



Improving water use for dry season agriculture by marginal and tenant farmers
in the Eastern Gangetic Plains

**Agricultural innovations for water security
in North West Bangladesh from institutional, gender,
food and livelihood security perspectives.**

Working Paper

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1. Executive Summary

Study objectives

The research conducted in Bangladesh that constitutes this report, is part of a project that seeks to test technological adaptation to seasonal water stress and more recent stresses induced by climatic change in the States of West Bengal and Bihar in India, and Saptari District in Nepal. Bangladesh is seen as a potential source of learning in view of ongoing experiences of technology adoption in Bangladesh to adapt to these challenges. This report therefore highlights existing technological and institutional innovations in improving water security for food production in North and Northwest Bangladesh, and their production and socio-economic impacts from the perspectives of different stakeholders, especially differently capacitated farmer groups and women. Data was collected through a literature review and qualitative interviews from five villages distributed in Rangpur, Thakurgaon and Rajshahi districts between May 2015 and March 2016.

Diversity in agro-climatic conditions in Rangpur, Thakurgaon and Rajshahi

The contrasting agro-climatic contexts between Rangpur and Thakurgaon on the one hand, and Rajshahi on the other, are important to acknowledge in terms of adaptation. While rice remains the dominant crop in all three districts, and groundwater the main source of irrigation, Rangpur and Thakurgaon exhibit significant similarities by way of relatively good groundwater tables in the dry season, supported by relatively high rainfall (2000-2500mm annually) and recharge. This is especially the case in Rangpur where farmers supplied by Deep Tube Wells (DTWs) as well as Shallow Tube Wells (STWs) receive sufficient irrigation year round. Two important differences in Thakurgaon are that STW users in the study sites struggle to access sufficient irrigation for dry season Boro rice. In fact, in the village with only STWs, these are now virtually redundant, seemingly because of the drawdown in aquifer levels in this season by the DTWs. The operating context in Rajshahi and especially in the Barind area is significantly different, with lower groundwater tables, significantly lower annual rainfall (1500-2000mm), lower recharge rates, greater elevation variation in the landscape contributing to higher levels of drainage and higher temperatures. In fact, declining groundwater tables in many parts of Rajshahi now exceed the reach of STWs at 15.0 – 20.0m. These factors combine to generate severe drought conditions and significant water stress throughout the year, as opposed to seasonal water stress in the other two districts primarily in the main Kharif period. Despite better agro-climatic conditions, groundwater levels in Rangpur and Thakurgaon has also dropped from the 0-5.3m to the 5.4-7.6m, though such levels not represent an issue in the short term at least, given water tables remain within the reach of STWs.

Emerging climatic stresses threaten to alter existing agro-ecological contexts, and increase reliance on groundwater irrigation

Rainfall in Rangpur and Thakurgaon is observed to have changed. In Rangpur, farmers observe less rainfall events in a year and less rainfall overall. The monsoon begins early, with large intervals in rainfall during what should be the rainfall period. Inconsistent rainfall especially in the Aman season disrupts the alignment of land preparation and transplanting with rainfall, forcing farmers to transplant using irrigation. Irrigation is also used during parts of the growing period where there is further rainfall failure, with an estimated 25% of the water requirement for Aman now sourced from groundwater. In Rajshahi, rainfall has been low and irregular in the past 2-3 years, with uneven distribution of rainfall during the rainy season causing frequent crop damage. This is exacerbated by high temperature spikes and low temperature in all the study sites. In Thakurgaon, an increase of pests has also led to loss especially during the Aman and Boro seasons.

Convergence of agro-climatic change with a policy of rice self-sufficiency drives pressure on groundwater

As the dominant crop in Bangladesh, it accounts for 93% of the increase in gross cropped area, and 77% of gross irrigated area in the country between 1990 and 2010. These developments, and an increase in yields due to modern varieties, have underwritten Bangladesh achieving its policy of rice self-sufficiency in light of a rapidly growing population. Groundwater has played a pivotal role in supporting both the expansion of irrigated area and the large-scale adoption of irrigated Boro rice varieties with a yield approximately twice that of Aman and Aush varieties. This is important also because land area available for cultivation has declined driven mainly by the expansion of village populations. Today, 80% of the Boro rice crop is groundwater irrigated which accounts for almost all the consumptive water use of rice through irrigation, and supports 57% of total rice production. The northern and northwestern regions have been particularly important as centres of intensive Boro cultivation.

Adaptation through water supply augmentation as a standard response

Ensuring a secure supply of irrigation has been the traditional approach to addressing scarcity through expanding frontiers of water resource exploitation with the aid of technology developments. In the study areas, this began with the wide adoption of diesel and more recently electric STWs and emergence of water markets, following government policy to liberalize markets for inputs including irrigation that enabled a shift to farmer driven investments. In stark contrast to this project's sites in Saptari (Nepal) where lack of irrigation remains a primary production constraint, the well-developed informal water markets in the Bangladesh study areas ensure access to irrigation for even the most marginal farmers who could not afford a STW themselves. Also noteworthy is that at no point was it indicated that the water fee was exploitative. As such, STW-driven water markets continue to be of critical relevance for small and marginal farmers. Moreover, that the water seller is also entrusted to irrigate his clients' fields suggests a high level of social capital underpinning these arrangements. From a cost perspective however, STWs suffer from low efficiency which rarely exceeds 25%, resulting in the irrigation cost from a diesel STW accounting for approximately 57% of the total production cost of Boro rice, with this figure at 42% for electric STWs, with observers predicting these costs to increase, further eroding the profitability of irrigating Boro rice with an STW.

Further technological and institutional innovations led to a shift in government emphasis towards DTWs, first diesel and then electric, through government-sponsored programs. Electric DTWs arguably represent the most important water-sector adaptation linked to achieving rice self-sufficiency to date. They provided a buffer against surface water scarcity and errant rainfall, enabling full irrigation of Boro rice and supplementary irrigation to Aman and Aush rice and irrigation of other field crops. This has enabled a three-crop calendar in DTW command areas and vastly increased cropping areas and intensities, along with yield increases. The net result has been an additional estimated 5 million MT of food grains per year from areas supplied by DTWs established by the Barind Multi-purpose Development Agency (BMDA). Water conveyance through underground pipes also minimizes evaporation losses, and is estimated to have enabled an additional 20,000 MT of food grain production annually. DTWs have also almost halved the cost of irrigating rice, and have significantly reduced the time taken to irrigate, although farmers claim the higher discharge rate causes non-rice crops to be over-irrigated affecting yields. The smart card system attached to the DTW has also made irrigation more accessible to women who also no longer need to bargain which were earlier necessary with diesel pump owners - important in light of male outmigration. The dispersed nature in which farmers' land parcels are distributed also means that the large command area ensures some equity in who is served by the DTW, as well as access to irrigation. By replacing STW-based water markets, DTWs provide a uniform irrigation cost to large and marginal farmers alike. Agricultural profits have

consequently doubled for farmers with access to a DTW, freeing up funds for other investments for in household wellbeing.

Differentiated groundwater scenarios and divergent farmer fortunes between those served by STWs and DTWs

However, farmer interviews in each district have generated three distinct scenarios with respect to the condition of groundwater. Farmers in Rangpur supplied with DTW water have experienced any serious irrigation issue, though they are aware of a seasonal drawdown when Boro rice is irrigated. In contrast, farmers using STWs outside the DTW command area experience declining water discharge from STWs pumps towards the end of the Boro season that increases irrigation costs. In Thakurgaon STWs stop working in March-April (Boro season), and damage to their pumps is common. This obstructs timely supplementary irrigation for Aman rice, as rainfall becomes more unpredictable. The same issue occurs with Boro rice and Rabi crops such as potato, wheat and maize, causing lower yields and increased irrigation costs that farmers estimate result in a BDT 30,000 – 40,000 (USD 354 – 471) loss in annual earnings. Domestic hand pumps in most villages also struggle in March-April. In Rajshahi, where STWs and domestic hand pumps are now redundant, the DTW in the study site breaks down increasingly early in the Boro season. The decreased discharge rates from the DTW has increased irrigation costs by an estimated 300%. This suggests the benefits provided by DTWs are time-bound and that this adaptation itself may now be a driver of further water stress. As groundwater tables are driven further down, a major finding of this report is the inequality this may be creating between farmers who do and do not have access to a DTW. This includes farmers of the same village, some with more and less land within the DTW command (intra-village), and between villages with and without a DTW (inter-village) where STWs' utility especially in the Boro season, is either faltering or virtually useless. Needless to say, such divergence in water security in the dry season also brings divergent fortunes in food security, income and other secondary aspects of human well-being in rural areas still heavily dependent on agriculture.

Challenges to promoting demand side adaptations in Rangpur and Thakurgaon

In Rangpur and Thakurgaon, the primary adaptation measure is clearly the use of more groundwater primarily for Boro rice but also to supplement irrigation for Aman rice. Yet, by re-enforcing water security, farmers see little need to reduce crop water demand, and their focus in Rangpur and Thakurgaon remains squarely on rice production – i.e. a 'business as usual' scenario. This is the case even for farmers outside DTW command areas despite some seasonal difficulties in irrigating Boro rice. These farmer perceptions and attitudes contrast with the DAE's evolving strategy in Thakurgaon district where it now operates on the principle of minimum groundwater use by promoting crops with a minimum water requirement, including Aush rice in place of Boro rice as it consumes 50% less water. Replacing Boro with non-rice crops is however proving to be a challenge given the relative ease of cultivating rice. Some crops such as potato also involve high risk given its susceptibility to disease.

Adaptations to reduce water demand in Rajshahi

The greater diversity in adaptive technologies in Rajshahi to water stress reflects the stronger biophysical imperatives at play. Adaptation is thus not a new phenomenon, with crop diversification and substitution in response to seasonal groundwater availability, rainfall variation and topography being distinctive features of farmer behavior and farmer-extension interaction. Agencies such as the BMDA, Bangladesh Agriculture Research Institute (BARI) and Department of Agriculture Extension (DoA) play important roles through research and development on crops and conservation agriculture practices and in-situ demonstration in villages. Farmers especially in the Barind area are well aware that DTWs are only a temporary measure, and therefore believe demand side measures are critical for managing this evolving water security scenario. Farmers and these agencies share the belief that

the largest potential for reducing crop water demand lies in replacing the traditional summer Boro rice crop with wheat and other high value crops that also increase farmer income. It makes room for another crop such as a pulse into the cropping mix. BARI promotes crop combinations based on crop water demand for specific seasons. Crop combinations across seasons are also driven by consideration of inter-crop relationships. Farmers are therefore encouraged to grow Nitrogen fixing legumes after wheat and prior to Aush rice. A scientific approach for optimal land and water use through crop choice is however disrupted by other critical practical considerations, especially the perceived profitability of suggested crops. Potato has been widely adopted given its profitability, which reflects developments in markets whereby it is increasingly sought from poultry and dairy farms and export markets, and the availability of affordable cold storage services, which allows farmers to withhold part of their crop until prices increase. Crop diversification and substitution is more prevalent amongst the larger and medium farmers who have more land and investment capacity for fruit orchards interspersed with crops that are more traditional. Many such farmers are also entrepreneurs and rarely depend on farming alone for income. Diversification notably occurs typically on land that does not receive DTW water, or where irrigation flows from DTWs are no longer reliable.

Despite the availability of new crop varieties bred in-country that possess drought tolerant and/or high yielding properties, large scale changes in cropping patterns is however still challenging mainly because farmers are not convinced of price stability in local markets, and over-supply remains a risk at local level if many farmers adopt the same crop. The large in-country supply deficits at national level for many non-rice crops suggests the need for better distribution systems. Local markets are also plagued by inequality between farmers and buyers (wholesalers, millers) which translates into low purchasing prices, and underpinned by a seeming absence of state support for collective farmer action such as cooperatives.

Following profitability: land use conversion from rice to fish culture

Adaptation in Rajshahi recent years is also characterized by the replacement of some rice fields with fishponds as a dual livelihoods strategy to generate income from both fish and cropping. Rising local fish prices makes fish culture 150%-300% more profitable than Boro rice, and at least twice as profitable as any other crop. Various permutations of fish and fish-rice appear to exist. In some cases, a pond owner may focus on fish only, managing the pond himself or leasing it to a third party. Others use some pond water to irrigate their own cropland or sell irrigation water to neighboring farmers through informal arrangements. Large ponds are however only feasible for the larger farmers, with small and marginal farmers benefiting only if they can purchase irrigation water. Fruit orchards are also the domain of the large farmer.

Conservation agriculture impeded by a paucity in modified mechanisation

Reducing crop water demand through water saving land management practices such as strip tillage and zero tillage to maintain residual soil moisture, can be considered as a relatively new frontier in adapting to water stress. Their scientific nature, farmer unfamiliarity and the need for specialized equipment to offset labor and temporal trade-offs for adopters has required considerable investment in collaborative in-situ trials with farmers, especially by BARI. Although these technologies can reduce irrigation costs by about 50%, and field trials may alleviate risk perceptions, the difficulties faced in supplying high quality labor saving equipment in sufficient numbers represents a critical barrier to converting demonstration and farmer interest to widespread adoption in Rajshahi. Consequently, adoption of these tillage techniques are estimated to be only around 10%, though interest levels of farmers suggests more would adopt if the machines are available. Thus, in-country capacity for manufacturing good quality machines at affordable prices. Another issue, even if machines are available, is that farmers are not used to collaborative problem solving. This presents a barrier to co-ownership arrangements that could reduce the per farmer investment in machinery. A lack of trust is

presented as the underlying cause, and reflects more general discussions around collective action in FGDs with farmers in all districts. This lack of collaboration or collective action thus emerges as weakness in the social capital and local institutional landscape in terms of sourcing adaptive technologies as well as addressing the challenges of local oligopolistic markets for their produce.

Adaptation is a multi-scale, multi-strategy and multi-actor process in Rajshahi

Other adaptation actions away from farm level have also been driven by government, such as the range of surface water supply augmentation activities (e.g. check dams, rubber dams, water diversions) and tree planting to improve microclimates by BMDA. The unique multi-dimensional, multi-scale and multi-actor nature of the BMDA's structure and operational approach, as described in this report, reminds us that adaptation needs to be a multi-scale, multi-strategy and multi-actor process. Interviews with other agency officers such as from BARI and the DAE also indicate a shared emphasis in collaborative adaptation between themselves as well as with farmers in Rajshahi.

The existence of a semi-autonomous, yet state funded institution such as the BMDA specifically created to address water scarcity and related agricultural constraints, working in tandem with other state agencies represents an institutional context an order of magnitude more enabling than a purely sectoral approach to addressing water scarcity and climate change that are inherently multi-sector in their impacts. BMDA's structure and wide-ranging mandate enables the integrated and multi-scale programs and institutional collaboration necessary for effective adaptation. This institutional innovation appears to be a key factor in the diverse adaptations occurring in Rajshahi, along with the openness of farmers to change where options for water supply are dwindling.

The equal emphasis to demand and supply side adaptive measures in Rajshahi through BMDA is also important given the absence of a single governing authority responsible for the management of groundwater that can transcend administrative scales and focus on long-term sustainable resource management. Reigning back groundwater consumption will require more imaginative approaches than through direct regulation. More collaborative approaches are likely to be more successful in address farmer attitudes and perceptions such as their belief that applying more water leads to higher yields, and in incentivizing farmers to adopt such technologies. Developing strong output markets for alternative crops is another major need if investments in on-field adaptation are to bear fruit.

2. Objectives

This study was based on the hypothesis that compared to the Eastern Gangetic Plains of Nepal and India, a more advanced range of technologies have been adopted in Bangladesh to adapt to seasonal water stress as well as more recent stresses induced by climatic change. We thus set out to identify these technologies, and analyzing the institutional and socio-economic conditions of successful agricultural innovations in Northern and Northwest Bangladesh, with a view to identifying potential learnings for Nepal and India.

Our findings are based on a literature review and qualitative interview data generated during fieldwork in two villages in Rangpur and Thakurgaon districts in northern Bangladesh from May 17th to 28th, 2015, and in four villages in Thakurgaon and Rajshahi districts from 27th February to 6th March 2016. The objective was to select and examine three villages as case studies to function as learning sites for the “Improving water use for dry season agriculture by marginal and tenant farmers in the Eastern Gangetic Plains” project. Data from these sites were supplemented by visits to other villages that represented different contexts for purposes of comparison. While the testing of novel technological and social approaches for improving farmers’ water security is envisaged in Nepal (Saptari, Terai) and India (Cooch Behar, West Bengal and Madhubani, Bihar), the component in Bangladesh focuses on learning from existing innovations for engendering greater water security amidst seasonal water scarcity and climate variation. The findings from Bangladesh may inform strategies adopted in Nepal and India. The research in Bangladesh therefore focuses on the following closely related research questions, while also seeking to contribute to policy discourses on food security and groundwater management in Bangladesh (**Error! Reference source not found.**).

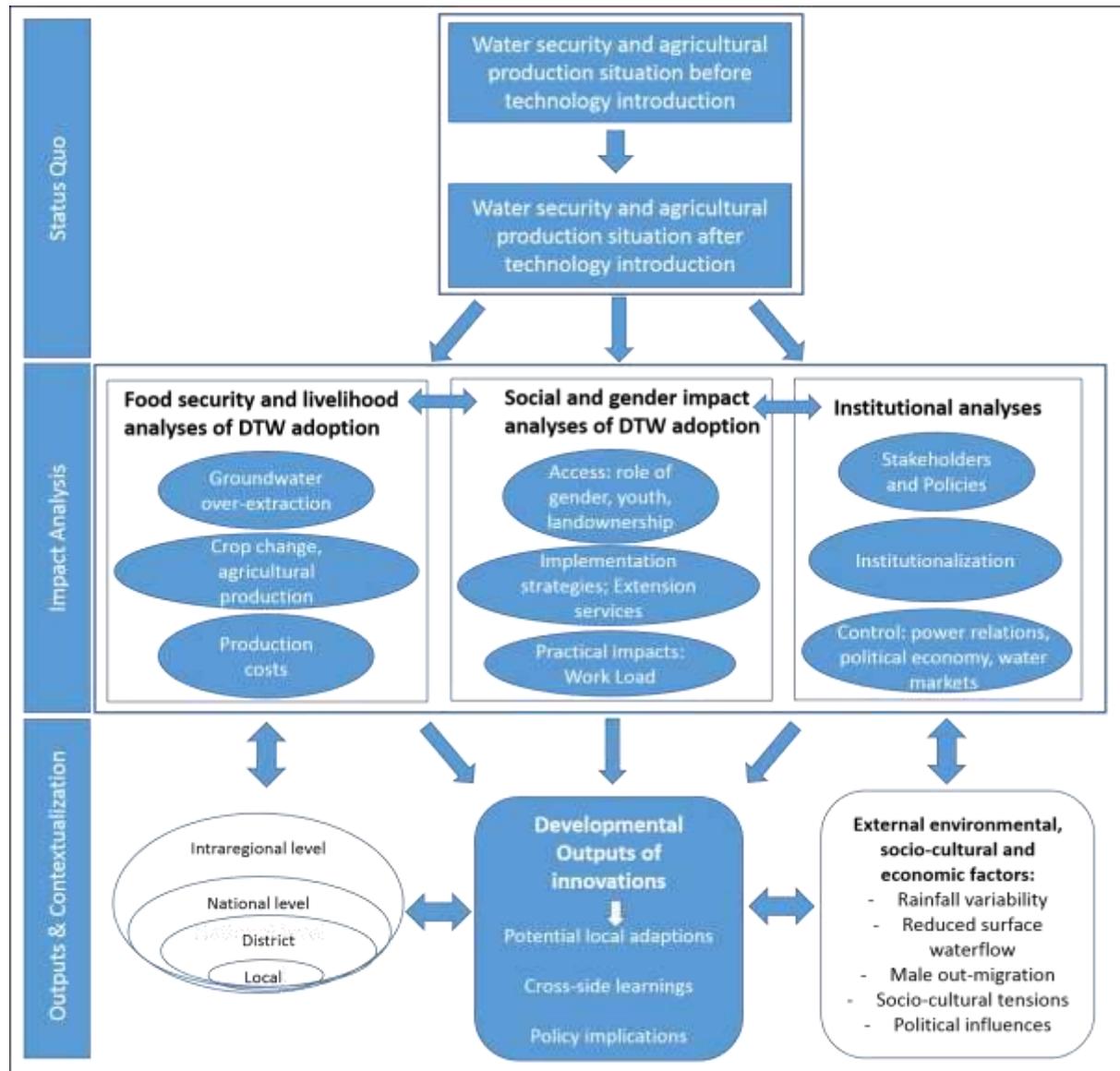
Figure 1: Research questions for this study

1. Which technological and institutional innovations in improving water security for food production in Northwest Bangladesh have been introduced (to the sites) by whom and how?
2. How far were these innovations adopted successfully and what are the impacts of these innovations from institutional, gender, equity and food and livelihood security perspectives?
3. In addition to the impacts of each innovation, what can we learn about the political economies associated with the adoption of each, and its influence in mediating how differently capacitated stakeholders are able to benefit from them?
4. What grounded perspectives on the introduction of electric DTWs emerges that can influence national policy discourses on the relationships and trade-offs between food security, groundwater management and sustainable and equitable rural development?

The structure of this study follows a multi-staged process (**Error! Reference source not found.**). At first, we will examine the status quo based on a comparison of the water security and agricultural production situation before and after the introduction of several technologies aimed at improving water security as a means to increasing agricultural production. These include deep tube wells (DTWs) that use electric cards as well as other hard and soft technologies that augment access to water; improve on farm water management (e.g. conservation agriculture techniques) or reduce crop water demand (e.g. crop substitution). During 2015-16, we analyzed the impacts of these innovations from three inter-related perspectives. The first is a food and livelihood security perspective, particularly looking at environmental and economic impacts of production system that rely on groundwater extraction as well as changes in cropping patterns and agricultural production costs. The second perspective takes a closer look at gendered technology adoption and examines their wider social impacts. Thirdly, an institutional perspective examines how far the institutionalization and implementation strategies were equitable in terms of the distribution of benefits and externalities

across different farmer groups; underlying political economies, and the roles of key stakeholders and policies in the process. These results will offer cross-site intra-regional learnings for the project's other sites in the Nepal Terai and India's Madhubani and North West Bengal. They will also have relevance to potential local adaptations in districts of North West Bangladesh as well as wider national policy discourses around food security, water security and poverty reduction.

Figure 2: Structure of this study



3. Theoretical background on technology adoption

Based on a literature review on studies examining groundwater irrigation in Northwest Bangladesh, as well as agricultural technology adoption and uptake, we noticed that empirical data on comprehensive institutional, gender and sustainability perspectives on groundwater access including deep tubewell adoption are missing. Therefore, we developed a conceptual framework for analyzing irrigation adoption from institutional, gender, equity, food and livelihood security perspectives.

Lee (2005) lists factors influencing the adoption and emphasizes institutions, infrastructure and collaboration. He views technology adoption from a systems-oriented approach as a social learning process. The enabling factors range from agro-climatic conditions, soil quality, and plot characteristics to input substitution, labor intensity, and improved management capacity. Capacities are based on farmers' age, experience and skills acquired in the formal educational system, through extension services and farmer-based organizations. Further enabling factors are access to quality information through institutions, networks of NGOs and CBOs, investment behavior, risk taking and land rights that are often interrelated and economic incentives. He further states policies that enable access to credit, water, land rights, and information. Venot et al. (2013) point out that not the hardware, in their case the drip irrigation technology, but the network of institutions, discourses and practices around it enact its characteristics. This perspective promotes how relevant the institutional set-up around a new technology is, and informs this report's aim of exploring these dimensions with respect to groundwater irrigation and other technologies linked to agricultural water security in Bangladesh. Concerning gender differences, Peterman et al. (2011) found that not the technology itself, but gender differences in non-land agricultural inputs, technologies and services are the reason for gender-differential technology adoption. These inputs are water access and available soil fertility, technological resources such as inorganic fertilizers, insecticides, improved seed varieties and mechanical power, human resources such as agricultural labor, extension services and life-cycle challenges, as well as social and political capital, such as group membership, information exchange through networks and political representation. In a study on improved maize technology in Ghana, Morris and Doss (1999) came to the same conclusion, namely that gender-linked differences in access to complimentary key inputs result in gender-linked differences in the adoption of modern maize varieties and chemical fertilizers. To increase the adoption rate of technologies, gendered access to land and access to agricultural extension services hinder women to take up technologies as successfully as men. These studies demonstrate that a gender and institutional perspective on technology uptake for food and livelihood security needs to understand the linkages to other resources and inputs that strongly influence the adoption of technologies.

4. Methodology

Three case study villages were selected for conducting in-depth analysis of the institutional, technological and socio-economic conditions under which agricultural innovations to adapt to water stress and climatic change have been adopted in Bangladesh. These villages are Ramnatha Para village in Rangpur district; Dhondogaon village in Thakurgaon district and Pachondor village in Rajshahi district, all of which fall within the Rajshahi Division. These represent a sub-set of six villages identified by the Bangladesh Rice Research Institute (BRRI), the project's primary national partner, primarily based on BRRI's role in monitoring groundwater use for irrigation. Visits to a number of other villages were also undertaken to follow up on information gathered in the case study villages.

The data collection is based on 108 semi-structured interviews and 20 focus group discussions (FGD) which were both gender-disaggregated and mixed. These primarily covered pre- and post-technology adoption scenarios regarding agricultural production; crop choice and cropping patterns; irrigation

and water markets especially around groundwater access and use; processes and actors involved in technology adoption; and, environmental conditions especially the links between observed changes in environmental conditions, technology adoption and agricultural production. We further investigated the role of local and state institutions as well as gender and other social, economic and cultural divisions in water access.

Table 1: Interviews and Focus Groups conducted for this study

Site	Interviews women including female farmers	Interviews men including male farmers	Interviews STW & DTW owners /operators	Interviews with government officials	Focus Group Discussions mixed	Focus Group Discussions with females
Thakurgaon	44	12	3	4	6	1
Rangpur	5	3	2	1	3	2
Rajshahi	18	9	3	4	8	0

The interviews were conducted with a range of stakeholders including shallow and deep tubewell (STW and DTW) operators; water sellers using diesel and electric STWs; male and female farmers of diverse social groups with differently sized landholdings; tenant farmers, non-farming women, and government officials. All interviews and FGDs were transcribed and coded using the software Atlas.ti.

In addition to the findings from these discussions and interviews, some supplementary information is included from similar fieldwork under the “Sustainable and resilient farming systems intensification in the eastern Gangetic Plains (‘SRFSI’)” project conducted in 2015 in other locations in Rangpur, Dinajpur and Rajshahi districts.

This report also contains additional contextual information on the broader agricultural, irrigation and policy and institutional settings in northern Bangladesh with reference to existing literature. This seeks to place the case studies in the overall national and regional contexts, and thereby facilitate the linking of findings at field level with regional social and economic trends and national policy objectives.

5. National Policy and Institutional Context

5.1 The rice production, food security and groundwater nexus, and emerging policy challenges

As with much of South Asia, rice is the dominant crop in Bangladesh, with three growing seasons: i) monsoon-season transplanted Aman (December to January); ii) irrigated, mainly dry-season Boro (March to May) and iii) pre-monsoon Aush (July to August). The country is now the fourth-largest rice producer, reaching near-self-sufficiency in rice (Mainuddin and Kirby 2015). Rice now occupies close to 80% of the gross cropped area (Amarasinghe et al. 2014), and its production has almost tripled from 11.5 tonnes in 1976-77 to 32 million tonnes in 2009-10 (Mainuddin et al. 2014), in spite of the decline in arable land since Bangladesh’s independence in 1971. Since the area of rice cultivation has only increased by approximately 20% (from almost 10 million ha in 1995 to nearly 12 million ha in 2010), the major driver of the production increase has been the significant increase in yield from 2.7 t/ha in 1995 to almost 4.3 t/ha in 2010. Other contributing factors have been the increase in rice area under

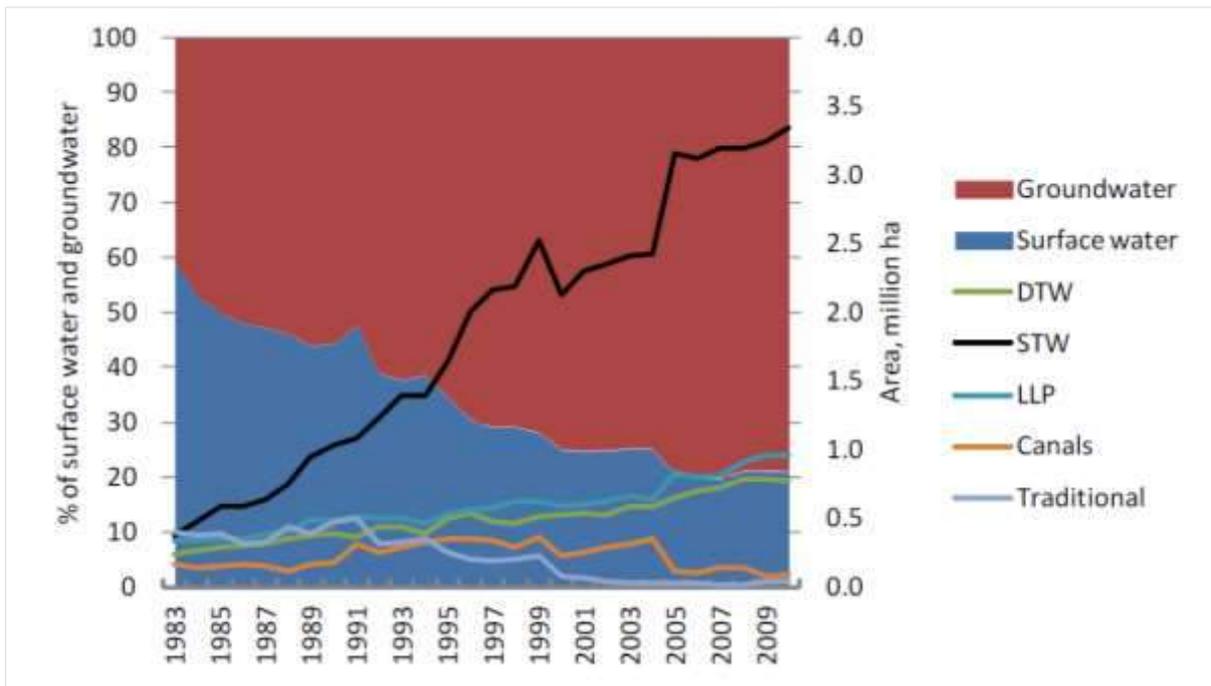
irrigation from about 30% to 77% from 1995 to today (Amarasinghe et al. 2014) and the use of modern varieties increasing from 52% to almost 80% during the same period. These varieties have increased tolerance to floods, drought and salinity, and often include high yielding traits. Short duration varieties have also further enabled farmers navigate environmental hazards. Aush rice area has decreased significantly, and Aman rice accounts for the largest gross cropped area (40% in 2010), while Boro rice has expanded rapidly, mainly at the expense of Aush, according to Amarasinghe et al. (2014). The same authors also note that rice accounts for 93% of the increase in gross cropped area, and 77% of gross irrigated area in the country between 1990 and 2010.

According to Qureshi et al. (2014), groundwater plays a pivotal role in Bangladesh's agricultural economy. Increased access to groundwater combined with the large-scale adoption of high yielding irrigated Boro rice varieties, has enhanced the agrarian livelihoods of millions of rural poor by enabling a dry season rice crop. The average yield Boro rice is nearly twice that of Aman and more than double that of Aush (Mainuddin et al. 2014). As of 2014, Boro covered 42% of the rice cultivation area, and accounted for 57% of rice production (Mainuddin et al. 2014). Today 80% of the Boro rice crop is groundwater irrigated which according to Amarasinghe et al. (2014) accounts for almost all the irrigation consumptive water use (CWU) of rice, and has made the country self-sufficient in rice. The north-west has been particularly important as a center of intensive cultivation.

As noted by Darbas et al. (2015) Bangladesh's history of conflict and famine left a powerful institutional legacy in the desire to achieve national food security. This in turn has resulted in a strong policy focus on agriculture, and rice production in particular, in light of a rapidly growing population. Consequently, Bangladesh has promoted irrigated agriculture since the early 1960s as reflected in the first Water Master Plan of 1964, which recommended for the first time using groundwater for irrigation in some areas of the country. This prominence of agriculture also prompted the Bangladesh Agriculture Development Corporation (BADDC) to be established in 1961. According to Faisal et al. (2005), it was the first institution to introduce groundwater-based irrigation in Bangladesh. The same authors also note that this emphasis on groundwater has been subsequently repeated in all key documents on the development of water and agricultural sectors.

Despite this early emphasis on groundwater irrigation, its rapid spread only gained momentum in the 1980s when low-lift pumps (LLPs) and STWs became widely accessible and affordable in local markets for individual farmer adoption (Figure 4). The National Water Policy of 1999 further envisioned using all available groundwater technologies including DTWs, which also were established by then. This was followed by the in 1992 by the National Minor Irrigation Development Project (NMIDP) under the Ministry of Agriculture, and coincided with government policy of full privatization of the irrigation sector and reduced import duties on irrigation equipment (Faisal et al. 2005).

Figure 4. Rapid adoption of LLP, STWs, and dependence on groundwater for irrigation.



Source: Mainuddin et al. 2014.

In northern and northwest Bangladesh, shallow tube wells are gradually being replaced by electric DTWs through government-sponsored programs, particularly in Rajshahi where declining groundwater tables in many parts now exceed the reach of STWs. The Barind Multipurpose Development Agency (BMDA) in particular has installed 14,901 tailor-made electric deep tube wells across Rangpur, Rajshahi and other northern districts. This also stems from the other benefits of electric DTWs in enabling faster and cheaper irrigation as will be discussed later in this report, even where groundwater levels are stable, as in Rangpur.

Another important dimension of groundwater use is energy consumption. In 2012, about 2% (980 million kwh) of the country's electricity generation was used to pump groundwater for irrigation, supported by a flat tariff system of 0.04 USD/kwh which equates to an annual energy subsidy of about USD 50 million (Qureshi et al. 2014). This however does not reflect the entire energy consumption or cost since as much as 87% of all STWs in Bangladesh are run using Chinese diesel engines (of 10-15 hp capacity) which are estimated to lift approximately 4.6 billion liters of groundwater at the cost of USD 4.0 billion according to Qureshi et al. (2014). In the north and north-west, diesel operated STWs are used primarily for irrigating Boro rice, and partially for supplemental irrigation to Aman and Aush rice and other crops. The same authors note that while groundwater markets in South Asia generally have begun to contract in response to increasing energy prices, the subsidies and growing investments in electric DTWs by the government continues to see groundwater extraction grow, even though groundwater levels are declining, with the rate of decline in some parts of the north and northwest being much faster than other areas. Boro rice nevertheless remains the most preferred Rabi crop despite its high water demand, because of the relatively lower profitability of wheat, according to Qureshi et al. (2014).

The continued reliance on diesel operated STWs also involves a significant financial disadvantage for farmers served by diesel pumps since cost of lifting water with these is USD 51/ha compared to only USD 20 for electric STWs of the same capacity (12 liters/sec). According to Hossain and Deb (2003), the higher costs for diesel operated pumps are also due to their low efficiency (poor manufacturing and maintenance), which rarely exceeds 25%, compared to 35% for electric pumps. Consequently, the

irrigation cost for farmers relying on diesel operated STWs for Boro rice accounts for approximately 57% of their total production costs, compared to 42% for farmers served by electric STWs. This percentage is likely to have risen further since the cost of irrigating a hectare of Boro rice in 2011 was found to be USD 141 by Dey et al. (2013), further eroding the profitability of this crop. The same authors calculate that if the present trends continue, the cost of irrigating Boro rice will reach US\$ 200/ha in 2030. This appears to be also supported by Amarasinghe et al. (2014) who note the additional water consumption in Boro rice is more than the increase in yield compared to Aush and Aman rice. They point out that since part of the increase in Boro rice has been at the cost of abandoning Aush rice production, this increase comes at the cost of substantially more irrigation. Furthermore, Mainuddin et al. (2014) note that net irrigation needs of Boro rice may increase by another 3% by 2050 due to further drying of the climate.

Figure 4. A typical post-harvest scene in Ramnatha para, Rangpur.



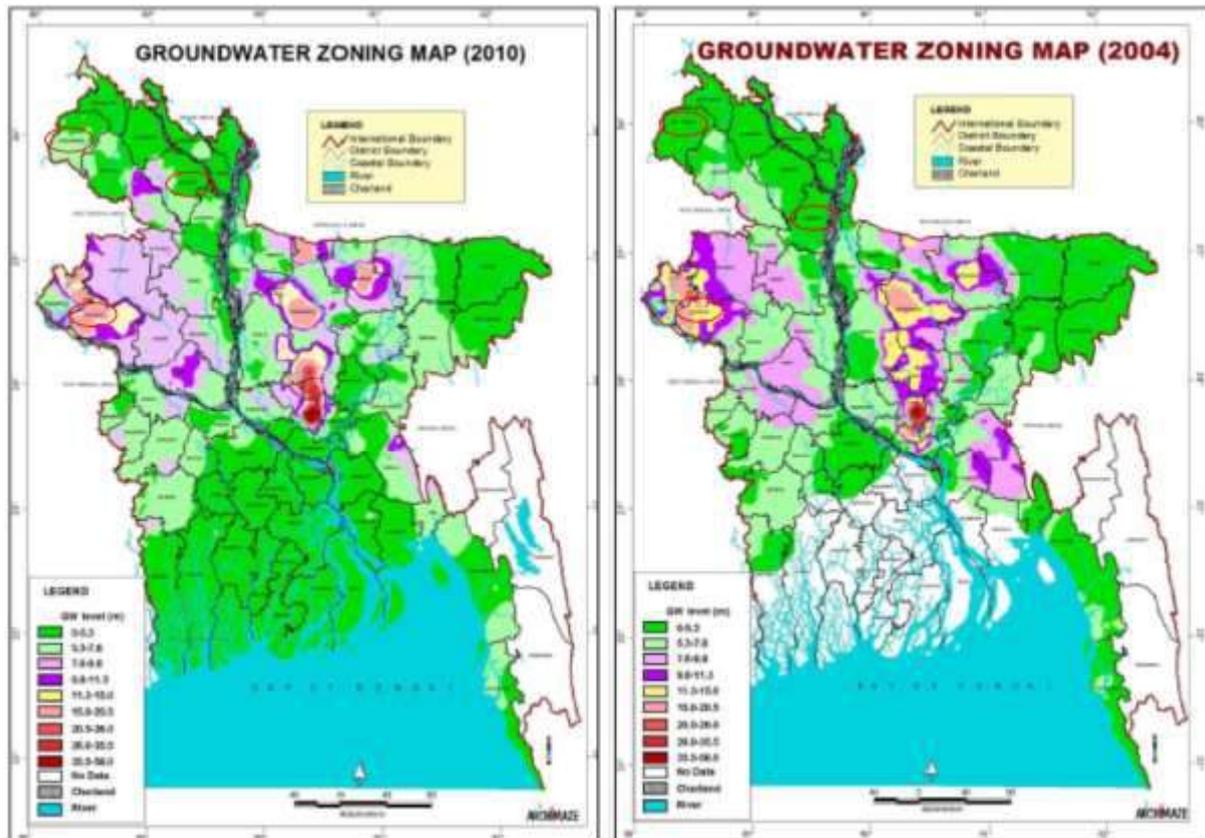
In addition to rising irrigation costs, Qureshi et al. (2014) point out that the quality of groundwater accessed is likely to decline. Furthermore, the same authors (citing Cassman et al. 2003), add that limits to the genetic and agronomic scope for yield increase in rice will constrain farmer's ability to offset rising irrigation costs with increased yields, thereby further eroding farmers' net incomes, and further threatening the economic viability of Boro rice production.

A study by Haque et al. (2012) cited by Qureshi et al. (2014) further found a significant difference in the quantity of irrigation applied between STW owners and water buyers in the Boro season: STW owners applied 15,300 m³/ha on average, while water buyers used only 10,500 m³/ha under similar conditions. Boro rice yields were consequently 5.2 tons/ha for water sellers compared to 4.8 tons/ha for water buyers. Qureshi et al. (2014) further surmise that these yield differences may also be due to higher fertilizer application by groundwater sellers

As key regions of groundwater irrigated Boro rice production, the above scenario is especially relevant to the northern (Rangpur and Thakurgaon) and north-west (Rajshahi) areas of Bangladesh. A

comparison of the groundwater zoning maps of 2010 and 2004 (Figure 5) in fact indicate a decline in groundwater levels in Rangpur, Thakurgaon and Rajshahi. In a large part of the former two districts, the water table has dropped from the 0-5.3m to the 5.4-7.6m stage, which does not represent an issue in the short term at least, given water tables remain within the reach of STWs. The scenario in Rajshahi district is more serious, with groundwater levels falling from 11.3-15.0m to 15.0 – 20.0m. In fact, according to BARI (2015), groundwater levels in the Barind areas are falling rapidly due to over exploitation through DTWs, so that many DTWs now have far smaller command area than expected, and irrigation costs are the highest in Bangladesh.

Figure 5. Changes in groundwater tables (2004-2010).

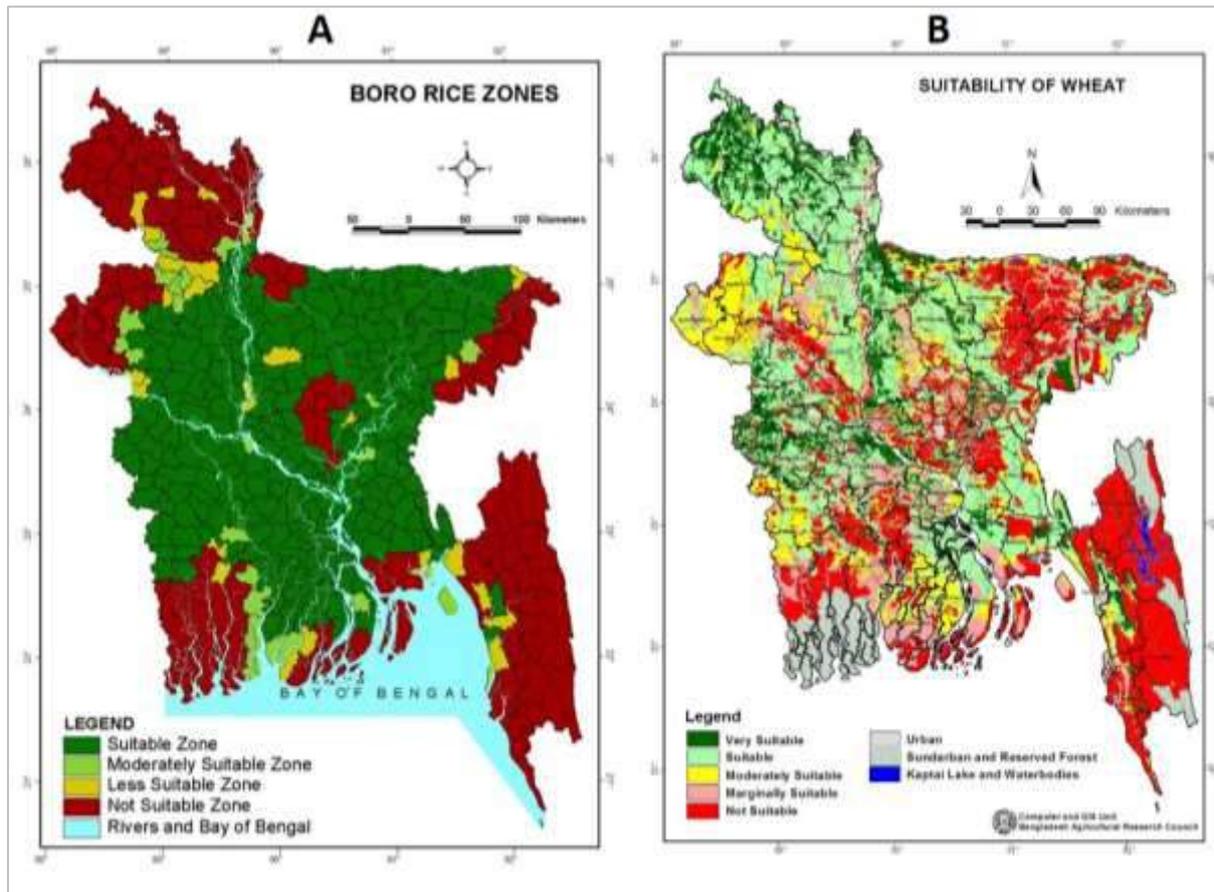


Source: Bangladesh Agricultural Development Corporation through The Bangladesh Network¹

An additional element that needs to be included to the analysis with respect to groundwater irrigation in these regions is the fact that they are some of the least suited regions for growing Boro rice (Figure 6A). As a result, the irrigation demand of Boro rice in these areas can be as much as 13,500 m³/ha compared to 4,840 to 5,720 m³/ha in Dhaka district (Qureshi et al. 2014 citing Dey et al. 2013). Interestingly however, in the Barind area, which covers part of Rajshahi, and part of this project's study area, the water requirement is significantly lower at 6,000 to 7,100 m³/ha than in other parts of the northwest (Qureshi et al. 2014 citing Karim et al. 2009; Rashid et al. 2009).

¹ <https://www.thebangladesh.net/ground-water-zones-of-bangladesh.html#info>

Figure 6. Areas in Bangladesh according to their suitability for growing Boro rice and wheat.



Source: Ansar Energy LLC²

Through the above assessment of groundwater – Boro rice relationships, Qureshi et al. (2014) question the sustainability of Boro rice as a future strategy for Bangladesh’s food security since 90% of irrigation water for Boro rice is supplied through groundwater.³ Future groundwater impacts of especially Boro cultivation will also need to factor increasing uncertainty due to climate change that is anticipated to intensify demands on groundwater. It is interesting to note here that the adoption of irrigated Boro production has come at the expense of wheat, the cultivation of which has decreased with the increased access to groundwater, despite its relatively high nutritional value and (along with maize) comparatively far lower water demand (Qureshi et al. 2014).⁴ A significant water requirement of these crops can in fact be met by the moisture present in the root zone from the previous rice crop especially if strip or zero tillage methods are used. Qureshi et al. (2014) therefore argue that adoption of wheat and maize would help check further groundwater decline, while simultaneously support food security and help save foreign exchange currently spent on the import of these two items. In terms of this project’s focal regions, it is also then pertinent to note from Figure 6B, that some of the most suitable land for wheat cultivation lies in the northern regions – areas presently dominated by Boro rice for which the land is least suitable. However, others such as Amarasinghe et al. (2014) predict, using time series data that the increase in Boro rice production, mainly through yield increases, will continue into 2030, and will account for almost all growth in rice production, enabling substantial production surpluses (Figure 7). However, they too recognize that such increases are likely to be difficult in practice, citing population increases, urbanization, limited land and falling groundwater

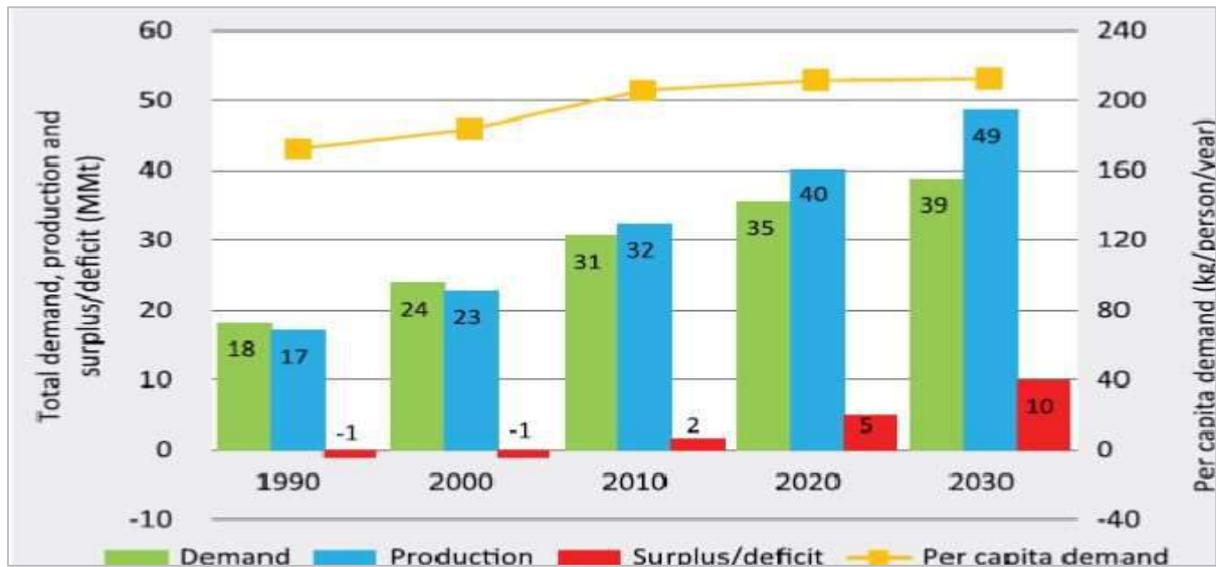
² www.ansarenergy.com/index.php/mechanized-agriculture/rice-and-wheat-crops-seasons-in-bangladesh

³ Achievements in switching from Boro in Rajshahi provides an example of how this can be done.

⁴ The Rajshahi case study may show how this can be reversed.

tables and water quality issues, and that BRRI in fact projects total rice area to contract from around 11.4Mha in 2014 to 10.3Mha by 2020. Amarasinghe et al. (2014) in fact recognize that a number of areas including Bogra and Pabna in the Rajshahi district have already passed the sustainable thresholds of groundwater use where irrigation CWU exceeds the usable groundwater recharge, with other areas in Rajshahi close to this threshold.

Figure 7. Rice demand, production and production surpluses/deficits



Source: (Amarasinghe et al. 2014)

Qureshi et al. (2014) correctly conclude that reigning back groundwater consumption will require more imaginative approaches than through direct regulation (e.g. permits) due to the diffused nature of especially the large number of STW ownership combined with ineffective institutional arrangements. They cite as evidence, the ineffectiveness of the ordinance of 1985 to manage agricultural groundwater resources, where licensing requirements to restrict installation of private tube wells in critical areas of groundwater level or quality decline. Similarly, the national environmental policy (1992), national policy for safe water and sanitation (1998), and national water policy (1999) which stressed the need for the protection of surface water and groundwater resources have had little impact on groundwater exploitation. The more recently introduced water act of 2013 makes it mandatory for any individual to obtain a license/permit for large-scale withdrawal of groundwater by individuals and organizations beyond domestic use. The same authors also note that despite the proliferation of policies and acts that call for regulation, the emphasis so far in practice has been on the continued development of groundwater resources rather than their management and conservation. Moreover, most policies and regulations including the groundwater management ordinance of 1985, also lack the broad spatial perspective required for aquifer management, dealing instead at smaller scales often aligned with administrative and not hydrological boundaries, such as the 1985 ordinance's focus at the Upazila (sub-district) level. This is aggravated by the absence of a single governing authority responsible for the management of groundwater that can transcend administrative scales and focus on long-term sustainable resource management.

The same authors further surmise that in addition to the diffused nature of groundwater use, another reason for hitherto only tacit attention to regulation could be the dependence on groundwater for rural livelihoods in several regions, and the reluctance of the state to implement stringent regulation. The foregoing assessment of the current groundwater trends however suggests it is time for serious consideration of alternate policy directions. Recognizing this policy conundrum, moving towards

profitable but less water demanding crops than Boro rice is presented as an option to maintain food security and livelihoods while stemming further erosion of groundwater resources. To do this, it is argued by Qureshi et al. (2014), effort will be needed to address farmer attitudes and perceptions such as their belief that applying more water leads to higher yields.

Other areas suggested by Qureshi et al. (2014) for making water use efficiency gains include the adoption of resource conserving crop management practices such as alternate wetting and drying (AWD), direct-seeded rice, and bed planting, though in the case of AWD, effort is required to facilitate water pricing structures that would induce farmers and irrigation service providers alike to reduce irrigation volume in Boro rice. The authors do however recognize the need to incentivize farmers to adopt such technologies; to develop viable markets for the equipment needed to prepare fields and sow crops using these techniques, and to develop strong output markets for these alternative crops. Amarasinghe et al. (2014) however believe that water demand management alone will not be sufficient to adequately curb groundwater use, as groundwater also meets domestic, industrial and environmental water needs, and therefore believe it is also critical that groundwater recharge be increased artificially by using a small percentage of surface water flows.

5.2 National and regional institutions

The management of water resources in Bangladesh is distributed amongst a number of agencies. The National Water Resources Council (NWRC) chaired by the Prime Minister formulates overall policies concerning the water sector and oversees their implementation. Groundwater also sits under different ministries: the Ministry of Water Resources and Ministry of Agriculture, which in fact has the jurisdiction to enact legislation regarding irrigation. At local level the Ministry of Local Government, Rural Development and Cooperatives has overall responsibility for monitoring and governing the sector.

The Water Act of 2013 is based on the National Water Policy, and is meant to promote integrated approaches to water resources management. The Act confirms that all forms of water in Bangladesh belong to the government, whereby a permit or a license is required for any large scale withdrawal of water by individuals and organizations beyond domestic use. It does not indicate any limit to the amount of groundwater that can be withdrawn by an individual or organization.

Ministry of Water Resources (MoWR)

As might be expected, the Ministry of Water Resources is responsible for a wide range of water management functions including flood management, irrigation, drainage control, river flow augmentation and water sharing between transboundary rivers, in collaboration with local stakeholders and other government agencies. This Ministry also provides oversight to a number of key actors namely the Water Resources Planning Organization (WARPO), Bangladesh Water Development Board (BWDB) and the River Research Institute (RRI). MoWR is also tasked formulating a framework for institutional reforms to guide water related activities.

Water Resources Planning Organization (WARPO)

WARPO was set up under Water Resource Act of 1992 under the MoWR as the multi-disciplinary planning organization at the national level. Its mandate was further elaborated in the National Water Policy of 1999 according to which, WARPO has two broad responsibilities: (a) to work as the exclusive government institution for macro level water resources planning and (b) to work as the Executive Secretariat of the NWRC and its Executive Committee.

WARPO has become the exclusive government institution for macro-level planning. As such, the preparation and updating of both the National Water Policy and the National Water Management Plan is a key responsibility of WARPO. It is also mandated to advise other water-related organizations in the development, use and conservation of water, and provide specialized multi-disciplinary and cross-sectional training to concerned functionaries. While WARPO is responsible for water sector macro

planning, it is also expected to promote appropriate linkages between macro and micro level planning and provide guidelines for the efficient use of the country's water resources by all users and in all uses.

Bangladesh Water Development Board (BWDB)

Major investments in the water sector are made by the Ministry of Water through the BWDB, which is responsible for the planning and execution of major projects, ranging from flood control, drainage and irrigation to coastal protection and erosion control. These are expected to support implementation of national and regional level plans developed by WARPO. BWDB is thus predominantly an engineering, construction-oriented agency with a large staff, almost all of whom are engineers. It has been criticized for its resistance towards adopting less centralized and more participatory approaches to project development and implementation once the national orientation towards water resources management shifted towards joint management and greater transparency and efficient management techniques (ADB 2003a). Some change though is noted after formulation of national water policy (ADB 2003b) where it now attempts to collaborate with NGOs for mobilizing beneficiary's group formation and resettlement (Hussain 2004). BWDB's role overall has nevertheless reduced following WARPO's creation (overall policy, macro planning and strategy functions) and greater emphasis given to local government and water users assuming increasingly important roles in project implementation (ADB 2003a).

The Barind Multipurpose Development Agency (BMDA)

A semi-government organization under the Ministry of Agriculture established in 1997, the BMDA is a key organizational actor with respect to the scope this project. Its goals are as follows:

- To convert Barind Area into a granary by creating irrigation facilities.
- Development of water reservoir & Massive plantation for climate change adaptation.
- Development of rural communication for Marketing of Agricultural product.
- To improve livelihood of the people.

The role of this agency in driving adaptation will be discussed in detail later in this report.

The Bangladesh Agriculture Research Institute (BARI)

BARI is another agency with critical roles especially with respect to food production in water scarce contexts. Its goals include increasing system yields in drought prone areas and improving soil fertility, nutrients and water use efficiency in these areas, to support sustainable crop production. These goals sit with a broad ranging research coverage of crops including cereals, tubers, pulses, oilseeds, vegetables, fruits in terms of new varieties, and associated with research on soil and crop management, disease and insect management, water management and irrigation, development of farm machinery, improvement of cropping and farming system management, and post-harvest handling and processing. It has actively promoted these in the northern region, specifically in the HBT where it promotes changes in cropping patterns (e.g. wheat-Maize-Rice) to assist water savings and intensification; developing new crop varieties such as new wheat varieties, and the promotion of alternate land management techniques such as the following:

- Raised bed-planting methods to increase crop yields by improving the establishment of crops in the soil, and enhancing soil moisture and water holding capacity. This reduces the use of water as well as labor, which is intensive especially for traditional rice transplanting.
- Conservation agriculture methods that increase surface partial crop residue retention (approx. 30%) and minimize soil disturbance
- Economically viable crop diversification and rotation to avoid pests and diseases

The Bangladesh Rice Research Institute (BRRI)

Given the dominance of rice production in Bangladesh, BRRI clearly has a major role in addressing current agriculture production-water management relationships. Its focus on rice involves research on all aspects of rice improvement and production including developing new varieties and related

training of farmers as well as agricultural extension personnel, and advising the Government on rice related policy issues.

Bangladesh Agricultural Development Corporation (BADC)

Operating under the Ministry of Agriculture, the BADC specializes in supplying agricultural inputs and dissemination of technologies among farmers. It was also involved in providing irrigation facilities through minor irrigation activities using surface and ground water, and provision of technologies for increasing irrigation efficiency. BADC was involved in introducing STWs and DTWs through cooperatives, but withdrew its irrigation services the late 1980s, leaving all irrigation equipment to farmers' groups or individuals (Hussain 2004).

Department of Agriculture Extension (DAE)

As its name suggests the DAE provides extension services to all categories of farmer in accessing and utilizing better knowledge to sustainably and profitably increase crop production to ensure food security as well as economic development of the country. Farmers' main point of contact for agricultural affairs is the DAE's Sub-Assistant Agriculture Officer (SAAO). It is located in the Ministry of Agriculture.

Local Government Engineering Department (LGED)

LGED grew from a rural works program started in the early 1960s. Located within the Local Government Division, it is responsible for planning and executing rural works. With offices in every district and Upazila, it provides technical guidance and personnel support to Upazila Parishads in implementing rural projects financed by Upazilas or government. LGED is also involved with stakeholder-driven small-scale surface water management projects with command areas less than 1,000 ha. It places a heavy emphasis on local participation, with representation on Upazila Co-ordination Committees. Concerning water sector projects, LGED draws its mandate from Upazila Parishad Act of 1998, which makes LGED responsible for ensuring the best possible use of surface water for adoption and implementation of minor irrigation projects. These are to support government objectives of poverty reduction and employment generation. LGED works with local communities in the development of rural infrastructure and, more recently with promoting community participation at all stages of project cycles as it implements various projects.

Local Government

In Bangladesh, the rural local government have three tiers, namely Zila Parishads, Upazila Parishads and Union Parishads, while in urban area the Union Parishad is frequently replaced by the Municipal Corporations and City Corporations. These bodies consist of elected representatives. Local government has historically had a marginal role in implementing water management investments. The National Water Policy however envisages this to change whereby local governments are to be principal agents for coordinating the participation of project-affected persons in planning, design, implementation, and operation and maintenance of publicly funded surface water development plans and projects. According to the NWPO, water management and allocation is to local government.

Department of Cooperatives (DoC)

The DoC is the principal government organization responsible for the promotion, development, and registration of cooperative societies in Bangladesh under the Cooperative Societies Act in 2001. It works directly under the supervision and control of the Rural Development and Cooperative Division of the Ministry of Local Government. It provides support for the formulation of rural development policy, co-operative laws, rules and policies, and supports policy implementation by forming formal and informal groups, along with implementing associated programs and projects. A central focus is entrepreneurship development through micro-credit, agricultural credit, cooperative-based small and cottage industries, cooperative banking, cooperative insurance, cooperative-based farming and marketing, as well as milk and other cooperative enterprises.

6. The study districts and local contexts

6.1 The Districts

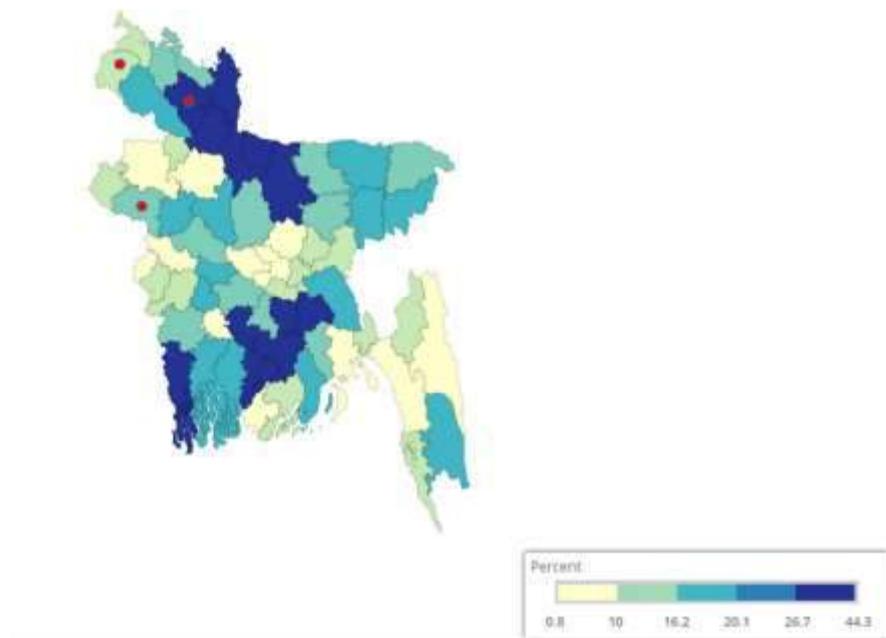
Rangpur District (Figure 1A) has just over 2.5 million people, of which approximately 90% is Muslim and 8% Hindu. Annual rainfall is 1932 mm (Bangladesh Bureau of Statistics 2013a). The village is served by four electric pumps. In Rangpur district, agriculture accounts for approximately 63% of economic activity, and rice production is by far the dominant agriculture activity.

Thakurgaon District (Figure 1A, also in Rangpur division) forms part of Bangladesh's border with India, being bounded by West Bengal state of India on the south and west. Out of a population of about 1.2 million people, 77% are Muslim and 23% are Hindu. Agriculture contributes to over 76% of economic activity, and rice is again the primary crop. The average annual rainfall of the district is 2536 mm (Bangladesh Bureau of Statistics 2013b).

Rajshahi District (Figure 1A) Rajshahi has almost 2.3 million people of whom 93% are Muslim. The main source of income is agriculture although its contribution at 59.35% is much lower than in Rangpur and Thakurgaon, because commerce is also important with an estimated contribution of 14.25%. Annual rainfall varies from 1250 mm to 2000 mm. Part of the district falls within the Barind Tract which suffered from severe drought due to low and erratic rainfall as well as high temperatures. Major investments in groundwater extraction and associated on-farm adaptation over the past 20 years has transformed the area and the livelihoods of the local farming communities. Rajshahi is also set apart from Rangpur and Thakurgaon by its undulating topography with greater differences in elevation between lowlands and highlands.

As indicated in Figure 8, the three study districts contain varying concentrations of the extreme poor,⁵ with Rangpur showing especially high numbers. This is somewhat surprising at least from an agricultural standpoint given that it is the least affected by drought and floods (see below) and enjoys well-developed access to groundwater for year round cultivation.

Figure 8. Study districts and poverty distribution in Bangladesh



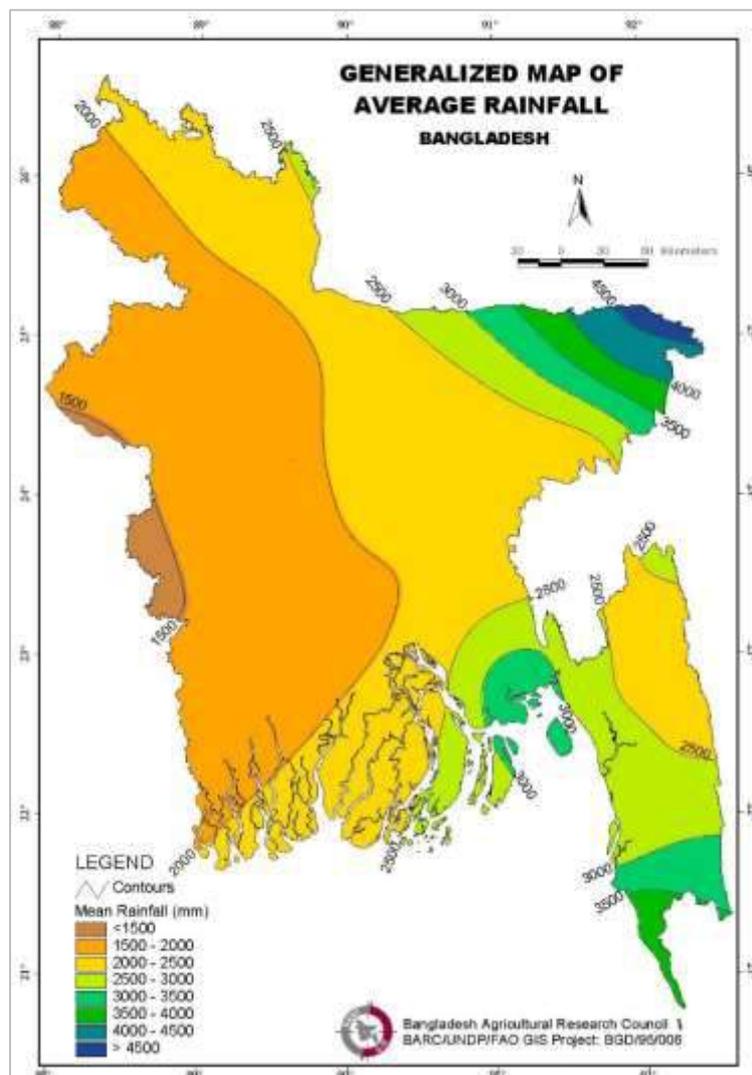
⁵ Extreme poverty is officially defined in Bangladesh in terms of total living expenses of a family falling short of the cost of minimum food needs.

Source: World Bank 2016.⁶

Bio-physical setting

Bangladesh for the main part consists of low, flat, fertile land, with the exceptions of the hilly regions in the southeast and northeast, and patches of highlands in the central and northwest regions. About 230 rivers and their tributaries, with a total length of 24,140 km, flow across the country down to the Bay of Bengal. While giving rise to flood risks in some areas, the rivers bring large silt deposits that enrich the alluvial soils during the rainy season. With a subtropical monsoon climate, summer temperatures range from 24 to 41 °C, while winter (November to February) temperatures range from 7 to 13 °C. The monsoon lasts from June to October and accounts for 80% of the total annual rainfall, which varies from 1,200 to 2,500 mm depending on the region (Figure 9). Rajshahi district is one of the regions that receives the lowest rainfall, while Thakurgaon and Rangpur lie in the 1500-2000mm and 2000-2500mm belts respectively (Figure 2). The aquifer underlying this region is unconfined with a high water level.

Figure 9. Rainfall distribution in Bangladesh.



Drought is a common issue although the northwestern region of the country is more prone to it than elsewhere (Figure 10 A-C). In keeping with rainfall distribution patterns (Figure 10), Rangpur is the

⁶ <http://www.worldbank.org/en/data/interactive/2016/11/10/bangladesh-poverty-maps>

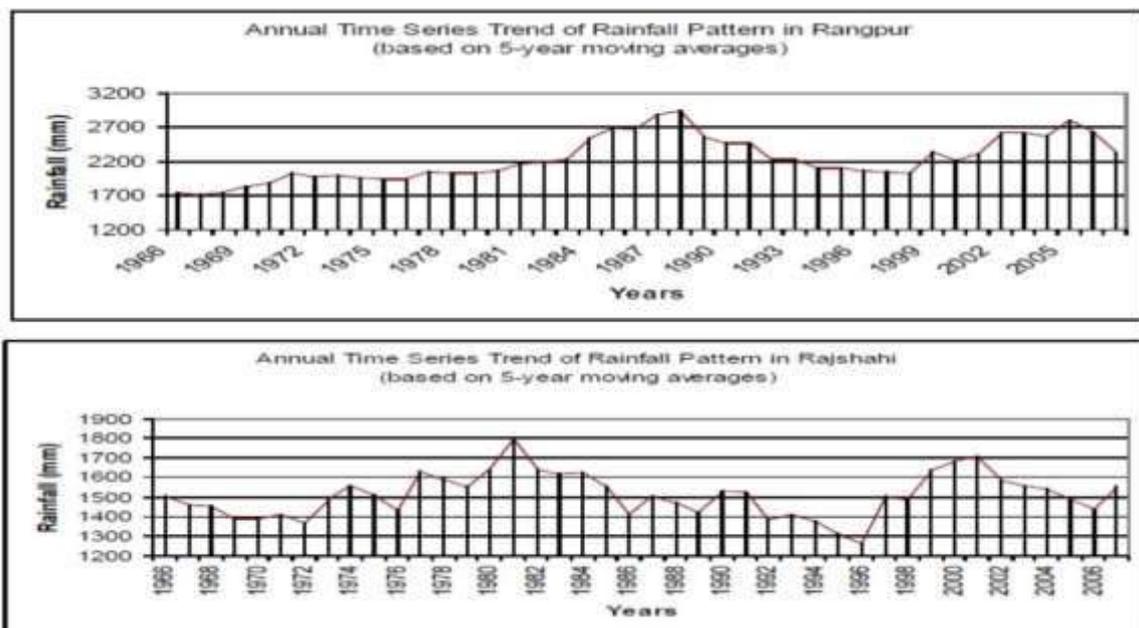
least affected of the project districts, while Figure 10 A – C show Rajshahi to suffer significant water stress throughout the year. In Rangpur and Thakurgaon, moderate to severe water stress appears to occur primarily in the main Kharif period (Figure 10B), when supplemental groundwater irrigation is used during the late monsoon since irrigation by small-scale tube wells and low-lift pumps commenced in the late 1970s and spread extensively when the importation of agricultural machinery was liberalized in the late 1980s. All three districts are relatively affected by large scale flooding although parts of Thakurgaon is shown to be at risk of flash floods (Figure 10D).

Figure 11. The Tista River in the dry season showing significantly reduced dry season flows. This has led to a decline in surface water availability and a thriving fishery in Rangpur and adjacent regions



A recent study of rainfall patterns in the Rajshahi division (including Rangpur and Rajshahi districts) by Shamsuzzoha et al. (2014) found rainfall to be characterized by variation of inconsistent magnitudes in both seasonal and annual rainfall. Annual rainfall variation was especially profound in Rajshahi: from 1542.1 mm to 2235.8 mm. However, despite this variation annual rainfall in both Rangpur and Rajshahi exhibit an increasing trend in recent years (Figure 12), especially in Rangpur. Rangpur also shows an increasing trend of post-monsoon rainfall percentage while Rajshahi exhibits a decreasing trend. It is in winter that rainfall has been consistent, with the percentage of total annual rainfall remaining almost same for the entire division. Interestingly, despite the significant rainfall variation from year to year, the same study found an increasing pattern of rainy days in the division, where rainy days have increased in all seasons. The monsoon was found to account for almost 70% of annual rainfall while the dry cool winter is the lowest period for rainfall.

Figure 12. Rainfall patterns in Rangpur and Rajshahi over the last 50 years.



Source: Shamsuzzoha et al. (2014)

Agricultural seasons

In Bangladesh as a whole, agricultural activities fall into two main seasons, namely Kharif and Rabi.⁷ The **Rabi season** (November - end of March) begins at the end of the humid period when the Southeast monsoon starts to ease off in November. This period is characterized by dry sunny and warm weather at the beginning and end of the season, while cooler temperatures prevail in December-February. The average length of the Rabi growing period ranges from 100-120 days in the extreme west to 140-150 days in the Northeast. Major Rabi crops include:

- Cereals - wheat, maize, barley, and Boro rice
- Tuber and roots crops- potato and sweet potato
- Oilseeds - mustard, sesame, groundnut, sunflower, linseed, and safflower
- Pulses - chickpea, lentil, grass pea, and cowpea
- Winter vegetables - cabbage, cauliflower, brinjal, tomato, carrot, turnip, radish, spinach, lettuce, bottle gourd, country bean, and garden pea
- Spices - chili, onion, garlic, coriander, sweet cumin, black cumin, and fenugreek
- Fiber crops - sun hemp
- Sugar crop - sugarcane
- Tobacco
- Fruit plants - watermelon. Rabi crops can use residual moisture stored down to 125 cm in soils.

Figure 13. Maize and vegetables grown on highland plots.



The **Kharif season** (April - November) covers spring or summer and also the monsoon period. This season is divided into two periods: Kharif I and Kharif II. Kharif I, often called Pre-kharif, begins from the last week of March and ends in May. It is characterized by unreliable rainfall and varies in timing, frequency and intensity from year to year, and provides only an intermittent supply of moisture for such crops as jute, broadcast Aman, Aush, groundnut, amaranths, teale gourd etc. During this transition period, soils intermittently become moist and dry. The relative lengths and frequency of

⁷ Banglapedia: <http://en.banglapedia.org/index.php?title=Crop>

such periods depend on the timing and intensity of pre-monsoon rainfall during this season each year. Kharif II or the main Kharif season lasts from May/June – November, and season is characterized by high temperature, rainfall and humidity. Main crops include rice, cowpea and sorghum (jowar).

6.2 Changes in agro-climatic conditions in the case study villages

Rainfall variability

Rainfall in Rangpur and Thakurgaon is observed to have changed. In Rangpur, farmers observe less rainfall events in a year and less rainfall overall. The monsoon now begins early, with large intervals in rainfall during what should be the peak season. Inconsistent rainfall especially in the Aman season including rainless days causes difficulties in aligning land preparation and transplanting with rainfall, which especially affects the transplanting of T. Aman. If rains do not occur after several days, farmers have no choice but to transplant using irrigation. Irrigation is also used during parts of the growing period where there is further rainfall failure. An estimated 25% of the water requirement for Aman now comes from irrigation according to farmers. In Bhondogoan Village in Thakurgaon for instance, the Aman rice crop in 2015 needed as much as 5 irrigation episodes compared to only 1 in 2014 and 2 in 2013.⁸ Irrigation adds an estimated BDT900-1,200/acre (BDT300-400/biga) to production costs of Aman rice. While there was consistency across the farmer dialogs on these changes, views on when these began to occur differ significantly. Some farmers believe this issue began 3-4 years ago and has occurred every year, others state that they have been observed over the past 16 years, while the elder farmers claim rainfall changes have been observed over the past 30-35 years. Another consequence of these changes has been that flooding which would occur every 2-3 years now occurs only every 8-10 years. Farmers feel this also reflects the high dependence on India for river flows of which 93% comes from India. The observations in Thakurgaon are similar. During the peak monsoon period in June-July, there has been no rain in most of the last 10 years. This has required irrigation for transplanting. T. Aman in 2015 needed as much as 5 irrigation episodes compared to only 1 in 2014 and 2 in 2013.⁹ As in Rangpur, there has also been a significant reduction in flooding from the Punagoba River and Romdhora Khal compared to 40 years ago.¹⁰ In both districts, this has meant a greater reliance on agriculture of households for food and income security, when in the past, many households benefited from fishing and farming livelihoods. Few households fish now, though many used to 5-7 years ago when the river would flood the lowland. Only a few private fish ponds remain.

In Rajshahi, rainfall has been observed to be low and irregular in the past 2-3 years, with uneven distribution of rainfall during the rainy season caused frequent damage to crops (Islam et al. 2014). This correlates closely with official rainfall data (Figure 14a) that validates farmer observations. According to farmers, there has been no rain since November 2015 – 5 months to when these interviews were conducted in March 2016. This was exacerbated by high temperature spikes with the maximum temperature reaching over 43°C (Figure 24b at right) further hampering crop production.

Increasing demand for supplementary irrigation for Aman rice

These observations provide a more temporally dynamic perspective on irrigation conditions, and contrast with the findings of a study in 2006 by Institute of Water Modelling (IWM), Bangladesh that concluded that the groundwater table regains its original peak position every year in the monsoon period, and that therefore further scope for development exists.¹¹ While recharge may be occurring during the monsoon season, some farmers believe increasing levels of abstraction linked to cropping

⁸ STW owners, Bhondogoan Village, Thakurgaon district

⁹ STW owners, Bhondogoan Village, Thakurgaon district

¹⁰ STW owners, Bhondogoan Village, Thakurgaon district

¹¹ Groundwater Model Study quoted in the BMDA presentation on the Development of the Barind Area.

intensity explain their intra-seasonal experiences of groundwater scarcity. They also recognize that underlying these factors is the widespread availability and affordability of pumping technology.

This perceived decline in groundwater availability is a concern for farmers across all age groups. Farmers are however not clear about how this trend can be managed, and expect guidance from government. Some feel DTWs are the solution, while others recognize that these may further exacerbate drawdown. An overall lack of understanding of groundwater systems was observed. This was confirmed in that farmers have had no training on groundwater behavior, though they are interested to learn.¹² They agree that it is important to know what the aquifer level is, but do not know how this could be done. The fact that there is currently an embargo on the installation of more DTWs¹³ indicates the farmers are not alone in their concern.

In Rajshahi where rainfall is naturally lower, the main change in rainfall observed occurs during the Aman season when rainfall has begun to taper off towards the end of the growing season. Some farmers also believe dry spells are lengthening as evidenced they say the absence of rain between November 2015 and March 2016.

Temperatures are intensifying

In Rangpur, changes in temperature have been observed during both the hot and cool seasons: lower temperatures in winter (December-January) over short periods while there are short periods of high temperature in summer and monsoon (latter part of the Boro crop) periods. These have occurred in 4-5 of the past 8-10 years. The low temperature periods mean that seedlings take a longer time to stabilize after transplanting. There can also be higher seedling mortality if transplanting occurs just before a cold spell. It also means the crops turn yellow and may be stunted, leading to an estimated 20-25% reduction in Boro yields. Some farmers also claim the cold increases pest infestations.¹⁴ It also delays harvest by 1 or 2 weeks.¹⁵

In Thakurgaon, the maximum temperature has increased, although there has been no change to the minimum temperature.¹⁶ Here, there was more emphasis on the increase of pests causing loss especially during T. Aman (monsoon) and Boro seasons in the past 2-3 years. There are no compensation schemes for crop damage. Farmers believe the increased incidence of pests is due to the increase in humidity levels because of increased irrigation. The greater high temperature is also linked by farmers to the decline in the amount of cattle. Nevertheless, farmers believe that cropping changes, especially the increase in Boro cultivation, have not been driven by climatic changes, but by opportunities to maximize the value of available water.

In Rajshahi too increased temperature and temperature spikes have been observed and again correlate with official data (Figure 14b) For instance, whereas the ideal temperature at flowering of lentils should be 16-28°C, the temperature has been over 30°C, which hampers the process and reduces yield. Wheat is also impacted by sudden temperature rises.

Figures 14a and 14b. Rainfall (left) and temperature variation in Rajshahi

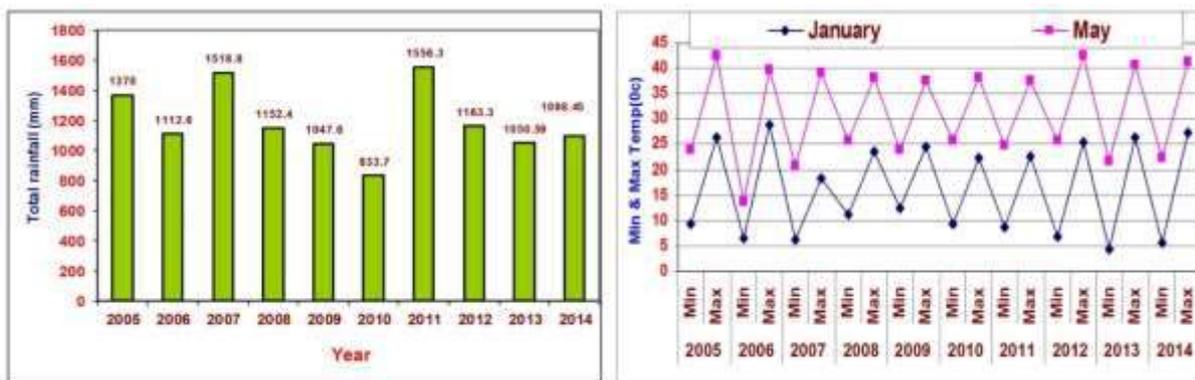
¹² Farmer interview, Rangpur

¹³ Electric DTW (BMDA-114-DTW) pump operator, Bhondogoan Village, Thakurgaon district

¹⁴ Farmer interview, Rangpur

¹⁵ Farmer interview, Rangpur district

¹⁶ STW owners, Bhondogoan Village, Thakurgaon district



Source: BARI (2015)

6.3 Land tenure

Total cultivable land area is declining

Although most households have access to cultivable land (owned or leased), the total land area available for cultivation has declined, driven mainly by the expansion of village populations. In Rangpur for instance, villages that consisted of 20-30 households thirty years ago, have expanded to 200 households today, thereby driving a conversion of land use from cultivation to homesteads. In the past in Thakurgaon, the average farming area owned by a household was 5 acres. Today, this average is estimated to be between 0.5 and 1 acre, although on average the total land cropped by a household averages between 1 and 2.5 acres due to leasing arrangements. Moreover, this is lower than respondents' estimation of the minimum land needed for a reasonable standard of living for an average household of 4-5 people, which is considered to be 2.5-3 acres.

Farmers have access to land overall, but the percentage of land owners is declining

In both Ramnatha Para in Rangpur and Dhondogaon village in Thakurgaon, the percentage of households with access to cultivable land (owned or leased) was high at between 75-85%. Large farmers are considered to own¹⁷ 10 acres or more in Rangpur¹⁸, and over 5 acres in Thakurgaon¹⁹, and comprise approximately 12% of the HHs. However, the percentage of households that own land has declined compared to 30 years ago when most households owned land. Today, respondents from Thakurgaon estimate that about 30% of households are pure tenants.²⁰ The role of external landowners was not prevalent in discussions in Rangpur. In Thakurgaon too, the impact of absentee landlords appears to be declining, with 3-4 such landlords owning about 10% of the land in Bhondogoan Village. They are businessmen living in towns in the same or surrounding districts, and rent this land to about 25 tenant farmers. In Rajshahi, Pachondor village, 88% of households lease land, while the majority of land owners reside in the nearby towns is in fact an extreme case. This dominance of leasing was not prominent in other villages. In fact, larger farmer samples under the SRFSI Project indicate that in both Rangpur and Rajshahi, the small owner cultivators (<0.5ha) represent about 40% of farmers, although the medium and large owner cultivators account for approximately 55% of farmland in both districts.²¹ This suggests a re-distribution of land holdings, which is also supported by the finding that the average size of land owned by smallholders was 0.17ha and 0.14ha in Rangpur and Rajshahi respectively – quite marginal holdings. A dynamism to land

¹⁷ Land ownership is underwritten by the registration of land titles.

¹⁸ FGD with marginal and tenant farmers, Rangpur

¹⁹ FGD, Bhondogoan Village, Thakurgaon district

²⁰ FGD, Bhondogoan Village, Thakurgaon district

²¹ Thakurgaon was not part of the SRFSI surveys.

ownership in Thakurgaon is generated by the exchange of land between Hindus in this district²² and Muslims in India to facilitate the movement of the Hindus to India and Muslims to Bangladesh.

Of particular note in all three districts, but particularly in Rajshahi is that most farmers have access to multiple plots in different parts of their respective village. While such fragmentation may negatively impact production capacity, it emerges as an important strength in adapting to variability in context, not only with respect to climatic stresses, but also in relation to the location of DTWs in the village, as demonstrated in Poshtin Para of Pochandor Village, Rajshahi discussed under section 5.2 below.

Figure 15. Fallow land amongst highlands cropped with vegetables in Ramnatha para, Rangpur



Leasing is a major means of accessing land

Given the significant growth in human populations on the one hand, and the decline of total land area for cultivation, leasing plays a key role in providing access to land especially for the poorer households. Furthermore, since irrigated rice is labor intensive and requires intensive management, and since a number of family members in each household now work off-farm, landowners choose to rent out the land they cannot cultivate themselves. This is preferred to hiring labor that is costly²³.

The cost of labor appears to vary, with a range of figures quoted in different villages. In Hasla village in Rangpur, men are paid BDT250/day and women receive BDT200/day, where this differentiated wage structure follows local customs, despite men and women carrying out the same tasks.²⁴ The rates are lower in Thakurgaon: BDT200/day for men while women receive only BDT100/day, showing a greater degree of discrimination, even though women are involved in all aspects of cultivation other than the spraying of chemicals and fertilizer application.²⁵ However, other interviews in the same village in Thakurgaon indicate that wages also vary according to the specific activity performed, and that the rates are higher this year. Labor is sourced mainly from within the village or adjacent villages.²⁶ Dependence on paid labor is exacerbated in the absence of any traditional system of reciprocal labor.

²² 70% of Bhondogoan are Hindu, and 30% Muslim.

²³ FGD, Bhondogoan Village, Thakurgaon district

²⁴ Female marginal farmer, Hasla village, Rangpur

²⁵ Bhondogoan village.

²⁶ Interview with landless tenants, Bhondogoan Village, Thakurgaon district

Several leasing systems exist:

1. Under the *Thibhugar* method, 1/3 of produce goes to the landowner, and all inputs are provided by the tenant.
2. Under the *Achi* system, the produce is shared equally between landlord and tenant, and the former contributes to irrigation and fertilizer costs. This form is usually in effect during the Boro season. This does not occur in the Aman season with respect to fertilizer (there is no irrigation anyway).
3. Contracts – of which there are two types:
 - a) 6 mons (40kg x 6)/biga is given to the landlord, or
 - b) A cash payment of BDT10,000/biga for the whole year.

Dialogues with farmers in Thakurgaon also indicate that leasing strategies vary according to capabilities.²⁷ Some farmers rent in land (cash contracts) for only the Boro season; others rent in land for 2-3 year periods, while others adopt a combination of short and long-term leases based on up-front cash payments. A written contract is signed and witnessed. Seasonal leases cost BDT7,000/biga for Boro and T. Aman.²⁸

In each type of lease, the tenant enjoys autonomy over deciding what is grown on the land. The 1/3 system is considered by respondents to be profitable and hence the preferred renting option. They calculate that since the income from 1/3 of the total crop covers all production costs, accounting for this 1/3 in addition to the 1/3 due to the landlord leaves the final 1/3 of the crop as their profit. Interestingly, while the number of tenants have increased and leasing clearly is an important feature of the agrarian structure, the perception of respondents is that the dependency on renting land within a household's overall livelihoods context has in fact declined compared to 10-15 years ago when people had less livelihoods options. There are now more off-farm livelihoods options with a resulting less dependency on tenancy.²⁹

Figure 16. A small-scale tenant farmer in Bhondogoan village, Thakurgaon



²⁷ Interview with landless tenants, Bhondogoan Village, Thakurgaon district

²⁸ Interview with landless tenants, Bhondogoan Village, Thakurgaon district

²⁹ FGD with marginal and tenant farmers, Rangpur

7. Technologies and Institutions for adapting to water stress

It is important to reiterate at the outset the significantly different adaptation contexts between Rangpur and Thakurgaon on the one hand, and the Barind areas in Rajshahi on the other. While all three districts depend on groundwater, Rangpur in particular and Thakurgaon enjoy significantly better-endowed groundwater tables. Rajshahi in contrast belongs to a different agro-ecological setting defined as already noted, by naturally lower rainfall and groundwater conditions, and a landscape with higher drainage. Investments in adaptation in each district reflect these different conditions and the experiences and perceptions of farmers. For this reason, this discussion on adaptation treats each district separately to bring out relative differences.

Moreover, adaptation in this section is to be understood as the adoption of institutions and any hard or soft technology to address existing or emerging constraints to agricultural production. As such, it can be argued that the installation of DTWs represents the most prevalent adaptation to water scarcity and the uncertainty arising from rainfall variability in all three districts, though the consequences, as noted in previous sections of this report, have been varied across the districts. Evidence, including from the fieldwork that informs this report, is emerging that the benefits provided by DTWs are time-bound and that the adaptation itself is becoming a driver of further water stress in Rajshahi and more recently in at least some villages in Thakurgaon. As groundwater tables are driven further down, this inequality assumes two typologies: 1) between farmers of the same village, some with land within the DTW command area and those with land outside (intra-village), and 2) between villages with and without a DTW (inter-village) where STWs' utility is either faltering or virtually useless as in the case of Rajshahi. Needless to say, such divergence in water security also brings divergent fortunes in food security, income and other secondary aspects of human well-being in areas still heavily dependent on agriculture. In Thakurgaon, for example, rice other than rainfed Aman is limited mainly to land irrigated by DTWs, since the cost of irrigating rice by STW is double that of DTW irrigation. High yielding Boro rice cultivation in fact began only after DTWs were introduced, giving rise to an Aush – Boro/IRRI rice cropping calendar in lowland plots. Land under STWs are restricted to crops such as mustard, wheat and potato. Given that the advent of DTWs and their impacts have already been discussed in detail in previous sections, the following discussion focusses on other forms of adaptation on both supply augmentation and demand management perspectives.

7.1 Augmenting access to irrigation (supply side strategies)

Ensuring a secure supply of irrigation has been the traditional approach to addressing scarcity through expanding frontiers of resource exploitation with the aid of technology developments. In the study areas, this began with the wide adoption of STWs and emergence of water markets, with further technological and institutional innovations leading to a shift in government emphasis towards the DTWs. These developments and their consequences, both positive and negative, are described and assessed in this sub-section.

Shallow tube wells and water markets

STWs could be considered as the most widespread irrigation technology in response to relatively low surface water availability, especially in relation to supporting year round rice production. STWs and water markets based on these are however no longer prevalent in Rajshahi due to the difficulty of operating STWs at current aquifer levels. The details on STWs and water markets therefore reflect the situation in Rangpur and Thakurgaon.

STW ownership and the prevalence of water markets based on diesel or electric STWs varies given the relative affordability of diesel STWs for most farmers and the prevalence of electric DTWs, one of

which can displace over 20 diesel STWs (with command area of about 5 acres each³⁰). The Boro rice crop is entirely irrigated, with supplementary irrigation provided for T. Aman rice and a range of other crops such as wheat, maize and vegetables. The density of pumps was low, with access to irrigation depending mainly on water markets.

The investment needed to become a water seller is estimated to be BDT50,000 for electric and BDT20,000 – 25,000 for diesel STWs. Diesel pumps cost BDT15,000 with another BDT7,000 required to finance the STW. For some farmers, the purchase of these pumps is primarily to support their own cultivation, while the excess pumping capacity is sold to other farmers. For other farmers, the rationale for purchasing a pump and STW is the reverse.

Figure 17. A diesel STW (left) and an electric STW (right)



Irrigation fees quoted during interviews with water sellers and in farmer FGDs varied, reflecting a range of contextual conditions. In Rangpur for instance, irrigation for lowland Boro cultivation from diesel pumps is sold at BDT 1,000/biga that covers the entire cropping season. The water buyer must also supply fuel for the pump that typically amounts to between BDT2,100-2,240 (30-32 liters) for the season depending on the type of land. In contrast, the rate for irrigating the highlands is structured by the hour at BDT60/hr plus fuel. Supplementary irrigation also occurs in the Aman season on highlands at the same rate. This has been the case over the past 4-5 years.³¹

Explanations of the process by which irrigation pricing is determined also varied in terms of whether the price reflected a seller-buyer consensus based on dialogue. In some villages, it was stated that the water price is agreed between the sellers and buyers through dialogue at the beginning of each season. In other villages, water buyers claimed they have no influence on pricing, and there is no dialogue between seller and buyers on pricing. There was more consensus on the factors taken into account in determining a fair price for water, which include the wage of the pump operator; pump and STW maintenance costs for the season; asset depreciation; land condition and crop type. The criteria appear to be the same for electric and diesel STWs.

Overall responsibility for ensuring timely and sufficient irrigation is received lies with the water sellers. They will respond based on prevailing rainfall conditions. This also includes arranging water supply from other sellers if the seller's machine breaks. A seller irrigates his clients' plots on a rotational basis, while for efficiency, tail-end farmers receive water first and the head end last. It was also claimed that priority is normally given to women farmers as they have many household duties. The system appears to work well given the absence of any statements to the contrary even during discussions with small scale farmers. In fact, FGDs with farmers in the study sites confirm the existence of competitive water markets that have kept prices low, making these water markets feasible for even marginal and tenant

³⁰ The command area of an electric STW is about 12 acres.

³¹ Farmer interview, Rangpur

farmers. The only issue arises at times of irregular electricity supply where water is supplied by an electric STW, but the lower water fee from electric pumps means farmers do not complain even though these interruptions can last for 2-3 days. In such cases, the farmers themselves make temporary arrangements with diesel pump owners at BDT100 + fuel/irrigation episode.³²

These interruptions in electricity supply especially in the Rabi (winter) season and the high starting costs dampen interest in electric pumps. Much of the irrigation from electric STWs occurs during the night when electricity supply is better, but is less convenient and may lead to over-irrigation. While sellers use their knowledge of the time taken to irrigate one plot to schedule their sleep (they sleep in the pump shed), they sometimes oversleep leading to inefficiency and losses to the seller. This becomes easier when there are multiple plots close to each other since the duration is longer. On the other hand, it is believed that pumping in the night gives some savings through less evaporation and less pumping. In the case of irrigation supplied by STWs, much of the in-farm canals remain unlined.

Figure 18. Access to domestic water is an important dimension in groundwater management



DTWs, their electrification and displacement of STWs

While STWs are still used in Rangpur and Thakurgaon, the irrigation landscape in Thakurgaon and Rangpur districts is being rapidly altered by the government-financed installation of electric deep tube wells (DTWs) with much greater command areas. In Dhondogaon Village, Thakurgaon district for example, there were about 100 STWs where 6hp pumps supplied about 450 acres.³³ After an electric DTW was installed in 2014, the total area served by STWs today has dropped to 100-125 acres.³⁴ The STWs that still operate draw water from 55-100 feet. The depth of STW boreholes appear to vary from 20 feet in Rangpur to over 100 feet in Thakurgaon. This gradual increase in electric DTWs has meant reduced diesel STW command areas to as low as 2 acres in Rangpur and Thakurgaon.

³² FGD with marginal and tenant farmers, Rangpur

³³ The maximum command area of one 6hp pump is 15 acres, though the area supplied in Bhondogaon village is about 4.5 acres (9 biga).

³⁴ Interview with landless tenants, Bhondogaon Village, Thakurgaon district

DTWs were introduced by the Bangladesh Water Development Board (BWDB) in 1963-66 and were originally diesel powered. This was under the first major irrigation project in the Thakurgaon area, when 380 DTWs were established (Zahid and Ahmed 2006). The establishment and oversight over DTWs in Northern Bangladesh was handed over to the BMDA in 2001-2 due to the poor performance of the BWDB.³⁵ Under the BMDA, there are now almost 15,000 DTWs in its geography of influence.³⁶ The establishment and oversight over DTWs was handed over to the BMDA in 2001-2 due to poor operations and management (O&M) by BWDB.³⁷ Under the BMDA, there are now almost 15,000 DTWs in northern Bangladesh.³⁸

Technical aspects and innovations involved in DTW adoption

Around 1990, the energy powering DTWs changed to electricity due to the unreliability of diesel DTWs and resulting crop losses. BMDA modified the original DTW design by inverting the system to reduce the depth of the screen (Figure 19). This was necessitated by the low water transfer capacity of the conventional DTW design. The new design can output over 3 cusecs of water. DTWs are cased wells where pump is set within the well below the water level. A diesel engine or an electric motor is mounted above the well and is connected to the pump by shaft.

The electric DTW in Dhondogaon Village, Thakurgaon district provides insights into the practical differences between these DTWs and the STWs as well as the institutional arrangements for their establishment and operation. The technical specifications of this DTW are as presented in Table 2.

Table 2. A sample of the technical specifications of an electric DTW.

Well depth	Housing pipe length & diameter	Blind (feet)	Strainer (feet)	Static water level (feet)	Drawdown (feet)	Pump
67.22m (approx. 220 feet)	98 feet, 14 inch diameter	33	85, 8 inch diameter	24.33	9.33	17.5 KW /hr (10hp)

This DTW has a command area of 60 acres, although it currently irrigates only 47.5 acres. Much of the water that supports 65 farmers is conveyed to the fields through 2,000 feet of underground pipes, although more pipes are needed to cover the entire command area – the primary reason for the DTW to be running at under-capacity. While this command area in this village is calculated based on rice production, the area that a DTW can irrigate will vary depending on the specific water demand of selected crops. The command area would be the least under Boro rice, followed by other irrigated rice (T. Aman rice), and significantly more with less thirsty crops such as wheat. The system can run for 16 hours a day, so long as the aquifer level does not unduly stress the pump.

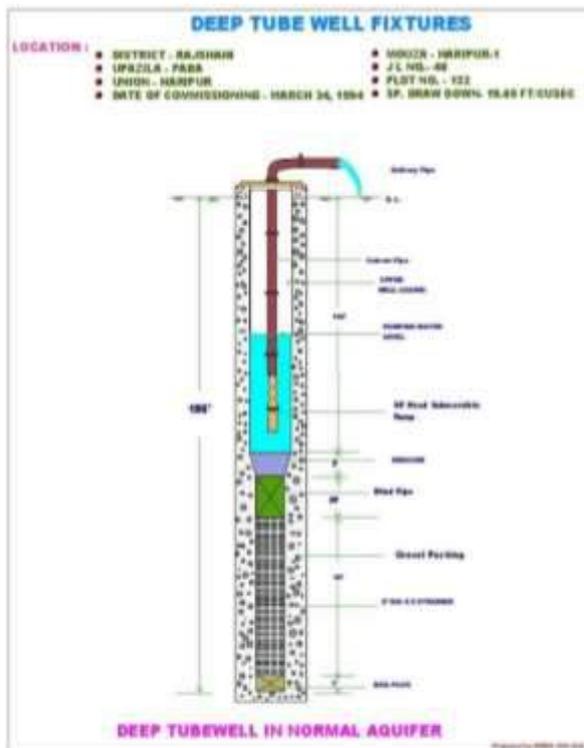
Figure 19. Conventional and inverted DTW designs.

³⁵ Interview with Chairman, BMDA (conducted under the SRFSI Project, August 2015)

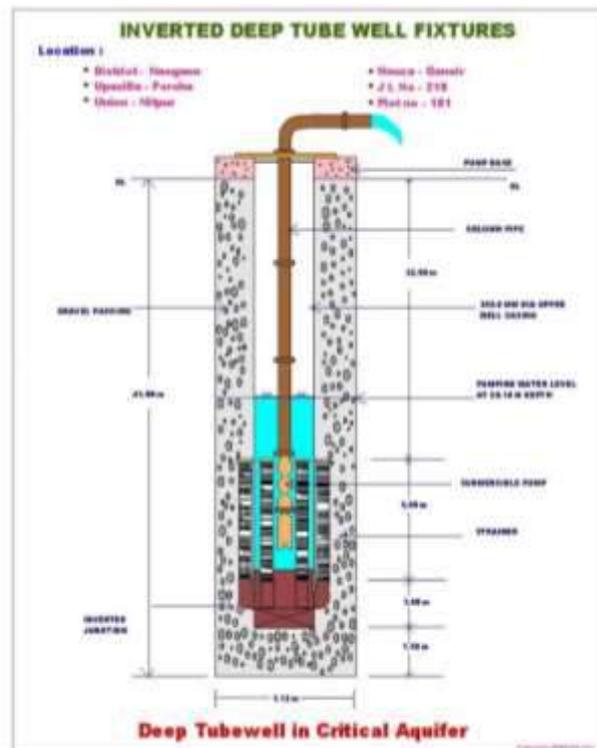
³⁶ Presentation on the Development of Barind Area by BMDA, June 2015.

³⁷ Interview with Chairman, BMDA (conducted under the SRFSI Project, August 2015)

³⁸ Presentation on the Development of Barind Area by BMDA, June 2015.



Conventional DTW



Innovated DTW

Source: BMDA (2015)

Establishment and operation of a DTW

At the beginning of the process of obtaining an electric DTW in Dhondogaon Village, one of the village elders deposited BDT100,000 with the local government on behalf of the farmers. This followed a discussion amongst the farmers in the village on where the DTW was to be located. Each farmer then gave the elder BDT 4,000/acre if they owned the land, or BDT2,000/acre if they rented the land as their contributions towards the deposit of funds.³⁹ The land for constructing the DTW and the operations room was donated by another farmer. Another requirement for eligibility is the formation of a 5-member committee and its registration with BMDA. This committee is needed also for the deposition of the BDT100,000. The committee consists of the individual who deposited the BDT100,000, the person who donated the land to site the DTW and three other farmers. It is noteworthy that these farmers were selected by the other two members and not through a vote amongst the larger group of farmers in the village. However, before agreeing to install a DTW, BMDA will survey the area for the suitability of growing rice, and only then agree to install a DTW. DTWs are thus today predominantly oriented towards growing rice, although this was not the case when they were first introduced.

Construction is carried out by BMDA which absorbs the costs of all infrastructure (around BDT1.5 million) including the DTW, the housing for the electric card system, transformer and electricity cables and the underground pipes. The pipes are favored over canals which tend to crack and also increase the water's exposure to evaporation. After construction electricity is supplied by the Rural Electricity Board (REB). There is no annual license linked to the DTW.

³⁹ Farmer interview, Bhondogaon Village, Thakurgaon district

Determining the command area when establishing a DTW

It was difficult to establish in the time available, how the command area was determined due to contradictory information from different farmer dialogues. Some farmers claimed that which fields come within the command area was determined through a farmer meeting,⁴⁰ while others suggested there was no such meeting.⁴¹ Therefore, although 65 farmers in Dhondogaon village registered to be part of the command area by signing a form submitted to the BMDA, the lack of any formal organization amongst the farmers makes it difficult to ascertain how they and not others registered.

The current extent of land served by the DTW is less than its full command area due to the lack of 1,500 feet of underground pipes for water conveyance. Although BMDA has agreed to supply another 1,200 feet of pipes,⁴² there is no indication of how decisions will be made with respect to the directions in which and to what extents the additional pipes will be laid, and consequently which farmers will be benefited. Furthermore, this extension will still leave some farmers in the village outside of the DTW's reach. One challenge faced in reaching farmers closer to the tail end emanated from head end farmers' unwillingness to allow a canal to be cut to give water to farmers further downstream. These canals represent a loss in productive land that translates to the loss of about 20kg of rice. In such instances, it was claimed that the committee negotiated with the farmers to compensate 50% of their loss, though eventually the farmers have agreed to donate the required land with no compensation.⁴³

The smart card system

To access water, the card must be inserted (Figure 20) to complete the electrical circuit. A card costs BDT 155 from BMDA or BDT 200 from a local dealer registered with BMDA. Each farmer registered against the DTW is issued a card from BMDA and purchases credit as needed, as with mobile phones. As such, it allows each farmer to control the amount of water used. If a card is lost, a new one can be purchased. The system also enables BMDA to cross-check usage at the DTW, and the usage per farmer data stored on the cards can be aggregated. The card is valid within a district but operates only with those DTWs established since 2006.⁴⁴

Figure 20. A distribution gully to which water is pumped from the DTW (left), and a women operating the electric card system (right).



⁴⁰ Electric DTW (BMDA-114-DTW) pump operator, Bhondogaon Village, Thakurgaon district

⁴¹ Farmer interview, Bhondogaon Village, Thakurgaon district

⁴² BMDA has currently agreed to provide 1,000 feet.

⁴³ Electric DTW (BMDA-114-DTW) pump operator, Bhondogaon Village, Thakurgaon district

⁴⁴ Electric DTW (BMDA-114-DTW) pump operator, Bhondogaon Village, Thakurgaon district

Operation and maintenance of DTWs

The government owns the DTWs, but these are operated by the local operator and the farmers. The operator is said to be selected by the farmers through a meeting. When selecting the operator, the farmers are said to consider individual motivation to serve the community, and whether candidates have good connections with government agencies needed for effective management.⁴⁵ In Dhondogaon village, the land on which the DTW is located was given free of charge by the operator's father, which probably also contributed to him being chosen as the operator. While the BMDA maintains all infrastructure such as the pump, motor, pipes and canals,⁴⁶ the costs of repair to the transformer will be divided equally between the farmers and BMDA, while if stolen, the farmers will be fully liable for its replacement.⁴⁷ This measure militates against the common occurrence of transformer theft given their high economic value. According to farmers, the BMDA officers only visit the DTW and not the fields, since their interest is limited to the condition of the hardware and not how the irrigation water is utilized at field level.⁴⁸

The main challenge expressed in this village is the interruption in electricity supply, though the incidence of interruption is less since the Ministry of Agriculture now ensures farmers receive a reliable supply of electricity through a preference to farmers over towns, especially during the Boro season. However, since the best supply occurs between 11p.m. and 5a.m., it is questionable whether farmers are in fact receiving precedence over other consumers since irrigation has to occur at night. Each cardholder needs to come to the operating room to insert the card and access the water.⁴⁹ In villages in Rajshahi (e.g. Pachondor), where groundwater levels are much lower, accessing water itself is now becoming a challenge (discussed below).

Irrigation scheduling

According to the DTW operator in Dhondogaon village, Thakurgaon district, a list of farmers who require irrigation is made every morning, on a first-come-first-serve basis. In practice however, those farmers with plots close together in a particular area will get irrigation at the same time irrespective of where they are placed in the list. The list is merely to document who needs water, while the order in which they get water is determined by irrigation efficiency to minimize energy consumption and water loss where conveyance is through unlined and/or open canals.⁵⁰ It was also claimed that the smaller farmers are given preference as they also need to work as wage labor, and that farmers will change places with each other where a farmer needs water more urgently. It takes 7 days to irrigate the entire 50 acres.⁵¹ These approaches were confirmed during a focus group discussion in Pachondor village, Rajshahi district involving the DTW operators and other farmers representing all farmer classes (tenant, marginal-small, medium and large). Another challenge in Rajshahi is the differing elevations within a small area – highlands (wheat, maize, potato, mustard) to lowlands (mainly rice). To ensure correct irrigation, when water arrives to the outlet, each farmer lets in as much water as needed to their respective fields with highlands irrigated for longer due to greater drainage. Each farmer will use his or her cards for continuous irrigation to the same outlet.

⁴⁵ Interview with landless tenants, Bhondogoan Village, Thakurgaon district

⁴⁶ Electric DTW (BMDA-114-DTW) pump operator, Bhondogoan Village, Thakurgaon district

⁴⁷ Electric DTW (BMDA-114-DTW) pump operator, Bhondogoan Village, Thakurgaon district

⁴⁸ Farmer interview, Bhondogoan Village, Thakurgaon district

⁴⁹ Interview with landless tenants, Bhondogoan Village, Thakurgaon district

⁵⁰ Farmer interview, Bhondogoan Village, Thakurgaon district

⁵¹ Electric DTW (BMDA-114-DTW) pump operator, Bhondogoan Village, Thakurgaon district

Irrigation fee

When DTWs were originally introduced, there was a minimum charge for the irrigation water, but fee collection was almost non-existent. After the shift to electric DTWs, these initially ran on a coupon system. This too was not satisfactory as the officers who collected the money from farmers spent it on themselves – sometimes as much as BDT200,000 at a time. The farmers also began forging the coupons.⁵² These issues were resolved with the introduction of the pre-paid electric card system in 2004 that provides the government the irrigation fee up-front. Farmers buy credit from dealers via a mobile vending unit at TK115/hr. The charge levied to the farmer is based on the flow rate that determines the area irrigable in an hour: BDT80/hr for 1 cusec; BDT100/hr for 2 cusecs, and BDT135/hr for 3 cusecs. The fee covers electricity usage, the DTW operator's wage (BDT10/hour) and the 2.5% commission of the credit vendor, leaving the rest as profit for the BMDA. The rates are decided by the BMDA and Ministry of Agriculture officer, and not the farmers.⁵³ The Rural Electricity Board (REB) provides the electricity at a subsidized rate which equates to BDT 60-80/hr. This may amount to as much as a 50% subsidy depending on the irrigation fee charged.

Maximising the command area - the commission system

Ensuring that DTWs irrigate their entire command areas (for rice) has been a key area of focus for the BMDA so that the full capacity of the DTW is utilized. Approaching full capacity utilization means less wastage of water and less overhead expenses. As such, a target command area is set for each DTW by the assistant engineer's office at the beginning of the irrigation season based on the soil and field conditions, and crop type. Then the concerned extension worker(s) try to materialize this target by mobilizing the farmers in the command area. To motivate the extension workers, a commission system has been introduced by BMDA where a minimum achievement level is set at 60% of the target. No commission is paid unless this limit is exceeded. For achievement levels higher than 60%, the extension worker(s) get 1–10% commission on the total water fee collected. Faisal et al. (2005) believe this has effectively contributed to the doubling of the actual area irrigated with a DTW's command area.

This scheme re-enforces existing affinities between BMDA staff and farmers since about 60% of the officers and most of the field staff come from the local communities. This has greatly contributed to the commitment among staff, as they feel more accountable to the communities from where they come. They also know the project area and may themselves be project beneficiaries (directly or indirectly).

Maximising the command area – Reducing conveyance losses

Another strategy to ensure water reaches all parts of the command area and with minimal loss to evaporation and seepage, was the replacement of earthen channels with underground PVC pipes. These convey water from the DTW to the various distribution points throughout the command area. This has increased conveyance efficiency 50-55% (traditional earthen channel) to an average conveyance efficiency of 92.55% with the buried pipes. Open but lines channels are sometimes used, in which case efficiency is approximately about 88%, also a significant improvement. This has enabled the water distribution system to reach an extra 15.7% - 24% of the command area (Rahman et al. 2011).

Social organization around DTW irrigation

The level of social organisation can be viewed as a weak spot in this system, or at least an area that appears to be neglected. The DTW management committee does not appear to result from a process that promotes its representativeness. The number of very practical issues that need to be addressed at farm level as described above, and their implications for equity, social harmony and the role of collective action to improve production clearly suggests a need for a greater level of farmer

⁵² Interview with Chairman, BMDA (conducted under the SRFSI Project, August 2015)

⁵³ Interview with landless tenants, Bhondogoan Village, Thakurgaon district

organisation. This need is further emphasized when considering the potential for such organisation to improve the terms of trade in local markets, which as farmers acknowledge, are stacked against them. The consistent reason for the lack of self-organisation, where external stimulæ are missing, is the lack of trust amongst farmers. In the case of organising to collectively invest storage capacity for some types of produce, the imperative to covert produce to cash to settle debts is said to militate against this.

Monitoring

BMDA monitors groundwater levels at two DTWs in each Upazilla. The DTW operator is not required to provide periodic reports, although he maintains a logbook to record when farmers access water. BMDA gets data on farmers' use of water from the smart cards and the electric system. There are no routine visits by BMDA officers. The DTW operator will contact BMDA if something is wrong.

To ensure that the annual withdrawal remains less than the annual potential recharge, the BMDA has specified a minimum DTW spacing of 2,500 feet (762 m) based on the hydrogeological conditions of the area. The BMDP collects regular water level data and water samples from a number of observation wells to assess the quantity and quality of groundwater.

Financial sustainability

BMDA recovers 100% of its O&M costs from water charges, including the salaries of all of its employees. A number of factors have contributed to this success. First, the BMDP sells water through pre-paid water coupons. Farmers buy these coupons from retailers who obtain a 2.5% commission on sales. These coupons entitle the farmers to have water from a DTW of a specified capacity for a specified amount of time (usually in hours). These rates are set based on full cost recovery. Thus, this pricing scheme promotes the efficient use of water and ensures financial sustainability of the project. the drive for command area development as mentioned above.

Achievements after the spread of DTWs

Before BMDA was established, there were only 500 DTWs and 5,000 ha of irrigated land. The Barind Tract was the most unfavourable agricultural region of the country where rain fed local T. Aman rice was the dominant crop. In other seasons, about 50% of the land was cultivated with pulses, but only if there was adequate seasonal rainfall, while another 5% would be under wheat. Today there are almost 15,000 DTWs, with those established after 2006 using the smart card system. The introduction and full irrigation of Boro rice, supplementary irrigation to Aman and Aush rice (now 50% irrigated in some villages) in the face of erratic rainfall and irrigation of other field crops has enabled a three-crop calendar in DTW command areas, with more productive cropping patterns including pulses, wheat and vegetables especially in Rajshahi. In addition to vastly increased cropping areas and intensities, yields have also increased. The net result has been an additional estimated 5 million MT of food grains per year from areas supplied by BMDA established DTWs. Another contributing factor is the water saved by using buried pipes to convey groundwater to fields, which is estimated to have enabled an additional 20,000 MT of food grain production annually (BMDA 2015). These gains have turned the region into a major contributor in achieving the country's food (rice) security policy. DTWs are also the only viable option for drinking water in many parts of Rajshahi.

While this transformation is the culmination of a range of interventions and innovations, the expansion and sophistication of the electric DTW system must be viewed as the primary or foremost adaptation to water insecurity. It could also be described as the trigger that lends meaning to most other innovations such as new conveyance methods and cop combination, all of which are subsidiary to this one adaptation.

Another important impact has been on the economics of production, primarily by almost having the cost of irrigation compared to irrigating with a STW. This was the view of farmers especially in Rangpur

and Thakurgaon, though less so in Rajshahi (discussed in the following section). In Thakurgaon, for example, while irrigation of Boro rice with a diesel STW water market cost BDT 3,300-3,500/biga, the cost after the electric DTW was installed is only BDT 1,300-1,500. Another advantage over STWs is the virtual absence of maintenance costs, since these are almost wholly subsidised by the BMDA. Diesel STW pumps break down often. A third advantage is the much quicker irrigation (30 minutes as opposed to 2 hrs/biga) due to the high discharge rate, although here too, this rate is significantly less in Rajshahi (discussed in the following section).

These benefits have combined to materially improve the socio-economic status of farmer households with land within a DTW command area. Farmers interviewed recalled how most households subsisted on only two meals a day. Agricultural profits have now doubled, freeing up funds for children's education, better clothing, and entertainment (TVs and phones). Small savings are even possible sometimes. This has also been facilitated by the construction of feeder and rural roads that have improved access to inputs and markets, and broader connectivity between villages and urban centers.

The smart card system has also changed the social dynamics amongst farmers with respect to access to water. Particularly significant is that it appears to make irrigation access relatively class-neutral since whoever has land around a particular field outlet will receive water together. The ability to invest in the means of water access has been removed as a factor, and STW-based water markets have been displaced. It is worth noting that no reference to inequity was recorded despite farmer class oriented FGDs and individual interviews.

Against these achievements, only two systemic issues were noted. One is the assertion by some farmers that non-rice crops tend to be over-irrigated due to the high discharge rate of DTWs, which can reduce yields. The other issue was some loss of flexibility in irrigation given that especially during the high demand Boro season, the scheduling of irrigation according to distribution outlet can result in delayed irrigation.

It should also be noted that while supply augmentation via the DTWs has been the primary strategy, BMDA and its partners are also engaged in lowering the water demand of agriculture especially in Rajshahi, not only through crop choices, but by experimenting with water saving land management practices.

The existence of a semi-autonomous, yet state funded institution such as the BMDA specifically created to address water scarcity and related agricultural constraints, working in tandem with other state agencies particularly BARI, the Bangladesh Rice Research Institute (BRRI) and the Department of Agriculture (the roles of an irrigation department are subsumed by the BMDA), represents an institutional context an order of magnitude more enabling than what appears to exist in the India and Nepal study areas. Despite manpower and other logistical constraints, most of the line departments were found to have good networks up to the upazila level. BMDA and DAE also maintain good networks and links at levels below the upazila level. For instance, the DAE has block level representatives where the Sub Assistant Agriculture Officers (SAAOs) operate with the community. The integrated nature of its programs that also involves the Power Development Board and the Rural Development Board should be noted. Such an approach in turn is enabled by a wide-ranging mandate covering a range of investments in necessary infrastructure (e.g. canals, small dams and road construction).⁵⁴ In terms of irrigation supply, this is perhaps best illustrated by the innovations BMDA itself has made in DTW technology by inverting the conventional DTW design to enable reduction in the depth of the screen, thereby enabling its operation even when groundwater levels are relatively thin. Few agencies can be found working with a mandate to overcome natural water stress now

exacerbated by climatic variation that enjoy the powers, philosophy and approach of the BMDA. As such, the BMDA remains the spearhead for ongoing adaptation in the agriculture sector in northern Bangladesh.

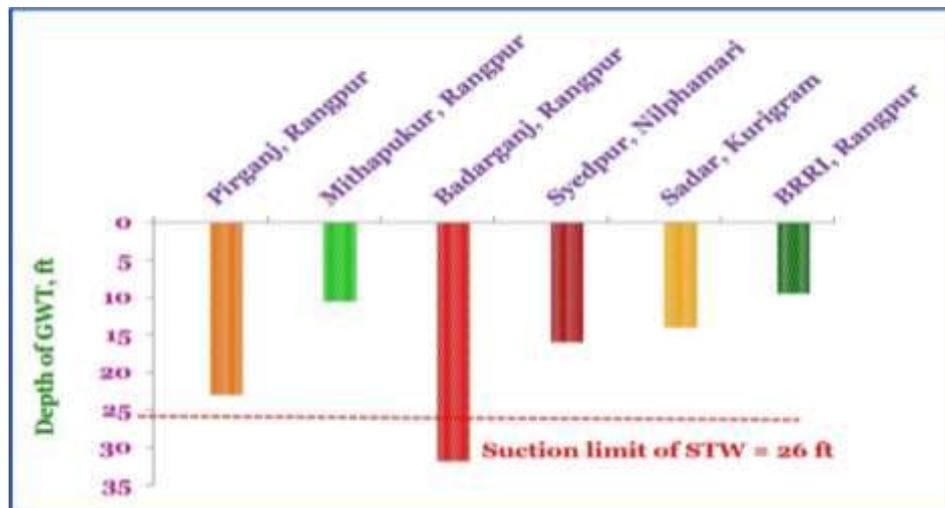
Emerging challenges

While access to electric DTWs has brought several benefits to farmers located within their commend areas as detailed above, the dialogs with farmers and some government officers do bring out some developments they attribute to DTWs.

Declining groundwater levels in some study sites

Farmer interviews in each district have generated three distinct scenarios with respect to the condition of groundwater. Most respondents in Rangpur, whether DTW or STW dependent for irrigation, had not experienced any serious issue with accessing groundwater, though they are aware of a seasonal drawdown when Boro rice is irrigated. Figure 21 from BRRRI (2014) however suggests that in some locations, the drawdown during Boro rice cultivation is beginning to have a seasonal impact on STWs. It appears from farmer experiences, that full recovery occurs following the monsoon, with no major impediments to irrigation overall.

Figure 21. Ground water status of Rangpur region during April 2014.



In Thakurgaon, farmer interviews suggest the district is more advanced along this trajectory. STWs stop working in March-April (Boro season), and damage to their pumps is common. Virtually all pumps in Dangi Para (Purbo Begunbari village) where there is no DTW were damaged in 2015. The decline in the water table means that STW users in this para can no longer provide timely supplementary irrigation for Aman rice, whilst rainfall becomes increasingly unpredictable. The same issue arises in the case of Boro rice and Rabi crops such as potato, wheat and maize. The knock on impact is lower yields across these crops and seasons, and increased irrigation costs that now constitute over 50% of total production costs. Farmers estimate that they therefore earn BDT 30,000 – 40,000 a year less than DTW supplied farmers. They expect this gap to grow as they believe production costs will increase. Domestic hand pumps in most villages also struggle in March-April.

The divergence of opinions amongst government officers interviewed in Thakurgaon on the state of groundwater levels is also worth noting. Based on Groundwater monitoring records, the Assistant Engineer, BMDA does not think there will be major changes to levels unless there are significant climatic impacts. Data from the monitoring wells suggest that the water level drops 25 feet towards the end of the Boro season, but recovers during the monsoon, and is available from 5-8 feet. In fact, he cites a 2015 study by the Institute of Water Modelling (IWM) that suggests groundwater resources

can in fact support additional DTWs. In contrast, the Agriculture Officer from the DAE expressed concern about groundwater depletion that is seen as a key challenge within the DAE. The DAE is therefore now operating on the principle of minimum groundwater use by promoting crops with a minimum water requirement in the district.

The water security scenario in Pachondor village in Rajshahi is more extreme. In this village, STWs and domestic hand pumps are now redundant, with farmers as well as households entirely dependent on the electric DTW located in the village. Yet this DTW is itself struggling during boro season. At the time of the farmer interviews, its pump was broken despite the DTW being re-located and deepened in 2014. This has occurred for several consecutive Boro seasons as pressure in the pump builds due to over-use (about 15 hours a day during this season), but in 2016 the pump broke earlier in the Boro season than in former years. The Sub-Assistant Agriculture Officer (SAAO) of the DAE overseeing this village estimates that decreased discharge rates from the DTW has increased irrigation costs because irrigation duration has increased by 300%. There is not surprisingly, a growing supply deficit in the Boro season.

A widening gap between STW users and DTW users

The DTWs and associated innovations have clearly contributed to continued gains in especially paddy production along with water security to farmers. However, dialogs on water security with farmer served by DTWs and those outside of DTW command areas (STW users) show a distinct divergence of fortunes of STW and DTW dependent farmers. The impacts of not being served by a DTW can be limited to the Boro season where the largest drawdown occurs, or year-round where more permanent declines in aquifer levels have occurred.

Seasonal problems for STW users were reported in the Ramnatha Para case study village in Rangpur district. Here, farmers using STWs (those outside of the DTW command area) infer that groundwater levels are gradually declining based on the declining water discharge of STW pumps towards the end of the Boro season. Consequently, more time is required to irrigate the same land area leading to higher production costs. Domestic manual tubewells also sometimes run out of water during the Boro season. This scenario in fact appears to be similar to that which is depicted for Badarganj village in Figure 21.

The scenario appears to be more serious for STW users in Dangi Para (Purbo Begunbari Village), Thakurgaon where increasing STW failure is significantly curtailing crop production and income. The net result has been lower yields (Table 3) and incomes that are BDT 30,000 – 40,000 a year less than those of DTW-based farmers. Farmers in this village expect this gap between DTW and STW farmers to grow especially as they expect production costs to increase. Another important facet to these changes is that domestic hand pumps in the village also struggle in March-April in the Boro season.

Table 3. Differences in yield between STW and DTW users as estimated by farmers in Dangi Para, Purbo Begunbari Village, Thakurgaon

Crop	STW (mon/biga)	DTW (mon/biga)	Notes
Aman rice	18-25	32-35	Cannot provide supplementary irrigation on time with STWs.
Boro rice	40	50-60	Cannot irrigate on time due to low GW levels.

While primary data collection for this study was limited to a few villages in each focal district, interviews with government officers such as Assistant Engineer, BMDA in Thakurgaon suggest the

situation faced by farmers in Dangi Para may reflect those in other villages in this district. The majority of villages in Thakurgaon in fact still rely on STWS since DTWs irrigate only 30% of cultivable land according to this Engineer.

Water insecurity is most advanced in Rajshahi where STWs do not function in much of the district, and struggle to access water where they are still found. The dominant view during interviews with farmer still relying on STWs is that this is a direct result of DTWs and the intensification of cultivation.

These different farmer experiences are reflected in their very different perceptions about the current and future water security scenarios. Farmers in DTW command areas in Rangpur and Thakurgaon expect another 15-20 years of good irrigation, and feel no imperative to adapt their cultivation practices. STW users across the districts in contrast, are not surprisingly more anxious of further loss of irrigation, and are extremely keen to acquire an electric DTW. In Pachondor village in Rajshahi, the case study village for this study, farmers are concerned over water security despite their access to an electric DTW given it now clearly struggles to support Boro rice cultivation.

With irrigation costs rising rapidly (driven also by increasing diesel prices), where irrigation is even possible with a STW, and rainfall and temperature variation likely to increase irrigation demand, the plight of STW users thus emerges as a fundamental policy question. For these communities, absence of a DTW represents a dual problem since hand pumps used to supply domestic water also cease to function. The severity of the impact on human development can be illustrated by the fact that for farmers whose STWs no longer work, they may regress decades in their development if they become mainly reliant on rain fed crops. They will, in other words, be returned to the pre-BMDA era of subsistence.

7.2 Strategies to reduce water demand

The significant investments in enhancing farmers' capacities to intensify the exploitation of groundwater discussed under section 6.1 have clearly generated dividends in terms of rice production in particular. However, the diverse and in some areas, evolving groundwater security scenarios noted in the same section are driving greater farmer and government attention towards demand side adaptive strategies that seek to lower crop water requirements. Noting the diversity in groundwater conditions between the study districts and sites, the degree of such strategies was found to be significantly different, with the sites visited in Rajshahi representing a significantly broader range of strategies given the less favorable climatic and topographic conditions for irrigated rice production.

Adapting through crop selection

A number of factors were found to influence crop choices, with significant variation across the villages in the three study districts. Water availability was not always the driver, especially in the study villages in Rangpur in particular and in Thakurgaon. In fact, while intersecting with water availability, the primary factors influencing crop choices in different seasons appear to be differences in land elevation, markets and perceptions of food security that strongly wed farmers to rice production. In the Rangpur and Thakurgaon sites, crop choice is far less driven by a concern water availability compared to these factors. With markedly different water availability, the influence of water security is more prevalent in Rajshahi as described below.

Crop choices in Rangpur and Thakurgaon – responses to differences in land elevation rather than water scarcity

The impacts of land elevation apply across the three case study sites, and intersects with water availability in driving farmer decisions on cropping. In lowlands, high soil moisture and poor drainage makes it more suited to paddy cultivation. Land of medium-high elevation with better drainage (and

hence lower water retention) is more suited to less water intensive crops. This is especially the case given the undulating nature of land in the Barind area of Rajshahi. This influence of elevation is illustrated by the following. Mr. Selcadew Ali, a farmer in Ramnatha Para (Rangpur) grows

- Lowland: Late Boro rice and T. Aman rice
- Highland: Jute during Aush; Aman rice and Maize/Brinjal/potato during Rabi.

In contrast, another farmer in the same village grows the following:

- Lowland: Fallow in Aush due to flooding; Boro rice and T. Aman rice
- Highlands: Maize during Kaif I; chili/brinjal during Kaif II and potato during Rabi.
- Medium land: Potato during Kaif I; Jute during Kaif II and T. Aman rice potato during Rabi

Most non-paddy crops are grown on land of medium-high elevation, and many such as potato, mustard, maize and vegetables are fully irrigated. Although Boro rice can be technically grown on highland plots, the increased water demand due to better drainage makes it less profitable. Along with rice, jute is grown on medium elevation and on lowlands where the irrigation requirement is less as it can tolerate waterlogging if drainage is poor. For highland cultivation, the same crop is not repeated the following year in the same plot - a rotational system is followed to maintain soil productivity.

Perceptions of food and water security maintain a focus on rice in Rangpur and Thakurgaon

In Rangpur and Thakurgaon in particular, rice production remains dominant with two major (Aman and Boro) rice crops, using high yielding varieties (HYVs) that were introduced as a package along with irrigation. In addition to the strong practical (food security) significance of rice to farmers, relatively high yields of 4,000kg/ha are another major reason for the stability of rice in the cropping calendar. The DTWs are clearly another major factor. Not only have they renewed water security, but have halved irrigation costs and significantly reduced irrigation time. In terms of water security, most farmers in the Rangpur and Thakurgaon sites (where electric DTWs operate) are of the view that no significant changes to the water level will occur next 5 years, but rather in next 15-20 years. They also feel that by then there will be innovations that will reduce cropping time that saves water.

The choice of rice variety in lowland cultivation is influenced by yield potential, household taste preferences and profitability. There has been a shift away from traditional rice varieties that were mainly suited to rainfed cultivation to new varieties that provide higher yields and enable irrigated cultivation in the dry season. Farmers with several lowland plots may in fact grow the rice variety preferred by the household on one plot, with another variety for sale on the other plots. According to farmers in the Rangpur site, the cost of irrigation is not a factor given all the varieties require similar irrigation, amounting to 20% of production costs for Boro rice.

These farmer perceptions and attitudes contrast with the DAE's evolving strategy in Thakurgaon district where it now operates on the principle of minimum groundwater use by promoting crops with a minimum water requirement. According to the Sub Assistant Agriculture Officer, central to this strategy is trying to move away from Boro rice in favor of Aush rice, which consumes 50% less water, wheat, maize, potato and vegetables through farmer training, onsite training and creating farmer groups. However, he too acknowledged the challenges in implementing such a strategy, citing the relevant inelasticity in rice cultivation to even the low rice prices experienced over the past 2 years. He too re-iterated the role of food security, and the fact that rice is relatively easy to cultivate in comparison to vegetables which needs large amounts of chemicals and labor. Some crops such as potato also involve high risk given its susceptibility to late blight in the Rabi season.

In contrast, it is worth noting that focus group discussions in Dinajpur district (located between Rangpur and Thakurgaon) under the SRFSI project indicate some degree of farmer driven change in

cropping patterns, including a reduced focus on Boro rice mainly amongst farmers served by STWs. Some of these farmers now crop T. Aman-potato-maize or T. Aman-maize-T. Aman instead of T. Aman-potato-Boro. This is due to paddy prices that lag behind rises in production costs that include higher irrigation costs. Farmers stated that the cost of irrigation (using STWs) has doubled over that past 10 years due to a doubling of diesel prices.

Crop choice as adaptation to water stress in Rajshahi

In the Barind area of Rajshahi, while the advent of DTWs has increased overall cropping intensity and crop diversity, crop substitution has been a key adaptation. Although cultivation is also dominated by rice including Boro rice given its high yields, substitution for Boro rice is a somewhat established trend unlike in Thakurgaon and Rangpur. With respect to intensification too, the additional (third) crop choices have been those with a low water demand: lentils, wheat, potato, chili, brinjal and mustard. The reasons connect to the specific biophysical conditions of higher drainage, greater water insecurity (lower rainfall, lower groundwater levels with slower recharge rates). Moreover, given the multiple natural biophysical constraints to agriculture, adaptation has a much longer history in Rajshahi. This has importantly also been characterized by close collaboration between farmers and government agencies such as the BMDA and BARI in identifying adaptive strategies. Farmers especially in the Barind area are well aware that DTWs are only a temporary measure (a band-aid) given the continuing decline in groundwater levels. They therefore believe that demand side measures are critical if they are to keep adapting to this continually evolving water security scenario. In fact, as is the case in Poshtin Para in Pochandor Village (the case study site in Rajshahi), STWs have lost their utility since 2013/14 when groundwater levels dropped beyond their reach. With STWs no longer able to provide irrigation, Boro rice is not feasible, unlike in the other two districts where even farmers using STWs or associated water markets can still grow Boro rice, be it at higher production cost. The only rice crop in this part of Pochandor village is rainfed Aman rice, while other crops such as fruit trees (lychee, lemon), and pulses such as lentils, turmeric and wheat that require less water are grown where a pond or mini-DTW is available. These provide a year round income. Yet further challenges appear imminent, as Aman has become risky due to greater rainfall uncertainty especially towards the end of the growing season when it has tended to fail. These farmers are however able to cope because many also own/lease land in other parts of the village that are served by a DTW. As such spatially dispersed and ownership/leases acts as an incidental buffer to growing climatic risks linked to water security.

It is believed by both farmers and state agencies such as BMDA and BARI that the largest potential for reducing crop water demand lies in replacing the traditional summer Boro rice crop with wheat and other high value crops, that reduce water demand and increase farmer income. It would also allow for adding another crop such as a pulse into the cropping mix. Potato has also been adopted given its profitability and with support from BMDA. Its profitability stems partly from an increase in demand from poultry and dairy farms and export markets, and the availability of affordable cold storage services, which allows farmers to withhold part of their crop until prices increase. This however would only be an option for farmers who do not need to convert their entire crop upon harvest to settle credit. Consequently, Boro rice production has reduced by 20% in recent years, replaced by wheat, maize and pulses.

BARI promotes crop combinations based on crop water demand for specific seasons. Crop combinations across seasons are also driven by consideration of inter-crop relationships. Farmers are therefore encouraged to grow Nitrogen fixing legumes after wheat and prior to T. Aush rice. Extension is therefore critical given such choices are highly knowledge and time dependent, and will be challenging for farmers to work out on their own. A scientific approach for optimal land and water use through crop choice is however disrupted by other critical practical considerations, especially the perceived profitability of suggested crops. Therefore, market conditions are a major determinant of farmers' crop choices, linking directly to their perceptions of risk. Extension officers therefore select

crops based on prevailing market and water conditions on a seasonal basis and promote these with farmers.

While there has been some success with this approach in this district, large-scale changes in cropping patterns is however proving to be challenging. Most farmers are yet not convinced that markets will provide price stability, and over-supply remains a risk if many farmers adopt the same crop. At national level however, markets for many non-rice crops are characterized by large in-country supply deficits. Rice however is over-supplied. Markets therefore involve a meso-micro dynamic that is difficult to manage at the local level. Another issue with local markets is the inequality between farmers and buyers (wholesalers, millers) which translates into low purchasing prices. Part of the buyer's power arises from high levels of collusion with government officials. This problem persists despite the creation of a buying center in each Upazila in Rajshahi district, as these centers are controlled by political parties.

As may be expected, crop diversification and substitution is more prevalent amongst the larger and medium farmers who have more land and investment capacity. A number of these farmers in the case study site in Rajshahi and elsewhere are converting land to orchards of fruits such as lychee, guava and lemon given their profitability, or interspersing these crops with more traditional crops. Lychee cultivation, which has begun in 2016 according to farmers, is typically on land that does not receive DTW water, or where irrigation flows from DTWs are no longer reliable. Guava cultivation is increasing amongst these farmers, given it can yield a profit of between BDT 250,000 – 500,000/biga. Many large farmers are also entrepreneurs and are rarely dependent on farming alone for income, and also have greater flexibility in finding investment funds, including the transfer of earnings from business into agriculture. Crop diversification is further assisted by larger landholdings more often being distributed across lowlands, medium-elevation and highlands, affording greater crop options according to prevailing environmental conditions. This also helps generate income from other crops while guava or other fruit trees mature for two-three years before they can fruit.

Overall however, crop substitution has clearly had a major impact on agriculture production in the Barind area. Evidence gathered under the SRFSI project in fact shows that even in areas that do not have a DTW, a larger area of land is cultivated with wheat and pulses. Underlying these results are also the new crop varieties bred in-country that possess drought tolerant and/or high yielding properties.

Rotational cropping in Rajshahi

Many villages in the Barind area face water scarcity despite having a DTW, and this includes the case study village where the DTW pump breaks down in the Boro rice season. When it does operate, discharge rates are low. This often means that cropping areas are far smaller than the command area. Rotational cropping has been introduced by BMDA in such areas since 2012 to ensure all farmers with land in a command area get access to irrigation in an equitable manner, although no evidence of this was found in the study village. Where this does occur, the yearly rotation is managed by the farmer committee which manages the DTW. This method is applied mainly to lowland fields growing rice. Highland fields will be excluded as these are used to grow crops with a much lower water demand. This is not seen as an exclusionary approach, but simply a practical one.

Other adaptation measures identified from Rajshahi district

From crops to fish/fish and crops

Fish culture in ponds is not new in the area, being practiced by Hindu villages for at least 20 years. However, the conversion of farmland to fish ponds appears to be accelerating due to its adoption by Muslim communities as well, driven by the profitability of fish in local markets where demand and

prices have risen over time, in contrast to prices of rice. The commonly grown carp and Rui varieties can fetch profits of BDT 50,000 - 100,000/year, which are 150%-300% more profitable than Boro rice, and at least 100% more profitable than any other crop. Ponds range from small to large, the later covering 2.5 acres or more. The larger ponds are only affordable to large farmers given a pond of 2.5 acres costs BT 300,000 to dig or BDT100,000-150,000/year/acre to lease. The adoption of fish culture does not appear to be the result of or supported by government extension services. Pond owners interviewed learn about fish culture mainly from feed and medicine suppliers, and obtain fingerlings from local suppliers.

In some cases, farmers combine fish with irrigation. Thus, a farmer owning a pond of 2.5 acres can irrigate 1.5 acres of Boro, Aman and mustard. The actual area irrigated depends on the context. The entire area is irrigated if the pond is used as a buffer where a DTW exists, but cannot satisfy the entire irrigation demand. A lesser area is irrigated if the cropland is outside of a DTW command area. Ponds however are generally located close to a DTW or mini-DTW (discussed below) even if the farmland is outside its command are. This ensures that when the pond water level drops, it can be filled by purchasing water from the DTW at BDT100/hr. In the case of a 2.5 acre pond, 15-20 hours of pumping is required. It is also common for pond owners or lessees to sell pond water to other generally marginal to small farmers for irrigation using a Low Lift Pump (LLP). In return, these farmers pay the cost of replenishing the pond water from a DTW/mini-DTW. Where a farmer pays for one hour of pumping from a DTW, he is entitled to for 3 hours of pumping from a LLP. Such access is generally given to farmers growing non-rice crops given lower water demand. Water can be pumped out up to the minimum level needed for the fish, which is clearly marked. While ponds are one method of storing monsoon water for multiple uses, their adoption appears to be driven more by the high profitability of fish, and farmers' belief that fish will be even more profitable in the future. The fish also provide financial flexibility to the owners who also grow crops as they can be easily converted to cash in local markets if money is needed for inputs.

Smaller or mini-ponds are much smaller. One such pond for example was 40² feet in area and 10 feet deep. Some such ponds, as in this case, have been renovated by the Bangladesh Rice Research Institute (BRRI). This particular owner uses the pond to grow fish for his family and for sale, and sells water to four marginal farmers who between them irrigate 1.5 biga (the ponds can irrigate up to 5 biga depending on the crop). They grow lentils and other non-rice crops during the Rabi (winter) season, and also use the pond to supplement Aman rice that increases their yield by 50%. The farmers pay the pond owner BDT 120/biga each as a contribution to the cost involved in replacing the pond water from a mini-DTW. For the owner, the primary value of the pond is the BDT 3,000-4,000 he saves by supplying fish for his family year round. In this instance, no minimum water level has been set, and water is given to the farmers on trust that they will leave sufficient water for the fish, a system that have worked well for three years.

Mini-DTWs

Unlike their government sponsored larger cousins, these tube wells are private investments. According to one such investor, his well can reach similar depths as a large DTW (his is 134 feet deep), but the discharge rate on mini-DTWs is lower, and their command area is generally between 15-60 biga. Their costs, at BDT200,000-300,000 to establish and a BDT 70,000 bribe to Rural Electricity Department, are also within the reach of large and medium farmers. This farmer financed hi mini-DTW through a loan from the Agriculture Development Bank and a mortgage of part of his land to a local money lender who enjoys the right to cultivate this land until the loan is repaid in full. The lower discharge rate means it requires 5-8 hours to irrigate 1 biga at a cost of BDT100/hr, which makes irrigation significantly more expensive at BDT500/biga than the large electric DTWs and even diesel STWs (though these are not feasible). He sells excess capacity at BDT120/hr, and claims that he recovers his entire monthly irrigation cost in this way, which enables a total Boro rice profit of between

BDT 108,000-114,000. Permission for mini-DTWs have also been suspended, by way of not granting an electricity connection.

Conservation agriculture

The promotion of new tillage options such as strip tillage and zero tillage, along with bed planting, can be considered as a relatively new frontier in adapting to water stress. Tillage options, promoted primarily by BARI, seek to maintain residual soil moisture to reduce the time between crops through early crop establishment. Minimizing damage to soils and crop water demand are seen as important elements of agriculture sustainability as cropping intensifies to support growing populations. These efforts are supplemented by the Department of Agriculture Extension (DAE), which promotes organic and green manure. While the DAE claims 30%-40% of farmers use organic manure, no examples of such use were found in the villages visited for this report. Use of organic manure is in fact a traditional practice which is in decline due to chemical inputs, and being labor intensive, they are considered to be more expensive than chemicals. The economics is therefore clearly against adoption, and it is only those who value longer-term benefits (soil fertility, sustained yields) that continue to use organic manure.

BARI has promoted purpose-modified machinery for a number of tillage practices through long-term demonstration sites in collaboration with farmers to whom BARI guarantees full compensation in the event of crop loss or low yields. The original machines are imported from China after which they are modified to suit the various land preparation methods being promoted. Additional parts are manufactured in Bangladesh to be fitted by which the machines are suited for use by farmers. The experiments involving farmers include the provision by BARI of bed planters and power tillers over the past 5 years. The bed planter can also be modified to become a strip tiller by attaching a purpose-built plate. These are meant to reduce barriers to adoption by reducing the labor needed for land preparation. The power tiller for instances requires the land to be dug only once, compared to two or three times with traditional land preparation practices. In the case of bed planning, the machine can reduce labor costs from BDT1,500/biga to BDT300/biga, while such technologies can also lower irrigation costs by about 50%. Wheat with zero tillage sometimes requires no irrigation at all. Strip tillage is being trialed with maize, wheat, lentils and mung bean, while bed planning is applied to wheat, lentils, mung bean and sesame. Strip tillage appears to be the most profitable according to these trials. It also has minimal impact on the soil, is low on labor demand and is easier to carry out for farmers.

While field trials appear to demonstrate real benefits of the tested tillage methods, the machinery meant to reduce associated labor costs currently remain difficult to operate for farmers. This is an important challenge, and a USAID-funded project is currently looking at how the machines can be made easier to operate. The dearth of such machines in local markets and repair centers is another major impediment since farmers have to rent them from either BARI or a few large farmers who have purchased them. Attempts to involve the private sector in manufacturing these machines have not been successful and the government's machine tool factory in Gazipur has also not been responsive. Significant financial support is needed to develop good machines and train farmers in their use. This dearth of machines materially reduces the flexibility afforded farmers in scheduling their farming activities. Adoption thus also remains closely dependent on BARI's support by way of access to the machines. This means that were BARI's assistance to stop, most current adopters will have little choice but to return to previous practices. These are seen as the major constraints with respect to the adoption of water saving tillage options. In the case of zero tillage, an added challenge is to convince farmers who have been used to frequent tillage that crops can be successful without any tillage at all.

Consequently, adoption of these tillage techniques are estimated to be only around 10%, though interest levels of farmers suggests more would adopt if the machines are available. BARI staff who

work directly with farmers further point out that farmers are not used to collaborative problem solving. This presents a barrier to co-ownership arrangements that could reduce the per farmer investment in machinery. A lack of trust is presented as the underlying cause, and reflects more general discussions around collective action in FGDs with farmers in all districts.

Overall, conservation agriculture is relatively new, and remains in the trial phase, with no extension system to promote its widespread adoption. Given its dependence on the availability of purpose-modified machines, which are critical to minimize labor costs, these tillage and other land preparation practices are unlikely to gain traction until in-country capacity is developed for manufacturing good quality machines at affordable prices.

Alternate wetting and drying (AWD)

This water saving method is being promoted by several agencies including BMDA, BARI, DAE and BRRI for rice and other crops such as wheat. Boro rice is a particular target given it is the primary driver of groundwater decline. Adoption levels however are low in Rajshahi as well as in Rangpur and Thakurgaon. The issue appears to be not so much farmer awareness, but the complexity of the method, needing timely monitoring of water levels by farmers who also see it as too much work. Failure to introduce any methods to reduce the groundwater footprint of Boro rice can be viewed as a significant missed opportunity to avoid the substitution of Boro rice that is taking place in Rajshahi in an effort to save groundwater. Given that the Boro crop has underwritten national self-sufficiency in rice, its replacement threatens to reverse these gains.

7.3 Other factors influencing the adoption of adaptation technology

Agriculture extension

Experiences in Rangpur in terms of agricultural extension services varied. Some farmers claim that extension officers will visit the village mainly if they are requested to come. Much of these requests for technical advice centers on dealing with pests and disease. Water management is not discussed as it is not seen as an issue.⁵⁵ According to others the Sub-Assistant Agriculture Officer (SAAO) of the Department of Agriculture Extension (DAE) visits frequently to provide information on rice varieties, chemicals that need to be used and how to use them. They ask for information on pests and other issues as they occur. Water management does not feature since it is not perceived to be an issue.

The DAE has established a livelihoods group for women where members contribute BDT100/month which is deposited as savings. Members will get their savings back along with interest when their respective memberships mature in 5 years, though the interviewed member did not know what the interest rate is. This member plans to use the funds for starting a business or improving the house. She is reluctant to take a loan from the group as she is not confident of being able to pay it back, as she belongs to a marginal farming household. She does not participate in the meetings due to the lack of time, although she would like to do so to access information and acquire new skills such as growing good quality seedlings and good seed preservation, home gardening and cattle rearing practices.⁵⁶

In Thakurgaon, some tenants claim that the SAAOs only focuses on land owners, and that even amongst land owners, the focus of the SAAOs is on larger farmers due to their close personal contacts. If these farmers are unable to attend, they are replaced with one of their relatives. It is claimed that priority is given to landowners also since the government knows they have greater incentives to apply what they learn, and that these can be implemented year on year. The representatives of the companies that sell chemicals are also consulted as they respond faster. The SAAO does respond to

⁵⁵ Farmer interview, Rangpur

⁵⁶ Female marginal farmer, Hasla village, Rangpur

request for assistance, but it takes longer.⁵⁷ Women interviewed in the same village have received a range of training including on integrated farming systems, livestock, poultry, orchards, and home gardening. They also received orchard plants and money which they have used to purchase mainly poultry. Consequently, they feel women and men have the same training opportunities, though they point out that time is a major constraint for women. Women's outstanding knowledge needs were described as proper paddy seedling transplanting and seen preservation. There appear to be no NGOs in either case study village in Rangpur and Thakurgaon.

Volatile and manipulated markets

Although the government sets a price floor for paddy via a multi-agency committee based on the cost of production, farmers can rarely obtain this price due to the bargaining power of the local middlemen and millers who also maintain arrangements with government officers such as the Food Control Officer tasked with enforcing the price floor.⁵⁸ The duality in market prices is clear given that while the current official farm gate price for paddy is BDT880/40kg, the actual market price received by farmers in Thakurgaon is only BDT550-600/40kg. This represents a loss of BDT330-280/40kg (37.5% - 32%) for farmers who are forced to sell at this lower price set by the middlemen and millers who collect the paddy from the village. The farmers have tried to negotiate with the middlemen without success. It is however notable that such negotiations have occurred on an individual basis, indicating a critical lack of social capital for collective bargaining. This is attributed partly to the different situations of farmers. Those who rely on credit require cash soon after harvest to settle these debts. There is also no storage capacity in the village. This would have provided an option of selling some of the produce once the market price increases some months after the harvest season. Currently, the farmers are not willing to come together to get a better price and look at collective savings to finance common storage facilities.⁵⁹

Restricted access to credit

Most credit programs target women through savings groups. Credit in farming is through intra-village borrowing.⁶⁰ Chemical companies give the cheaper and less effective chemicals on credit, but not the better quality ones. This differentiation creates incentives for the use of lower quality chemicals.⁶¹

8. BMDA: institutional innovation driving multi-dimensional adaptation in the Barind area

Noting low levels of agriculture production in the North and especially in the Barind and in Rajshahi, the Barind Multi-purpose Development Project (BMDP) was begun in 1985 under the Bangladesh Agriculture Development Corporation (BADC). To improve livelihoods and increase the area's contribution to the national food security drive, the BMDP was tasked with bringing 0.4 million acres of land under irrigation. The approach was conjunctive in nature, given it included installing a network of over 5,000 DTWs, augmenting surface water resources through the restoration of thousands of water tanks, re/excavating over 100 km of canals, raising cropping intensity from 117 to 200%, and constructing 110 km of feeder roads. The project also aimed for electrification of irrigation equipment and agro-based industries, large-scale afforestation and expansion of nurseries to achieve ecological balance. Upon review in 1990, the completed project was deemed a success, and a decision was taken to accelerate this development approach in the Barind area, for which a separate authority was

⁵⁷ Interview with landless tenants, Bhondogoan Village, Thakurgaon district

⁵⁸ Farmer interview, Bhondogoan Village, Thakurgaon district

⁵⁹ STW owners, Bhondogoan Village, Thakurgaon district

⁶⁰ Farmer interview, Rangpur

⁶¹ Interview with landless tenants, Bhondogoan Village, Thakurgaon district

deemed necessary. Thus, the Barind Multipurpose Development Authority (BMDA) was created in January 1992 under the ministry of Agriculture.

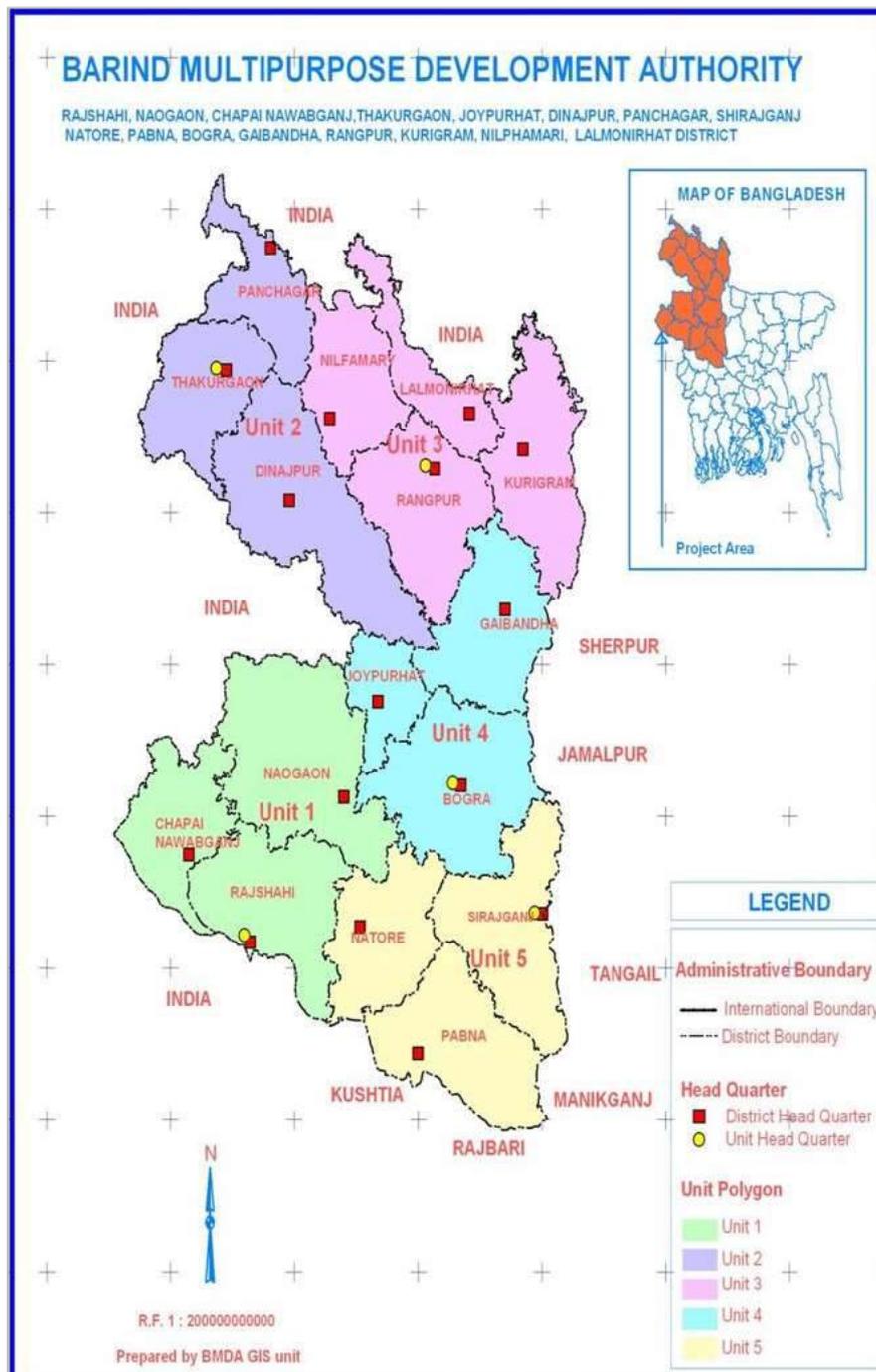
The distinctive features that made this project a success and which formed the conceptual and operational foundations of the BMDA, are noted by Faisal et al. (2005). They observe that most water projects in Bangladesh have had a narrow focus, typically on flood control, drainage and irrigation, while relevant socio-economic, institutional and environmental aspects received only passing attention. They also note the absence of explicit provision for systematic monitoring and post-evaluation. This meant that project results fell short of the initial targets, and in many cases, the projects became major financial and institutional burdens to the government. The BMDP was an exception since and in fact challenged the prevailing notions that a groundwater-based irrigation project in a semi-arid area cannot be sustained in the long run. The pressure to succeed ensured pragmatic planning that recognised the need to provide equal weight to technical and socio-economic elements within the project's strategy and activities. Therefore, since the very beginning, the BMDP incorporated an integrated approach in the project design and operation, with emphasis on technical, economic, social and environmental sustainability. This innovative institutional model has not only delivered results on the ground, but has also and critically, allowed the BMDA become a financially independent entity.

Another important aspect to note regarding the process by which current production results have been generated by the BMDA and its partners, is the adoption of a phased approach that provided the space of cycles of deliberative planning with time, with new objectives added when necessary. One such change has been the expansion of the original geographical scope of the BMDP that focused on the Northwest (Rajshahi Division⁶²) to now include much of the Northern districts. These has meant the addition of Thakurgaon, Dinajpur, Panchagar, Rangpur, Kurigram, Nilfamari, Lalmonirhat and Gaibandha districts of Rangpur Division 63 (Figure 22). Consequently, BMDA's mandate today covers some 1.9 million acres of land including 1.44 million acres of cultivable land.

⁶² Rajshahi, Chapai Nawabganj, Naogaon, Joypurhat, Bogra, Sirajganj, Pabna and Natore districts.

⁶³ BMDA website: <http://www.bmda.gov.bd/site/page/5a3b7fc6-05ab-474c-886b-3a5ae2e7d78c/Jurisdiction>

Figure 22. Geographical scope of BMDA's mandate.



Source: BMDA (2015)

Given its integrative approach, the BMDA engages in a range of cross-sectoral activities to provide multi-dimensional interventions for supporting agriculture production. Its wide array of functions include irrigation through DTW installation and surface water augmentation, crop diversification, afforestation (to improve the local climate), infrastructure development and renovation (e.g. canals, cross dams, check dams, roads, power lines and substations), facilitation of agriculture markets, training workshops for farmers on integrated farming, promotion of organic fertilizer and pest control, the establishment of nurseries, and the setting up a seed collection and distribution programme.

To optimise the limited surface water resources especially in Rajshahi, BMDA constructs cross dams and rubber dams to increase storage and diversions via canals to re-distribute additional storage of monsoon water. Such measures enable irrigation of 50,000 ha, and in some areas where slopes are steep, also mitigate flooding by reducing flow rates. Given these dams are not very high, downstream flows resume after the water limit exceeds the dam height. BMDA also lifts water from the Padma River to canals via a 3.5km pipeline to irrigate 2,000ha. While the electric DTWs mainly for irrigation, they are increasingly also linked to domestic water supply depending on groundwater availability (i.e. where domestic hand pumps can no longer access groundwater). Domestic water is further supplied through community dug wells, which also support homestead and field vegetable cultivation. Where groundwater levels are too thin for a DTW, dug wells are adopted to support homestead production and household water needs. Water is pumped using solar pumps at a charge of BDT50-60/hr to cover the homestead irrigation. The pumps are operated by a local committee representing the households served. Establishing such a system costs BDT 1 million.

Large-scale afforestation attempts to dampen the impacts of climate change and improve soil management, while providing additional sources of food and other forest products to local communities. Between 1985 and 2013 27 million trees of different varieties including fruit, forests and medicinal trees were planted, though data on survival rate is not available. In keeping with its participatory and inclusive ethos, driven by a sense of pragmatism, production from afforestation is shared with a range of stakeholders including villagers and other government agencies as detailed in Table 4.

Table 4. Distribution of revenue from planning in support of participatory afforestation.

Participant	Share of revenue
Owner of the Land	20%
Local People (Nursing Group)	40%
Local Union Parishad/Municipality	10%
Owner adjacent to planted land	10%
Fund for plantation	10%
BMDA	10%

Source: BMDA (2015)

These measures are supplemented with a range of programs seeking to curtail the demand for irrigation mainly through crop diversification to low water consuming crops, new drought tolerant varieties and adoption of land management methods such as zero tillage and bunding, linked to farmer training. Recognising that these programs can succeed only if markets provide farmers sufficient incentives, BMDA also develops agro-based industries in the area and constructs roads to improve market access. Efforts to increase the economic returns from water also include the re-excavation of ponds and seasonal wetlands for fish culture and irrigation. Many of these activities are in conjunction with other sector agencies under the umbrella authority the BMDA is vested with. The current status of the full range of BMDA's activities is summarised in Table 5.

In terms of water demand management, crop diversification and intensification are key strategies as already noted, with Boro rice being targeted for replacement given it requires 9 hours of irrigation to irrigate 0.33 acres for course soil, and 6 hours for clay soil. It is claimed that this transformation has not been forced, but by demonstrating that other crops can reduce water demand and costs while increasing profits. These include new varieties have been developed that are more resistant to insects

and drought and high value and short duration crops such as potato, pulses, mustard and cotton (introduced in 2014). This is supported by production of quality seeds (short lifecycle, heat and drought tolerant) which is critical for better yields and reducing water demand. Market access is augmented by new roads connecting farmers with local markets to help farmers avoid middlemen and get higher prices.

Table 5. Current status of BMDA activities.

Activities	Implementation	Results
Afforestation	227 million	Facilitate the environmental balance. Temperature reduced significantly. Grey Barind area converted to green.
Buried pipeline construction	11762 km	About 10,000 bighas, of land has saved and about 20,000 MT food grains produces per year. Besides this wastage of water reduced.
Construction of electric line		BMDA constructs 11 kV electric line where there is no electric connection in the village by its own supervision. Then Palli Bidyut Samity supplies electricity to that areas by using that electric line. That is BMDA facilitates electric connection to that remote area by constructing deeptubewell.
Delivering river water to canal/ponds and use for irrigarion	60 LLPs	2400 Metric Ton food grain is producing per year for irrigating 2400 ha of land.
Drinking water supply construction from irrigation deeptubewell	1100	There was drinking water crisis in the remote area. People would like to take ponds, canals and beel's water for drinking purposes. About 12 lac people are getting safe drinking water for construction of water distribution system from Deeptubewell. So, they are free from water borne diseases. A project has been approved for constructing more 550 nos. of water supply system.
DTW instalations	14,901	Single cropped land converted to three crops land. Othter areas yield of crops also increased due to irrigation facility. So, 50 lac MT food grains are producing per year by BMDA'S operated Deep tubewell
Feeder Road Construction	903 km.	It facilitates the marking of agricultural products for the development of remotest rural comminucation. It also facilitates the livelihood of the village people.
Irrigation Equipment operated by prepaid meter	11600 nos	Farmers are giving irrigation according to the requirement of crops. So, irrigation cost and wastage of water reduced. Financially cheating possibility of farmers also reduced.

Activities	Implementation	Results
Khas Canal & Ponds Re-excavation	1403 km & 2975 nos.	About 87000 ha lands come under supplementary irrigation facilities. Temperature of surrounding areas decreases including increasing the yield of crops.
Sinking of Deeptubewell	14901 nos.	Single cropped land converted to three crops land. Other areas yield of crops also increased due to irrigation facility. So, 50 lac MT food grains are producing per year by BMDA'S operated Deep tubewell

Source: BMDA (2015)

To empower BMDA implement its multi-functional mandate, its governance structure is decidedly inclusive of other critical agencies with which it needs to collaborate. Thus, the composition of its Board includes key agencies in the agriculture sector and the Deputy Commissioner of the Districts in which BMDA works. This ensures the 'political will' required to carry out the project objectives in an undeterred manner. In this way, the BMDA acts as a point of sectoral convergence that enables collaborative effort towards particular objectives. This is itself a rare occurrence in institutional landscapes typically fragmented and operating within a logic driven by this compartmentalise which is often divisive and competitive rather than collaborative.

9. A gender perspective on the adoption of agricultural innovations

9.1 Changing gender relations, norms and practices in agriculture

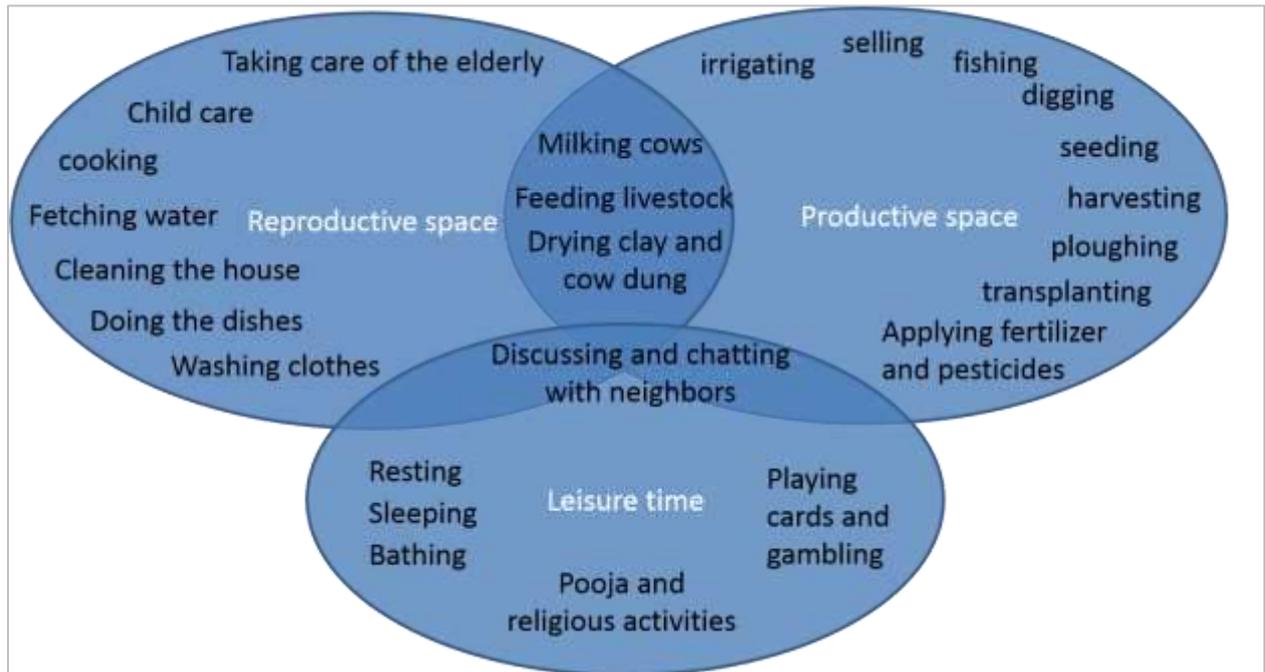
Within the agricultural sector of Bangladesh, labor has been traditionally divided into separate tasks for women and men (**Error! Reference source not found.**). Due to the out-migration of predominantly male and young farmers to surrounding towns or Dhaka in the search for better economic opportunities, the traditional gender relations within agricultural labor are changing. However, a change of gendered access to and control over resources such as land and water, as well as extension services and technologies, is lagging behind. Land is registered in the name male farmers, even in their absence because of migration or death. With the registration as landowner, several responsibilities come into play, such as decision-making on concerned crops and receiving income through renting land or selling the crops. This displays how land ownership, in particular to water access, sustain existing gendered power relations. These inconsistencies display great challenges for food and livelihood security, which can be addressed through gender-sensitive agricultural innovations. These need to consider time constraints due to a double work burden through reproductive tasks, such as taking care of children and the elderly, household chores and livestock rearing. Furthermore, cultural constraints exist for women in terms of mobility and speaking up, as well as decision-making on expenditures. This implies that new technologies, which includes new management tasks and income generating labor, may sustain, reproduce or even create new gendered vulnerabilities, rather than uplift communities as a whole with minimal social divides.

Gendered norms and practices can constrain opportunities to adopt agricultural innovations, as these mean to engage in public and economic activities which were traditionally meant to be the space of men. This adversely impacts opportunities for women to access knowledge, acquire skills and strengthen bargaining power necessary for technology uptake. Furthermore, how community members can access resources, and hence, adopt technologies varies strongly not only with gender, but also age and position within the household, religion (Muslim/Hindu), educational level and the economic background. Hence, it is relevant to examine the introduction of new technologies with a holistic perspective and understand in which ways it can support or constrain women depending on their access to resources and decision-making power within their families.

This chapter investigates how changing gender relations impact women's access to resources relevant for the adoption of deep tubewells with the smart card system. Related to increasing agricultural production through irrigation technology uptake is access to land ownership, institutions and markets, which provide the resources, skills, knowledge and networks necessary for the adoption of technological innovations (Morris & Doss 1999, Peterman et al. 2011). Gendered relations to material, social and human resources are investigated to examine how the rise of women-headed households, is changing agricultural processes, which influence the successful adoption of technologies.

Gendered norms and the division of agricultural labor

Figure 23: Reproductive and productive space observed in the field sites



While women's tasks have been traditionally within the reproductive space and male's in the productive space, this division changes due to male out-migration and other factors, such as increasing exposure and education (**Error! Reference source not found.**)⁶⁴. While women's tasks in agriculture were limited to house chores, only the poorest of the village had to work on the field. However, this is changing. While land is divided amongst sons, a process, which can take months and often leads to family quarrels, the size of land per family is decreasing. This also contributes to increased male out-migration, leading to a feminization of agricultural labor. We spoke to a great amount of women who are now involved in tending the fields in the absence of their husbands. Their work includes now prior male tasks such as irrigating, transplanting, weeding, harvesting, composting of fertilizers, and carrying fertilizers and seeds from their homes to the land. However, some tasks, such as ploughing and fertilizing, have particularly strong notions of being male work, as these are perceived as requiring hard physical labor, experience and expertise. Instead, husbands, brother-in-laws, sons, or male neighbors are asked to apply fertilizer to the fields. In the absence of men, women also take over tasks such as appointing wage laborers, however, women in an FGD stated that this is one of several challenging tasks, as both male and female wage laborers prefer to go to male landowners, which makes it difficult for women farmers to hire wage laborers.

With the changing division of agricultural labor, gendered norms and practices influence the access to resources and the manner of farming. In a FGD in Thakurgaon, women stated to be less productive in farming as they have less knowledge than men, it takes them time to get money as they depend on calling their husband to put fertilizer, and they also depend on asking male to apply fertilizer, pesticides, and do the transplanting. They also stated that such restrictions depend on the economic well-being of the family, as poor women have to struggle particularly under these aspects.

⁶⁴ The perceived need for girls' education is increasing, as women stated that it is encouraging to see neighbors and friends receiving education.

Those with more money can get fertilizers in time, poorer cannot which negatively affects their productivity. In general, there is a close link between more empowered women to their more empowered families or husbands.

Due to gendered norms that imply that women have to seek support from male counterparts, female farmers have to make greater efforts to access resources. These sustained dependencies on men could also translate into difficulties of taking new technologies up:

“Women farming has a negative impact on agricultural productivity as women know less about it. It takes time to get money, as they need to call their husbands and also depend on asking someone else to apply fertilizer, seeding, pesticides (BD_FGD9, female Hindu)

Women’s capacities of being able to farm are influenced from an early stage on, and the power of community gossip limits girls and boys in that it determines which tasks they have to do and within which space they are supposed to move:

“Sons receive training from their fathers since childhood as they take them to the field, whereas daughters stay at home with mothers and learn how to clean and cook...Girls should go to the field, but there is gossip if adolescent girl goes with father (or mother) to field” (FGD with Hindu women in Thakurgaon, NW Bangladesh)

Due to these constraining gendered practices since childhood, it seems that women feel as “substitute farmer”, or “second choice farmer”. With these changes in agricultural labor division, we asked multiple women farmers of different age, marital status, religion and income, how they feel about the new responsibilities in agriculture. As their husbands used to be the farmer, but is now not available due to out-migration, all women said they see it as their duty to take over farm labor. One 27-year old women stated that she started agriculture after her husband’s migration, and it makes her feel better as she can contribute to family’s earnings (BD_I11). One women (BD_I9) stated that she does not feel uncomfortable because she sees it as her task to work on the field when her husband is gone. She does all the work except fertilizer, which her husband does on his visits. This demonstrates the motivation of working on the field to please the husband and family’s needs. However, the majority of women stated cultural reasons, which do not consider it as desirable as a woman to work on the farm. While women feel it is their duty to take over the tasks which were done by their husbands, they feel “discomfort doing this as it is work for men... (as they are) not used to doing it” (BD_I15). They also stated that it is very hard and tiresome work. Instead of explaining particular obstacles why it may be difficult for women to frequently visit fields to apply fertilizer, the social norm that it is not the task of women to do so, is often stated:

“During my husband’s absence I managed 15 decimal of farm, I had to check the weeding and damage by animals; I visited fields less often, my brother-in-law applies fertilizer.”

Why? (Interviewer)

“I’m a woman” (BD_I3)

Despite these strong restrictions, we found one women who applies fertilizer herself as her husband died, her son migrated, and she has no money to pay some male to do it (BD_FGD9). However, being asked how the community reacts to this, she stated that everyone in the village knows about her situation. She said that she also takes her granddaughter to the field to teach her farming, which

creates some gossip, but she does not care about this. This demonstrates that gendered norms of farming as a male domain are less strict on poor female farmers without male support, and that these are also more accepting in the threat of community gossip.

Apart from economic and marital status, gendered restrictions vary with age, religion and the presence of daughter-in-laws and sons within the family. Restrictions to working on the field are particularly strong on young Muslim daughter-in-laws. We observed the prevalence of early marriages. Girls are often married at the age of 13, after dropping out of school in class 8. The restrictions on daughter-in-laws change slowly with the birth of a son with which a mother gains in status. Roles abruptly change when a son gets married, and a new daughter-in-law moves in the house. By then, the mother-in-law has more decision-making power and thus authority over family matters, and most likely also over farm-related work.

The gendered division of agricultural labor has led to perceptions that women's work is of less value, which is also reflected in wage differences for laborers. The reason given in a FGD with male farmers (FD_BD1) was that women work less in the same tasks, which was refuted for many cases by statements of other male and female farmers, as well as our own observations, which also included reverse cases in which women had harder physical labor than men. Hence, deeply entrenched gendered perceptions on abilities and labor create economic injustice to women. Women earn as agricultural wage laborer around 150-200 taka per day, while men earn 200-250 taka or more. These wages vary with the seasons. In case there is scarcity of work, wages can be as low as 100 taka. This wage division is also true for other economic sectors, such as the garment factory. Women farmers stated that they think the wage should be the same for women and men, but they do not to organize themselves into a union and ask collectively for more wage.

The importance of women in decision-making has increased compared to 20 years ago. There is now more discussion between husbands and wives on family matters, and both parents are more conscientious about matters such as children's education and proper livestock management. Income is now handed over to the wife, and in some HHs, women are included in decisions on crop choice.

The greater responsibility required of women regarding cultivation means that they are also more knowledgeable about cropping methods including transplanting, fertilizer and so on. They still are not however sufficiently targeted for agriculture training, including in the cultivation of vegetables that is an increasingly valuable and popular activity amongst women.⁶⁵

This chapter outlined that women farmers have an increased share, but not income of agricultural labor, and how they perceive these new tasks. As the following subchapters will outline, with an additional labor burden, women farmers continue to be exposed to gendered constraints in terms of mobility, bargaining positions and decision-making at the household and community level. This serves as explanation for the perceived lower productivity of female farmers.

⁶⁵ FGD with marginal and tenant farmers, Rangpur

Figure 24. A youth helping his mother position what is clearly a heavy load on her head in Bhondogoan Village, Thakurgaon.



Sustaining control through remittances

Women with out-migrated husbands are dependent on them to send remittances or to visit to give them directly money to pay for agricultural inputs such as water, seeds, fertilizers and laborers.

When money is need for greater investments and other strategic decisions, husbands are consulted through mobile phones for direction. Hence, despite their absence, men maintain control over how and when the money is spent on irrigation and other agricultural inputs. This may reinforce women's perceptions of being dependent and inexperienced farmers. Nevertheless, receiving money has become easier through mobile transfer, as it can be obtained in shops, and no additional costs have to be bargained with middlemen.

After receiving money, wives often keep the money. However, they do not have the choice to spend greater amounts for non-daily needs without their husbands' consent.

In other cases, women repetitively stated that their mothers-in-law or fathers-in-law keep the money, adding to the husband one more layer to consult when spending money. Often it is the father-in-law who decides when to use fertilizer and irrigation, and the distribution is decided by the eldest male within the family, either the father-in-law, or brother-in-law. Women and men often stated a strong collective identity within the family, in that no particular money keeper or spender is identified, as everything belongs to the family. Whoever has money would spend on family matters.

In a FGD, about half of the women stated to keep money, but would always discuss all expenditures with their husbands, and sometimes father-in-law. They would give preference and importance to his opinion, as he is more exposed to the outer world, and in most cases, his estimates prove right. Despite this sustained dependence, women feel that their part in decision-making increases, because women receive more education and are more exposed to the world than ten to twenty years ago. Women

stated that their decisions have become more important in case of male out-migration, as they can inform their husbands better on crop choices, and know the proper timing of transplanting and fertilizing. However, they stated women need more training on how to improve vegetable farming. One elderly women stated the aspirations for more decisions, despite the slow change of gendered norms: “We have hope to have more decisions but at that time I have died” (BD_FGD9).

Gendered norms restricting mobility and market access

As women, particularly young daughter-in-laws and Muslims, are traditionally confined to the household, participation in agriculture, and all related activities such as access water and entering public space is proscribed. With increasing male out-migration, it is accepted that women access fields as laborers. However, gendered norms hinder women like an invisible wall from accessing markets, which represents economic participation, and accessing decision-making processes, speaking up and raising their voices within the community.

Women with absent husbands face a double vulnerability: those of community gossips, and those of real dangers. One young wife of a migrated husband stated fear of sexual harassment, particularly because of the house’ location close to road. Another woman stated to buy less livestock in her husband’s absence, as she is afraid of theft when he is not there. Women reported that they are more comfortable when husbands are at home. In their absence, they have to sell their crops and shop for agricultural inputs, which they feel uncomfortable doing because of the restrictions for women to be confined to the private, not the public sphere. Women stated to be shy and unfamiliar to bargaining processes at the market, as they do not know prices and often end up paying more. In case of seeds, for example, this results in them preferring lower quality seeds from their neighbors rather than going to the market where the quality is better. However, one outspoken female farmer stated entrusted: “If I need water and my husband is gone, I will not wait for him and stop eating!” (BD_FGD9). Her statement signifies that the woman is aware of the restrictions of husbands’ presence, but would access public space against gendered norms if he is not available.

Further, women mentioned that they feel stronger if their husbands are at home, as they solve quarrels, or tensions with neighbors about children and cattle destroying crops of other people’s fields (BD_FGD4). This demonstrates the power of men’s presence which places women in more comfortable positions, as they can maintain their space within the private sphere and do not have to expose themselves to community quarrels. These examples demonstrate that women are perceived and perceive themselves as more vulnerable without their husbands at home.

Women feel that people gossip and tease them when they go to the field or to the market. Women were told by their husbands that going to the market is “shameful work for women” (BD_FGD9, BD_FGD7). However, women stated that they think differently themselves, but to maintain family peace, it is better to accept that the husband knows better (BD_FGD7). Women who enter the public sphere are perceived as those who are alone and poor, and therefore forced to resist the gendered norms. Hence gendered norms display going to the market as a woman not as a choice. For example, a Muslim woman whose husband has been working in Pakistan for 10 years stated that she is still uncomfortable going to the market and handling money, and hence she pays her brother-in-law to buy fertilizer, seeds, and water. Other women stated more clearly that they perceive to be given less importance than male when they ask for fertilizers and seeds, and therefore prefer to ask men to buy these (BD_FGD9). Women stated in general more gossip when the husband is out, e.g. when they have to work on the field. However, if their husbands allowed them to work in field, they feel justified to work outside.

The role of the market as a public place of trade exemplifies how women are excluded from the economic space. While women can go to the fields or other place, they face sexually abusing words and accusations to go to the market to see other males. Women submit to these threats and try to

avoid the market place. If they have to go, it is because they do not have the support of a husband to go to the market. In that case, they ignore bad comments of the community. Women revealed that they would be interested to go to the market in a group, but never address this towards men.

Several mothers-in-law would buy seeds or apply fertilizer particularly if they had taken a prior training course. They also face less gossip. One mother-in-law was said to be good in bargaining, as she has been exposed to different places, has been associated with a range of people, and has been trained by NGOs such as RDRS and BRR. This example demonstrates that age, as well as training interventions can reverse gendered restrictions on market access.

One young female farmer from Thakurgaon town and not the village stated that gossip is limited to the village, as she did not observe this in the town. She stated that people just like to make a scandal when women go to the field or to the market (BD_I13). That is why she plans with her husband to go to Dhaka, as she thinks that this is a good environment for women, where they do not have a problem walking around. As long as she is in the village, she arranges that her father-in-law or even the landlord take care of irrigating the field. She further states that gossip is only among Muslim society: "My religion and culture constrain me" (BD_I13).

However, women stated that in the last ten years, this teasing of those who are going to the field is decreasing. It used to be considered the need of only poor women to go to the field. Now however, the participation of women in agriculture has increased in the last ten years, and more women get involved and "have less time to criticize" (BD_FGD9). Other women stated the increasing value and rise of women's education, which also contributes to weakening social norms against female farmers.

In meetings, women in both villages stated do not speak, as men tell them there is no need to participate, as it is the men's job. Hence, women, raised to please men, also state that they do not want to participate against the will of men. This demonstrates covert power (Lukes 1974) of gendered restrictions. One young Muslim stated that she never participates in social gatherings with other Muslims, nor would she mingle with Hindus. This indicates that particularly young Muslim women are excluded from the community, which leads to less access to information and support in agriculture.

9.2 Gendered technology adoption of agricultural innovations

Within increasing male out-migration and changing gender relations, agricultural innovations in this context can create incentives to (re-)invest in agriculture, as well as mitigate gendered norms and practices, which affect women's work burden, restrict their access to the market as well as sustain household's dependence of remittances. With regard to the relevance of agricultural innovations, it is necessary to note that the only hope for economic improvement and better living standards currently comes from migrating to work outside agriculture and the community. In an interview, one woman admitted to feel as a female farmer to be in a

"continuing crisis, as I have so much work, I am not happy, and cannot read and write to change anything, only rich families can afford to read and write, and the government doesn't help the poor to write" (WB_I1).

Now this woman does "not dare to dream to be able to read and write because she does not have time" (WB_I1). Her dream is to build a house, that her son and her daughter can read well, and maybe that she even has a TV. To these dreams, her children answer that they will later "go outside the state and give her a TV and a room" (WB_I1). This indicates that the woman does not see any chance for herself to improve her decision-making opportunities, but that she hopes for the future generation, her children, to have more choices than herself. In case she is given the choice, she would turn away

from agriculture. This points out to the role of agricultural innovations: decreasing the barriers, to livelihoods and food security within agriculture, particularly for women and the marginalized.

This is particularly relevant with regard to educated young people who are less interested in agriculture. Even less educated youth seek to move out of agriculture to lower paid jobs. Part of the reason is the perception of increasing risk in agriculture compared to more stability provided by off-farm jobs. The monetization of living and increased material aspirations of especially young people means agriculture now struggles to provide for these.⁶⁶ Innovative technologies and age- and gender sensitive policies enabling reliable access to resources as well as technology diffusion are highly relevant to provide incentives for female and/or young farmers to (re-)invest in agriculture.

Gendered implementation and operation process of DTW

The DTW implementation and operation process is highly gendered and depicts the assigned gender roles within society: While men are involved in the development, implementation and operation process of the DTW, women are the water users and customers. Women do this work in the name of their husbands who legally own the land to be irrigated, and in whose name the smart card is therefore registered. This exemplifies how women are detached from the ownership of their agricultural labor, because they are culturally confined to stay at home and not attend representative meetings.

The development and implementation of electric DTWs as well as related extension services is done by (male) BMDA staff. While the pump operator was elected, the (male) DTW committee which is registered with the BMDA was not elected. As pointed out in chapter 5.4, one of the male village elders deposited BDT100,000 with the local government on behalf of the farmers, and every farmer paid the elder money for his land to fall under the command area of the DTW. The DTW committee consists of the male elder who deposited BDT 100,000, the (male) who donated the land to site the DTW and three other farmers who were selected by these two individuals. A smart card for irrigation can be obtained from a local (male) dealer. In Dhondogaon village in Thakurgaon, the DTW operator was collectively elected by the community members, which were male since women's participation in the public sphere is restricted. This was also strongly visible in the meetings we conducted in the villages' schools or open places: women would either not attend, or sit quietly in the back. One exception of a female who participates in public meetings is the pump operators' wife who demonstrated us how to operate the DTW, although she is not a water user herself. She is visible and involved in supplying irrigation to the community in her husband's absence, which indicates that women benefit from their husband's higher status.

With the exception of the pump operator's wife, women are as main users of water excluded from the DTW implementation and operation process, and hence remain excluded from decision-making processes concerning irrigation. This is striking since the majority of the water users are female, but the landownership belongs to men, women have limited agency to influence these processes with new technologies, as they happen within the public sphere which is only culturally limited accessible for women.

Benefits of the DTW and the smart card system

Those farmers who are within the command area of the DTW benefit to a great extent from this agricultural innovation. In FGDs with female farmers, it was stated that the DTW with the smart card system is beneficial for women. Particularly women farmers stated the easier water access, as they can circumvent bargaining processes, which were earlier necessary with diesel pump owners and middlemen. Despite the higher costs than for diesel pumps, the card system saves time of asking a diesel pump owner to rent it, as well as carrying the pump to their field and observing the duration of water flow to ensure sufficient water is covering the crops. These tasks do not have to be done

⁶⁶ FGD with marginal and tenant farmers, Rangpur

anymore, as the smart card can be inserted at the central spot within the village, and the system irrigates water according to the fixed amount of a time span and money decided before the irrigation process starts. This also prevents bargaining, which was earlier necessary to reduce the demanded price of the water sellers, a process in which women have been oftentimes in disadvantage. Cards are also handled flexibly in that cards from neighbors are borrowed, if women farmers have not received remittances in time to recharge their cards.

Concerning the order of irrigation, they start with the distant fields and come closer to the pump, as prior water leakages benefit unirrigated fields. If particular plots need to be irrigated urgently, farmers stated to do so. Whether we could not verify whether this holds true, the awareness on these aspects were there. Women farmers stated that they are given preference for irrigation during daytime because they are considered as more vulnerable at night. If daytime irrigation is not possible, they can rely on irrigation happening at night due to the smart card system, which deducts money according to the length of irrigation. While the irrigation is mainly done at night as evaporation is less, women go and check the next morning, whether their fields are thoroughly irrigated. Women stated that they usually did not face any problems. Male pump owners stated that women get privileged in irrigation, because they know about the amount of their household work. This surely holds only true for those who have their cards recharged through their husbands' remittances.

Technically, the DTW system is also more reliable than diesel pumps and STW, except that it only functions during hours of electricity service. Women stated STWs also took longer to irrigate and were damaged easily.

Constraints of the DTW and the smart card system

In comparison to the Nepal and India sites, agriculture seems overall to be more profitable and mechanized, however, the communities did not benefit evenly from the technological innovations. Only those who have land within the command area have access to the DTW, which was a decision-making process possibly not only based on technical factors, but rather on the influence of the elder man who could provide the financial deposit for the pump, as well as the farmer who provided his land for the DTW installation. These two people are influential within the village and have greater access to knowledge and networks than others of the village. The villages however approved the value of this innovation and stated that both men worked in the interest of the community. Some people stated that there have been quarrels in the serial system of the smart card DTW system, which has calmed down after intervention by the pump operator. This affirms that the pump operator holds a strategic position, and it is therefore relevant that someone who acts in the interest of the community and is accepted and respected by both male and female farmers, of various religions and castes.

It was however pointed out that only a section of the village benefited from the DTW depending on where a farmer has his agricultural land. Some farmers may have all or the majority of land in the DTW command area. Others may have only part or no land given most farmers have multiple land parcels situated in different parts of the village. The unequal access appears more pronounced with regard to agricultural trainings, where participation is usually decided by those economically better off within the village, while the marginalized often could not benefit from these interventions. Interestingly, even those within the command area of the DTW stated despite not having water problems, they had limited income opportunities because of limited land or livestock. This demonstrates that the DTW is one out of many needed agricultural innovations to make agriculture a productive livelihood.

As per our observations, the fields tend to be over-irrigated, as farmers pay per time span and not the amount of water. This has extensive consequences for the long-term sustainability of groundwater

availability. Hence, the positive short- or medium-term effects of DTWs should not be evaluated without a thorough estimate of the long-term impacts of water over-extraction.

With the absence of female leaders within the village, it is difficult for women to break with gendered norms. In both villages, a number of agricultural interventions apart from the DTW implementation has been taken place over several years. For women, there have been multiple trainings through RDRS on fertilizer and seedlings, in which charts were used for demonstration purposes. There are multiple saving groups, usually run by NGOs which give women loans. Notably, female members stated that they do not know the interest rate for savings and loans, and hence are vulnerable to fraud. Interestingly, members did not even know the name of the secretary, which demonstrates that there is low interaction with the groups. Some women who have not joined such groups stated that their participation is lower because of household duties.

9.3 Recommendations

Recommendations with regard to agricultural innovations are to tailor the implementation and operation process, as well as agricultural extension services to the particular needs of marginalized female farmers. These are highly restricted due to household work and religious practices from interactions with the public sphere, the market, and, correspondingly, men. Furthermore, the registration of smart cards could be considered independently of land ownership, in that it is promoted that those who do not have land titles can have ownership over water. Although land ownership is not a condition for the card, in practice mostly landowners owned these.

As women were used to dealing with outsiders, they demanded trainings regarding seed selection, the best time and amount of seeding and fertilizer and pesticide application. One women even demanded a training center. Some women stated that those who benefitted from trainings hide their knowledge as they want to grow and earn more than others, e.g. when applying fertilizer or learning a new technology. This shows that these aspects should be addressed in trainings, or even more, that trainings focus on strengthening collective approaches, as is done in the Bihar and West Bengal sites.

Recommendations in terms of agricultural policies are equal wages for laborers regardless of gender, as well as regulated water and crop prices, institutionalized trainings, and reformed land policies on land, which allow women easier access to land and other agricultural inputs, such as water, seeds, fertilizer and pesticides. As there were no formal representatives in the village, but only in one in further distance, it could be beneficial to have a closer cooperation between an elected village representative and the district and state representatives.

10. Conclusions

The biophysical and socio-economic contexts of Rangpur and Thakurgaon exhibit significant similarities in that both depend on rice production, which is heavily supported by relatively good groundwater tables in the dry season, supported by relatively high rainfall and recharge. This is especially the case in Rangpur where farmers supplied by DTWs as well as STWs continue to receive sufficient irrigation year round. Two important differences in Thakurgaon are that STW users in the case study site struggle to access sufficient irrigation for Boro rice, and in the village with only STWs, these are virtually redundant. The operating context in Rajshahi and especially in the Barind area is significantly different, with lower water tables, significantly lower annual rainfall, lower recharge rates and higher levels of drainage due to greater elevation variation in the landscape.

In hindsight then, it is not surprising that the majority of adaptation technologies identified by the fieldwork resides in Rajshahi where adaptation and revitalizing food production systems have been the focus of both farmers and government for several decades. The unique multi-dimensional nature

of the BMDA symbolizes this emphasis on adaptation, and its approach, as described in this report, is itself an integral aspect of ongoing adaptation. Interviews with other agency officers such as from BARI and the DAE indicate a shared emphasis in collaborative adaptation between themselves as well as with farmers. This contrasts with farmer attitudes in Rangpur and Thakurgaon case study sites, where they are far less oriented towards deviating from current agricultural practices dominated by multiple rice crops. Farmer interviews in all locations show that these attitudes are clearly linked to perceptions over water and food security, with the high yields from Boro rice linking strongly to household food security.

Which technological and institutional innovations in improving water security for food production in Northwest Bangladesh have been introduced (to the sites) by whom and how?

As noted above, a clear distinction emerges with respect to the adoption of technology between Rangpur and Thakurgaon on one hand, and Rajshahi on the other. In Rangpur and Thakurgaon, the primary adaptation measure appears to be the use of more groundwater especially via the re-engineered and electrically powered DTWs primarily for Boro rice but also for supplementary irrigation for other crops such as T. Aman rice. The driver in this process has been significant government investments through the BMDA's establishment and maintenance of DTWs, and the supply of subsidized electricity for its operation through the smart card system – itself an important innovation in improving cost recovery for service delivery. Yet, from a broader adaptation standpoint, by re-enforcing water security, DTWs could be cited as a primary reason for the seeming absence or paucity of attempts to reduce crop water demand. Farmers' focus in Rangpur and Thakurgaon largely remains squarely on production, reflecting the production drive under national food security policy. This is the case even for farmers outside DTW command areas despite some seasonal difficulties in irrigating Boro rice. This can thus be characterized as a 'business as usual' scenario.

The greater diversity in adaptive technologies in Rajshahi reflects the stronger biophysical imperatives at play. Adaptation is therefore not a new phenomenon, with crop selection and substitution in response to seasonal groundwater availability, rainfall variation as well as topography being distinctive features of farmer behavior and farmer-extension interaction. Agencies such as BARI and DAE play important roles through research and development on crops and conservation agriculture practices, with strong links with demonstration villages. This also contributes to broader advice on crop selection based on environmental and market conditions, based not on a policy of rice production as in the other districts, but on lowering crop water demand, often by displacing Boro rice. The collaborative approach of these agencies is also an important feature in the institutional links between policy, extension and farmers.

Adaptation in Rajshahi recent years is also characterized by further diversification into fruit orchards, and moved beyond crop selection to fish culture, but as a form of land use change as well as a dual livelihoods strategy to generate income from both fish and cropping. Cropping in such cases may relate to that of the pond owner/lessee or income from selling irrigation water to third parties. Fishponds and the evolution of the informal pond-irrigator institutions appear to be wholly driven by self-motivation rather than any external stimulus. Profitability of fish and financial capacity appear to drive these decisions. Interviews with farmers who have converted to fish culture suggests little or no connection exists with the fisheries agency. The same incentives apply to the self-adoption of fruit orchards.

Other technologies such as conservation agriculture originate from government, arguably due to their scientific nature (e.g. following field trials) and the need for specialized equipment to offset labor and temporal trade-offs for adopters. Furthermore, unlike fish culture which is not new and is hence

already 'demonstrated', the tillage and other land management practices that constitute conservation agriculture remain relatively unfamiliar to farmers, triggering perceptions of risk. While discussions with farmers and BARI officers suggest ongoing in-situ field trials with farmer collaboration may effectively alleviate risk perceptions, the difficulties faced in supplying high quality equipment in sufficient numbers, appears to represent a critical barrier to converting demonstration and farmer interest to widespread adoption in Rajshahi. One technology that appears not to have gained traction in any of the study districts is AWD promoted by several agencies including BRRI and BMDA. This may be rooted in its link to rice crops and farmer perceptions in Rangpur and Thakurgaon of water security, linked to the need for regular and systematic monitoring. This is both complex and an unnecessary investment of farmer time given water availability.

Other adaptation actions away from farm level have also been driven by government, such as the range of surface water supply augmentation activities and tree planting to improve microclimates by BMDA. While an analysis of the contributions of each of these measures to overall water security was not undertaken, it may provide a valuable reference to agencies in project location in India and Nepal, and a basis for this project to engage with relevant agencies where adaptation is understood to require action at multiple scales.

While the issue of DTWs as a driver of differentiated agrarian development between DTW farmers and those depending on STWs will be discussed in section 9.4 below, it is important to note here that STWs associated water markets, though by no means representing new technology, continue to be of critical relevance for small and marginal farmers who cannot afford to invest in irrigation equipment. This in turn stems from government policy to liberalize markets for inputs including irrigation, which enabled a shift to farmer driven investments and the emergence of local irrigation water markets. A more recent and seemingly growing narrative with respect to STWs is the impacts on their viability of changing groundwater tables, which will also be discussed under section 9.4.

How far were these innovations adopted successfully and what are the impacts of these innovations from institutional, gender, equity and food and livelihood security perspectives?

While the re-engineered electric DTWs are the most prevalent technological innovation across the three study districts, linked also to institutional innovations, this will be discussed under section 9.4 below. Of the other adaptation measures discussed in this report, crop diversification is the most prevalent, again across the study sites, while crop substitution, often at the expense of Boro rice also featured in Rajshahi. The institutional support provided over the past 20 years or more through dedicated programs in BMDA, BARI and DAE in particular has been critical in providing science-based advisory services to farmers in Rajshahi open to modifying their cropping patterns. These benefits are most notable in Rajshahi where households in the case study village have transitioned from food and income scarcity, subsisting on two meals a day, to relative security along with capacity for small savings. Underlying this has been the shift to a three-crop cycle and significantly reduced seasonally fallow land.

Other innovations such as supply augmentation through large and mini-ponds and private investments in mini-DTWs are also notable in Rajshahi, with fish culture and fruit orchards presenting highly profitable land use options. The market for a range of fish species appear to be robust and growing. This demand for animal protein is arguably a reflection of feedback loops into the local economy from improved agricultural performance over the past decades. Such a conclusion is supported by the World Bank (2016) which found agricultural activities to be the primary driver for the reduction of rural poverty from 48.9% in 2000 to 31.5% by 2010 (including significant reduction in Rajshahi), with over 87% of rural people deriving part of their income from agricultural activities. The study also found that a 10 percent rise in farm incomes generates a 6 percent rise in non-farm incomes. However, given

the significant investments these adaptations entail, they appear to be feasible only to large and medium farmers, many of whom are also entrepreneurs, which brings greater financial scope and flexibility, as well as social and political networks. If such adaptations are to become feasible for smaller farmer classes, changes in both attitudinal and tenure arrangements will be needed to support collective farming models. Such approaches were not found in this study. Moreover, while land pooling may provide sufficient land, other structural weaknesses will also need to be overcome. The high transaction costs associated with accessing credit, linked to rent seeking in both government and private credit sources, is a key constraint in affording the significant start-up costs and financial risk such land uses entail. In the case of bidding to lease the larger ponds also require socio-political capital derived from an individual's overall social status.

What is therefore clear is that without some form of collective farming, the adaptation options for small and marginal farmers will be limited to the more conventional crop diversification. In addition to a dearth of personal capabilities, the impediments noted by farmers to accessing external credit is a critical structural impediment. This could be seen as a missed opportunity to shift land use to more profitable uses such as fishponds, the combination of fish and cropping, and orchards. However, recent studies suggest that even diversification in conventional crops has become more profitable than in the past. Rashid and Deb (2016) for instance find that productivity of a range of crops has increased, notably significantly more in non-rice crops such as groundnut (37.3%). Moreover, per hectare net financial returns have increased substantially, again with significant differences between the rice crops (lowest increases) and other crops such as wheat and maize and some vegetables. Brinjal for instance yields a per hectare net financial return 24.6 times (or 2460%) higher than Aush rice.

The proposition that continued crop diversification within the conventional crop choices can still produce material livelihood gains is further supported by the finding by Deb (2016) that vegetable farmers received 51.1 percent of the price paid by the consumers in Dhaka, a high percentage compared to rice, although fish farmers receive 67-76% of the consumer price (Alam et al. 2012). The persistent issue for farmers however is the fluctuating prices in markets, an importantly, the oligopolistic nature of markets for crops such as rice, often means farmers are forced to sell at prices even lower than the price floor. Freeing these markets, perhaps through investments in regional buying centers linked to ICT systems may therefore further support farmers' willingness to diversify and substitute crops, and gain further financial benefits. Such investments such as in modern market infrastructure and agriculture related non-farm enterprises such as trading and processing are also seen as critical by the World Bank (2016) if recent reductions in rural poverty are to be consolidated.

Noting that overall food production in Bangladesh has improved remarkably in recent years, Deb (2016) believes a major reason to be the development and diffusion of over 550 improved crop varieties by the National Agricultural Research Systems covering 74 crops, with over 70 such varieties released between 2009 to 2014. Adoption of these improved varieties and hybrids by replacing low-yielding traditional varieties can also partially explain the gains in profitability. The role played by the availability of crop varieties adapted to increasing yields and mediating risks posed by local cropping contexts, also serves to highlight the connectivity across scales necessary for adaptation in the agriculture sector. It further highlights the highly scientific nature of important dimensions of adaptation in this sector (i.e. improved crop varieties) that further emphasizes the importance of coherent and well-funded national research programs, with end-to-end institutional connectivity between research and on-farm adoption. Another advantage in the Bangladeshi institutional structure that supports crop diversification and productivity that are critical for adaptation, is the low emphasis on subsidies compared to neighbors such as India where subsidies for critical inputs such as irrigation and fertilizer are significant (Deb 2016).

The importance of crop diversification is further highlighted by the World Bank (2016) if Bangladesh is to meet changing market demand, improve nutrition, and adapt to a changing climate, given the high climate vulnerability of the agriculture sector. The same report also notes that the impressive recent reductions in rural poverty masks that fact that a large percentage of the non-poor population are precariously placed close to the poverty line. Recognizing Boro rice as the main driver of crop productivity, this report's emphasis that this is nearing the limits of current technological potential, coupled with limits to the expansion of irrigation, provides critical perspective for policy evolution, where significantly more dimensions of rural development are at stake than rice self-sufficiency. For instance, the same report also notes that poverty reduction has not as yet translated into improved rural nutrition, where malnutrition remains high, with serious human development and economic impacts.

The World Bank (2016) therefore concludes that the overall structure of agriculture has changed little, with farmers heavily invested in rice even though non-rice crops and non-crop agriculture offer significantly higher incomes, reflecting also, the findings of Deb (2016) and others. This also resonates with the findings from our fieldwork in Rangpur and Thakurgaon, and supports the conclusion that this scenario partly reflects the emphasis of policy and strategy on the production of food grains, principally rice, to achieve food security. Another important disincentive for diversification is the seeming sense of water security amongst farmers in especially Rangpur where groundwater levels bounce back during the monsoon season. One option for increasing crop diversification suggested by the World Bank (2016) is the scope for closing the yield gaps for Aman and Aush rice that could release land for crop diversification, without compromising national rice self-sufficiency.

The paucity of collective action is not limited to the absence of land pooling. It was also discussed as a means to undermine the control of commodity prices vested in middlemen, millers and similar intermediary actors. While one reason for the absence of collective bargaining is structural in the form of seasonal farmer debt, a more fundamental issue repeatedly put forward is a lack of trust. These local or internal challenges appear to be supplemented in Rangpur and Thakurgaon in particular, by no urgency on the part of agencies to build farmer capacities through group forming and cooperation. It may be argued that the introduction of a DTW into a community represents an opportunity for such initiatives given the creation of a new organizing point of focus. However, no such organization is required, with farmers only temporarily collaborating during the application for a DTW.

The adoption of on-farm water saving technologies through conservation agriculture have not yet gained traction even in Rajshahi where concerted efforts to promote them have been made. As noted earlier in this report, the issue is less farmer interest, but structural weaknesses that preclude the provision of appropriate and affordable equipment. These include limited capacities within the government structures and amongst local private entrepreneurs to manufacture the necessary attachments to imported two-wheel tractors for the different land preparation practices.

In addition to the impacts of each innovation, what can we learn about the political economies associated with the adoption of each, and its influence in mediating how differently capacitated stakeholders are able to benefit from them?

As discussed under section 9.2 above, a distinction can be made between the more conventional forms of crop diversification and substitution prevalent across farmer classes, and emerging and seemingly highly profitable land use changes such as ponds and orchards that require natural, economic, social and political capital beyond the means of marginal and small farmers. One may also argue that the increase in conversion of land to fish ponds is as much a natural response to more favorable market conditions, as it is an adaptation to water scarcity.

What grounded perspectives on the introduction of electric DTWs emerges that can influence national policy discourses on the relationships and trade-offs between food security, groundwater management and sustainable and equitable rural development?

The re-engineered electric DTWs are clearly the dominant supply side innovation across the study districts. They, together with high yielding Boro rice, have been the foundation of a rice production and productivity boom in line with national food security policy, that. With 52 hybrids of rice available for cultivation during the Boro season, and more than 95% of Boro rice using HYVs and hybrids, Boro rice now contributes about 55 percent to total food grains compared to only 18 percent in the early 1970s (Deb 2016). As discussed in earlier sections, this has also brought several other benefits to farmers with fields within their command areas including greater profitability due to significantly lower irrigation costs, and substantially less time to irrigate. These would be especially meaningful to the marginal and small farmers, in terms of improved income, but also time available to provide labor to other farmers – a common practice to supplement income. Overall, as noted by the World Bank (2016) this combination of groundwater exploitation, increased land under rice and high yielding Boro varieties has underpinned an agriculture-driven reduction in rural poverty in Bangladesh.

Another important related feature benefiting marginal and small farmer classes is the equalizing impact in terms of access to irrigation across, based on the manner in which water delivery is organized. While this conclusion is derived from multiple farmer dialogs organized by farmer class, this may be further verified by consulting the results of irrigation monitoring conducted by BRR1 under this project. From a food security standpoint, those farmers who grow high yielding Boro rice have gained the flexibility to sell the majority of T. Aman rice, while using the lower priced Boro crop to meet the household rice requirement before selling the remainder. Consequently, this dual rice crop, especially in Rangpur and Thakurgaon appears to have enabled an optimization by farmers in meeting food security and income needs.

Notwithstanding these clear and major contributions to the socio-economic development in Bangladesh of the past 20 or so years, three important and inter-related development policy issues arise from the field. The first is the seeming gulf between the developmental trajectories of farmers on either side of DTW command areas. This may apply both within the same village as well as between villages. Within the same village, the differentiation arises because DTWs are capable of irrigating only a part of the total cultivable land area. Farmers within their command area will enjoy the benefits of greater water security such as better yields and time savings compared to farmers depending on STWs. These impacts would be most significant where local groundwater tables decline, even seasonally, whereby cropping either becomes more expensive or not feasible altogether. In villages that do not have a DTW, such as Dangi Para in Purbo Begunbari, this divergence is more obvious given the virtual redundancy of their STWs. In such situations, farmers are effectively transported back in time to virtually a pre-STW rainfed era. Discussions in Rajshahi suggest this scenario to be more prevalent, with even some DTWs struggling to meet Boro season irrigation demands, as is the case in Pachondor, the case study village.

Secondly, this dichotomous situation in agrarian development, speaks to the broader policy debates now emerging over the sustainability of the groundwater-based rice production model, especially the groundwater-Boro rice connection, as already discussed in detail in preceding sections of this report. While this study, based on data from limited case studies cannot make conclusions on the overall groundwater situation in the study districts, the voices from each case study village, when combined with dialogues in the other visited villages, present three distinct water security scenarios. These are continued water security for DTW and STW farmers in Ramnatha Para, Rangpur; water security for DTW farmers, but Boro season water stress for STW users in Dhondogaon village, Thakurgaon, and the redundancy of STWs altogether in Pachondor village, Rajshahi, where even its DTW breaks down in the Boro season. In Thakurgaon too, the scenario in Purbo Begunbari village indicates the scenario

can be far worse in villages without a DTW. The concern over future water security arising from these case study scenarios also resonate with the current suspension of new DTW installations – a clear indication of concern within policy circles.

The third policy consideration links with the emphasis placed by the World Bank (2016) on the need for greater agrarian diversification if multiple developmental goals are to be met, including sustained rural poverty reduction and addressing high levels of rural malnourishment. The findings from farmer dialogues suggest that the innovations around DTWs may ironically be responsible for stifling crop diversification in Rangpur and Thakurgaon where DTWs combined with higher water tables provide little incentive for farmers to shift from their comfort zone of rice cultivation. The lack of traction with AWD suggests attempts to at least reduce the water consumption of Boro rice will also be difficult to promote. In other words, diversification to less water demanding crops and other water saving methods is unlikely to occur voluntarily until a water insecurity threshold is experienced, by which time diversification would be reactive rather than a proactive adaptive strategy.

Overall, given that adoption of some technologies encounter technical and structural constraints (e.g. conservation agriculture, AWD), while others are feasible mainly for the more affluent farmer classes (e.g. fish ponds, orchards), more conventional crop diversification and substitution appears as the most viable adaptations to water stress available to marginal and small farmers under current contexts. The above discussion also makes clear that diversification can also be seen as a need and opportunity to build on recent gains in rural poverty reduction, and alleviate other constraints to rural development such as persistent malnutrition. At the same time, the greater openness to changing agricultural practices in Rajshahi suggest opportunities to test approaches such as collective farming to overcome some of the capacity and structural disadvantages faced by marginal and small farmers in broadening their adaptive options in the agriculture sector.

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Annex 1: Measurements and conversions

Table 1. Official land size classification in Bangladesh in acres and decimals (dec.)

Landless	Small	Medium	Large
<0.5 (<50 dec.)	0.5 – 0.99 (50-99 dec.)	1 – 2.49 (100-249 dec.)	>2.5 (250 dec. and beyond)

Table 2. Measurements and Conversions

Area:	1 bigha = 33 dec., 0.33 ⁶⁷ acres	1 acre = 100 decimals, 3 ⁶⁸ bigha,	1ha = 2.47105 acres 1 acre = 0.404686 ha
Weight:	1 Mon = 40 kg	1 metric ton = 1,000 kg	
Currency:	1 USD = BDT ⁶⁹ 78.00		

⁶⁷ According to farmers in Thakurgaon, this is 0.5 acres in this district.

⁶⁸ According to farmers in Thakurgaon, this is 2 bigha in this district.

⁶⁹ Bangladesh Taka