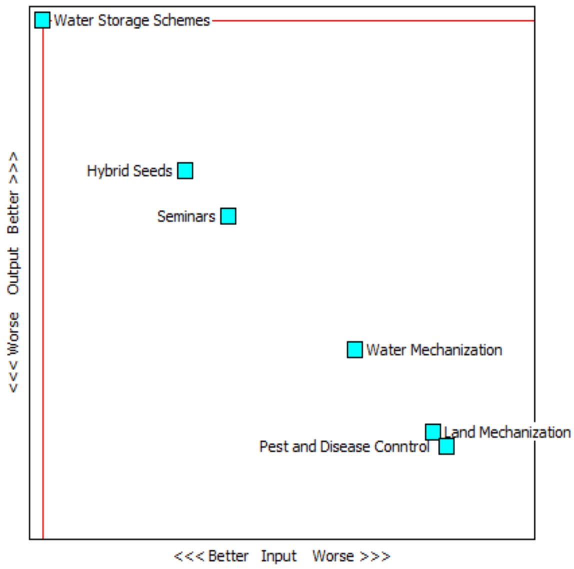


Figure 8.8 Ranking assessment for Rajshahi region.

Also, the individual interventions to be mostly voted in each group are also presented in brackets. For instance, in the case of the flood-saline Barisal region, the Improved/Hybrid Seeds were ranked first and the BRRI dhan 47 was the most favorable variety suggested by the experts. Likewise, the deep tubewell was voted as the most promising specific intervention within the Water Storage group for Rajshahi region. The ranking results of both regions signify the overall importance attributed to the Improved/Hybrid Seeds group by experts and the potential to alleviate climate change in rice farming through better rice varieties.

Table 8.4 Numerical representation of the ranking assessment

Flood-Saline Barisal Region		Drought Rajshahi region	
Group (Particular intervention)	Scoring	Group (Particular intervention)	Scoring
Improved/Hybrid Seeds (BRRI dhan 47)	**0,73**	Water Storage Schemes (Deep Tubewell)	**0,80**
Training Seminars (Surface and Groundwater Management)	**0,31**	Improved/Hybrid Seeds (BRRI dhan 56)	**0,51**
Water Storage Schemes (Blocked Canal)	**0,15**	Training Seminars (Surface and Groundwater Management)	**0,31**
Pest and Disease Control Systems (Integrated Pest and Disease Management)	**-0,21**	Water Mechanization (High lift mechanical pump)	**-0,41**
Water Mechanization (Low lift mechanical pump)	**-0,45**	Land mechanization (Transplanting machine)	**-0,54**
Land Mechanization (Transplanting machine)	**-0,54**	Pest and Disease Control Systems (Integrated Pest and Disease Management)	**-0,66**

8.3.3 GAIA Results

The GAIA results indicate a strong opposition between the marginal and water productivity criteria in Barisal region as presented in Figure 8.10. This suggests for instance that a high performance for marginal land productivity criterion in the case of Land Mechanization group would be offset by an almost equally low performance of marginal water productivity criterion in the same group.

Figure 8.9 GAIA Results for Barisal (left Figure) and Rajshahi (right Figure) divisions.

Similarly, the sense of food security appears to have closer bonds with the marginal profit criterion in Barisal division. For Rajshahi division the sense of food security shifts to a much closer bond with marginal water productivity, which is considerably expected in drought prone areas. A loose relation appears between the marginal profit and marginal land productivity criteria.

8.3.4 Policy Framework for agricultural investments

The last decades, the national policy of Bangladesh has encouraged research and training in rice farming which in turn has boosted the rice productivity of the country. Indicatively, the rice yield rose to 4.3 tons per hectare in 2012 from 1.7 tons per hectare in 1970 (IRRI, 2014).

The development of an adequate policy framework for agricultural investments is much needed. To this end, representative public bodies like the Ministry of Agriculture and the Bangladesh Agricultural Research Council (BARC) are striving to create favorable conditions for the attractions of new investments mainly from foreign funds for the improvement of farming conditions. Some general policies have been already adopted towards this direction as below:

- Investment promotion and facilitation
- Infrastructure development
- Improvement of financial sector
- More responsible business conduct

These principles are also encompassed in the Policy Framework for Investment in Agriculture (PFIA) designed by the Organization for Economic Co-operation and Development (OECD, 2014). In effect, OECD has developed a policy framework which helps governments to evaluate their investment policies, creating an attractive environment for investors and enhancing the development benefits of agricultural investment. Many developing countries in South and Southeast Asia and Africa have already adopted PFIA principles in their agricultural policy and Bangladesh is moving towards this direction. The participation of international organizations, public bodies and research institutes in the development of a policy framework for agricultural investments in Bangladesh has already presented some positive effects in farming sector. Still though, there is much work to be done for the improvement of rural livelihoods given the anticipated climate change constraints.

8.3.5 Ongoing initiatives in rice farming

Indicatively, a series of projects are currently coordinated by BARC for the enhancement of agriculture and livelihoods in Bangladesh which are highly matched to the objectives of our research. The Bangladesh Agricultural Research Council (BARC) is the representative public body to coordinate and supervise national agricultural projects related to farming, welfare and climate change. A major project currently coordinated by BARC is the National Agricultural Technology Project (NATP). NATP is a comprehensive ongoing project with focus on revitalizing the agricultural technology system and increasing agricultural productivity in Bangladesh (BARC, 2014). Similar interventions to the ones assessed in our survey are also scrutinized in NATP project. The overall objective of NATP is to improve national agricultural productivity and farm income given the climate change constraints, with particular focus on small and marginal farmers.

In another instance, the International Rice Research Institute (IRRI) which is a dominant player in rice farming research and development in the world, has a strong presence in Bangladesh. IRRI has set as a foremost priority to cope with climate change in Bangladesh by building the adaptive capacity of farming households and help policymakers to deliver more effective climate adaptation programs. The improvement of farmers' adaptive capacity is sought by various projects through the development of better rice varieties that can tolerate flooding, drought, and salinity conditions. Also, the development of sustainable rice production systems is another parameter for the empowerment of adaptive capacity through the increase of productivity, profitability, and resilience of rice farming. Further, the knowledge sharing through training and capacity building activities is major aspect supported by IRRI in various projects for the improvement of rice farming conditions against climate change.

The initiative currently implemented by different organizations like BARC and IRRI, should be considered upon the up-scaling of the suggested interventions proposed by our study. Also, additional views expressed by national experts should be taken into account. Indicatively, many rice-farming experts from the Bangladesh Rice Research Institute (BRRI) claim that the water storage is the most prominent solution for Rajshahi as hinted in the experts' survey but there are strong doubts about the construction of deep tubewells in the region.

The reasoning for the selection of deep tubewell as the most preferred among the Water Storage Schemes group in the experts' survey, could be probably related with the discernible improvement of rice production mainly caused by groundwater use in this division. In effect, the extensive groundwater use in Rasjhahi has been strongly supported by the Barrind Multipurpose Development Authority (BMDA, 2013) since the early 1990s. The BMDA acts as an independent organization supervised by the Ministry of Agriculture, which develops and coordinates large scale irrigation projects. The BMDA has established extensive groundwater irrigation systems in Rajshahi where the pumping systems are equipped with sub-surface water pipes for reducing evaporation, friction and leakage losses normally observed in the open canals.

However, the rapid increase of individual tubewells together with the higher demand from connected farmers has provoked many incidents of groundwater depletion. These incidents have discouraged BRRI scientists to recommend tubewell as an appropriate option. Instead, the rainwater harvesting through the development of small and medium-size ponds is suggested as the most suitable solution in Rajshahi region in regard to water storage options.

8.3.6 Feasibility study on the implementation of agricultural interventions

A feasibility study has been conducted for the pilot implementation of various agricultural interventions in Rajshahi and Barisal regions in consultation with the results of the experts' survey. The feasibility study suggests the pilot implementation of the three highest-ranked intervention groups of the experts' survey which are the Water Storage, Improved/Hybrid Seeds and Training Sessions. The feasibility study aimed to evaluate interventions that:

- Increase the crop productivity and farm income in the project sites;
- Strengthen the water storage schemes in drought prone Rajshahi,
- Strengthen the high yielding variety (HYV) seed production schemes in saline and flood prone Barisal
- Improve technical knowledge farmers on crop production

The technical, economic and logistic aspects of implementation were considered for different interventions in both regions. A detailed analysis of these parameters is presented in Annex 1. In brief, the following interventions are proposed for the case of Rasjhahi:

1. Rainwater harvesting through the construction of small-size reservoirs (ponds) (estimated cost per pond, $ 1,200 USD)
2. Distribution and cultivation of improved seeds for different rice varieties and other cultivations (estimated cost for a 54ha area, $ 17,000 USD)
3. Arrangement of seminars on crop production, pest and water management (estimated cost for the training of 540 farmers, $ 2,300 USD)

Similarly, for the case of Barisal the following interventions have been proposed by the feasibility study as below:

1 Distribution and cultivation of improved seeds for different rice varieties and other cultivations (estimated cost for a 54ha area, $ 17,000 USD)
2. Arrangement of seminars on crop production, pest and water management (estimated cost for the training of 540 farmers, $ 2,300 USD)
3. Development of Blocked canals (temporary and permanent), sluice gate repairing, re-excavation of irrigation canals (estimated cost, $ 22,000 USD)

The feasibility study has adopted some representative indicators (World Bank, 2014) for the performance evaluation of the suggested interventions as presented in Table 8.5. These indicators could roughly estimate the potential improvement of major agricultural production parameters when the suggested intervention would be applied, as below:

Table 8.5 Evaluation of the potential improvement through performance indicators

Indicators	Performance (in %)	
	Rajshahi Region	Barisal Region
Increase in yield of selected crops	20-25	15-20
Increase in labor productivity	10-12	6-12
Decrease in production costs of selected commodities	6-10	5-8
Increase in volume of processed agricultural products	20-25	15-20
Increase in value of agricultural output	6-12	5-8

The fluctuation of the performance in each indicator is related to the implementation conditions of each intervention.

8.4 Discussion

This study has shiwn the need to promote the cultivation of improved/or hybrid seeds in the flood-saline prone Barisal region. The favor of the experts for the improved/hybrid seeds in Barisal could be in part justified by the recently encouraging field experiments in south Bangladesh for saline resistance varieties. Currently, the rice growth on soils with high salinity levels in southern Bangladesh can be hardly achieved and if harvested the rice is of poor quality for self-consumption and market exchange use (Deb, 2008). To this end, a series of saline resistant varieties have been lately released from the Bangladesh Rice Research Institute after a long standing cooperation with international organizations (BRRI, 2013). BRRI dhan 47 is a representative improved variety, which can tolerate high salinity levels at seedling stage and during the whole cultivation period. The initial cultivation of BRRI dhan 47 has indicated that a rice yield of almost equal quality and volume with non-saline cases can be produced by providing farmers food security and a sustainable income (IRIN, 2013). This could be useful to farmers located in areas vulnerable to saline intrusion in Bangladesh.

However, there have been many instances where the salinity levels have become so acute along the dry season (October-April) that even the most adaptive seeds can hardly grow. To this end, supplementary mitigation techniques should be also introduced. The canal blocking proposed by the experts' survey and the feasibility study is a supplementary mitigation technique which however may entail undesirable economic and health-related effects if improperly applied. In effect, the blocking of irrigation canal may obstruct the flow to the water-dependent rice crop and result in conflicts among farmers. Also, the stagnant water tables at the soil surface are reported to have increased the incidence of water borne diseases in local communities (BRRI, 2013). To this end, the development of canal blocking practices should be cautiously designed by experienced rice-farming scientists in cooperation with regional agricultural extension officers.

A promising large scale mitigation measure applied until two decades ago was the operation of a polder system for flood protection in the monsoonal (rainy) period and saline water intrusion in the dry season. At present, however, the sluice gates are not properly maintained and many of them are out of order. The polder revitalization could alleviate the current flooding and moreover saline impacts by offering a promising response to climate change as also suggested in the feasibility study. The polder system was not assessed by experts in the current study since it was only existent farm-level practices that were evaluated. By pondering, however, the solutions to be suggested at a regional level, the polder revitalization could be a costly but promising investment for the flood-saline Barisal region.

In the case of Rajshahi, the selection of deep tubewell as the most preferred among the Water Storage Schemes group, could be probably related with the discernible improvement of rice production mainly caused by groundwater use in this division. Nevertheless, an increasing competition for the same groundwater resources is currently noticed between the BDMA irrigation system and the rapid drillings of individual farmers. This competition has accordingly increased the groundwater abstraction rates by also lowering the water level to an alarming extent. In effect, the in-built BDMA pumps have sometimes failed to deliver groundwater from lower depths than 80m for which they were originally designed. The recent groundwater scarcity incidents have requested BDMA to establish better groundwater conservation practices while other water storage techniques like rainwater harvesting are well encouraged (BMDA, 2013).

The high credit given also to Rajshahi for the introduction of Improved/Hybrid seeds indicate the need for higher focus on the imminent release of more adaptive varieties. Also, the high preference for the groundwater management seminars in both regions is another spotlight to be well considered for rice farming improvement against climate change effects.

8.5 Conclusions

The current study has indicated the most prioritized interventions to be taken against climate change in Bangladeshi rice growing areas prone to drought and salinity events. The suggested methodology managed to evaluate a wide range of agricultural interventions through a transparent and user-friendly approach. The input of stakeholders' views has provided valuable feedback for the empowerment of the study findings. The presentation of the current policy framework and the ongoing activities in agriculture offers a broad framework on the challenges and constraints to be met upon application of the suggested interventions.

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