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

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1 Acknowledgments

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The following Partners led on-ground implementation:

- In Nepal – The NGO iDE, with support by the Department of Irrigation (DoI) and Groundwater Resources Development Board (GWRDB).
- In West Bengal – The Government University, Uttar Banga Krishi Viswavidyalaya (UBKV), and the NGO, CDHI.
- In Bihar – The Indian Council of Agricultural Research (ICAR) and the NGO, Sakhi Bihar.
- In Bangladesh – The Bangladesh Rice Research Institute (BRRI).

The project worked in collaboration with the ACIAR funded projects focussing on Socially Inclusive Agricultural Intensification (SIAGI), led by CSIRO (LWR/2014/072) and Sustainable Resilient Farming System Intensification (SRFSI) lead by CIMMYT (CSE/2013/099).

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2 Executive summary

The Eastern Gangetic Plains is one of the most densely populated, poverty-stricken belts in South Asia. Poor access to irrigation water in the dry season, limited investment capacity and low agricultural innovation, combined with entrenched social structures of class and caste, affects the predominantly marginal farming communities.

This project investigated opportunities for technical and socio-economic innovation to improve the livelihood of woman, marginal and tenant farmers in the region. This participatory action research project identified and piloted a series of institutional and technical interventions across thirty-five sites and six villages in Nepal (Saptari), Bihar (Madhubani), and West Bengal (Cooch Behar) and six villages in North West Bangladesh.

The project assisted farmers to migrate from predominantly single season rice based cropping systems to multi crop systems, including vegetables, with cropping intensity increasing from 100% to more than 200% in most sites. Groundwater is readily available across all study sites, yet utilisation was poor due to low technology awareness and access, not to mention social barriers. The project successfully introduced a range of improved irrigation systems and management practices. It was found in India and Nepal that technically advanced systems such as drip irrigation, solar pumping and irrigation scheduling showed potential, yet were sometimes challenging for marginal farmers. Low technology systems, such as improved surface irrigation and water conveyance through poly-pipe had the greatest impact.

In Bangladesh, there has been a substantial shift from subsistence to commercial farming, with diversified farming systems under intensified irrigation. In some areas, this has affected access to groundwater by shallow tubewells, and adaptation to water shortages has been through electric deep tubewells, which have halved the cost of irrigating rice, and doubled profits. Farmers were found to be efficient in applying water to the crops and water saving measures, such as alternative wetting and drying and piped distribution, have improved irrigation efficiency. The impacts on groundwater of expanding dry season agriculture, and different crop selections needs further research.

The project identified significant socio-economic, structural and institutional constraints to agricultural production by marginal farmers, including access to land and capital, inequitable landlord-tenant relations, migration and feminization of agriculture, which has affected labour availability. Innovative social interventions, through the formation of farmer collectives, proved beneficial to marginal farmers who could enhance their bargaining power and more efficiently use labour, while addressing the challenge of small scattered plots, to make the piloted irrigation technologies more feasible. While four different models of cooperative farming were successfully demonstrated, further institutional strengthening is required for longer term social sustainability. The government has a key role in creating the conditions for out-scaling collective farming approaches. While policies exist to support agriculture and water management, marginal farmers are not well equipped to follow procedures and access subsidies and support services.

The project provided significant capacity development resulting in improved farmer confidence with adoption of a range of new agricultural, water and technological management practices. Farmers have a greater capacity to work collectively through the cooperative models, which have evolved organically under the farmers' leadership. There were significant benefits to woman who comprise 60% of the farmers. Through collectives, the confidence of farmers has increased, government services have been mobilized and access to subsidised production inputs such as seed and fertiliser were facilitated. This coupled with the introduction of appropriate high value crops and cost effective irrigation systems, has substantially increased yield and incomes. This is a major achievement, which has important development implications, and makes this project highly relevant to food security and poverty alleviation in the Eastern Gangetic Plains

3 Background

The Eastern Gangetic Plains, which include the Nepal Terai, Bihar and West Bengal regions, is one of the most densely populated, poverty-stricken belts in South Asia. Behind this persisting poverty are deeply entrenched social structures of class and caste, with a high incidence of inequitable landlord-tenant relations. This combined with poor access to irrigation water in the dry season, has limited irrigation capacity and low agricultural innovation.

Technical, social and economic constraints have limited the effective use of groundwater and ponds for irrigation, and large areas of land remain fallow during the dry months. Access to year-round water for irrigation would significantly promote the productivity of agriculture, improving incomes and food security. Marginal and tenant farmers, youth and women were the target set of farmers who could benefit from a new approach to irrigation provision.

The project researched ways to alleviate poverty and achieve food security, in part through a program of improved water management and irrigation using efficient systems, and by using collective farming systems appropriate to the needs of the marginal and tenant farmer majority. This research is crucial to the long-term sustainability of small-scale agriculture in the Eastern Gangetic Plains.

Bangladesh can offer some lessons, where in contrast to the Terai regions of Nepal and India, dry season irrigation is considerably more developed. Irrigation expansion has allowed the country to more than double its cereal grain production since 1971 and maintain food security in the context of population growth. State policies facilitated a rapid increase in deep and shallow tubewells for groundwater extraction, and successful models of private sector engagement have improved irrigation access amongst marginal farmers. At the same time, there has been a downside to Bangladesh's success, including over-extraction of groundwater, declining soil fertility, and the tendency for dry season Boro rice to push out non-cereal crops.

The study sought a better understanding of these issues and piloted potential solutions, both technical and institutional. The project covered 35 demonstration sites across 12 villages, two villages in Saptari (Nepal), two villages in Bihar (India), two villages in West Bengal (India) and six villages in NW Bangladesh. Alternate approaches to land tenure, and their impact on livelihoods and resilience was evaluated only at the six villages in Nepal and India. The project researched both biophysical and socio-economic constraints of marginal farmers.

Bio-Physical Constraints

Improved irrigated agriculture during the dry months offers potential for increased income and enhanced food security. For these dry season activities however, it is essential to access water reserves stored during the monsoon– namely groundwater resources, and surface storage such as ponds. Groundwater resources across this region are extensive but under-utilised (Shah, 2007), with only a fraction of the cultivable area under irrigation of dry season crops, resulting in limited crop diversification, food insecurity and poor nutrition.

Another constraint relates to limited rural electrification and severe power shortages, which have made farmers in Bihar and Nepal dependent upon expensive diesel pumps (Shah, 2006). Technical barriers to irrigation include poor access to water, inefficient pumps, poorly maintained ponds and limited technical expertise in irrigation scheduling and the operation of water efficient irrigation distribution systems. Inefficient irrigation practices, including over irrigation or poor irrigation scheduling, leads to substantial volumes of water being pumped that are not used by the plant. This results in inefficient water use but also unnecessary additional expense.

Socio-economic constraints of marginal and tenant farmers

These constraints are aggravated by socio-economic inequalities. The small farmer majority in particular, cannot afford investment in pump sets or tubewells, and this is made worse by monopolistic pump rental markets, which further drive up the costs (Wilson, 2002). Furthermore, tenant farmers who constitute a significant proportion of farmers, have limited incentives to invest due to tenure insecurity (Sugden and Gurung, 2012). Labour opportunities elsewhere are also reducing local interest by young males, while women headed households, which are increasing in this context, face further constraints to accessing irrigation due to entrenched gender relations and limited access to resources. Marginal and tenant farmers, youth and women (in particular, those from women headed households) thus constitute an important set of farmers who could benefit from a new approach to irrigation provision.

While enhanced access to irrigation could significantly increase agricultural incomes, this is unlikely to occur without addressing some of the socio-economic constraints for marginal and tenant farmers. Land tenure is critical for equitable agricultural development (Sugden, 2013b, Kishore, 2004, Sugden, 2013a). Lack of access to land or secure tenure discourages investment in irrigation, even if cheaper pumping and distribution technologies can reduce operating costs (Sugden, 2013b, Sugden and Gurung, 2012). Farmers are unwilling to bore wells on land which does not belong to them, while high rent and fragmented rented plots make purchasing or renting a pump set unviable (Sugden et al., 2013)

While long-term solutions such as land and tenure reform are unlikely, there is considerable potential for solutions grounded in collective action. This project aimed to combine the experiences of local NGO partners to experiment with collective agricultural innovations through farmer groups of land marginal and tenant farmers who can jointly manage and own the irrigation infrastructure on land, which is leased and cultivated cooperatively by the groups.

There are also challenges posed by male out-migration and the feminisation of agriculture. Migration increases the workload of women and children who stay behind, and has increased the tendency to leave land fallow in the dry months. It is for this reason the project had a strong focus on gender.

4 Objectives

4.1 Overall Aim

The overall aim of the project was to improve the livelihood of woman, marginal and tenant farmers in the Eastern Gangetic Plains, through improved water use and increased dry season agricultural production. The project identified and tested a series of institutional and technical interventions, at a village scale, to increase dry season farming in the context of a highly stratified social structure.

4.2 Specific Objectives

Specific objectives and key activities are outlined below.

OBJECTIVE 1: Determine existing water resources and sustainable utilisation for irrigation from tanks and groundwater.

- *Village scale assessment of water resources, storage, irrigation potential and water management approaches.*
- *Assess efficiency of existing infrastructure and opportunities for efficiency improvement.*

OBJECTIVE 2: Determine the socio-economic, structural and institutional constraints to sustainable water use.

- *Analyse household vulnerability to both climatic and economic stress and how farmers cope with risk, to inform selection of interventions and beneficiaries.*
- *Analyse land tenure, gender, institutions and policies.*
- *Comparative research in Bangladesh on institutional aspects of ground/surface water interventions to understand applicability of successful interventions.*
- *Select six sites (two per district) in which to implement interventions.*

OBJECTIVE 3: Determine and evaluate approaches for access to water for irrigation, focusing on using renewable technologies and alternate approaches to land tenure, and their impact on livelihoods and resilience.

- *Pilot interventions in villages and identify feasibility of interventions for each site based on technical and socio- economic considerations.*
- *Engage with communities for capacity development and to determine best approaches to implement technological and institutional innovation.*
- *Develop interactive tools, training materials and market chain development packages to build local capacity.*
- *Monitor effectiveness of interventions and link research to broader development opportunities.*

OBJECTIVE 4: Facilitate long term up-scaling and out-scaling of approaches and alternative opportunities.

- *Develop and disseminate material, tools and business cases demonstrating technical (new irrigation technologies) and institutional innovations (e.g. collective leasing of land) for improved water management and dry season production amongst policy makers and practitioners at a central level (state or national government) level.*
- *Engage in dialogue with policy makers and practitioners to facilitate up-scaling of project results through changes in policy and practitioner interventions in response to project outputs.*
- *Facilitate out-scaling of interventions to neighbouring communities through ground level dissemination activities with farmers.*

4.3 Key Research Questions

The key research questions that were examined are:

1) What is the existing distribution of ground and surface water, irrigation demand and extent of irrigation in the study sites of India and Nepal? What are the technical constraints of existing irrigation systems utilising different energy sources?

2) What are the existing patterns of vulnerability and the social structures (e.g. land tenure, roles of women and young people), institutions and policy context, which mediate access to ground and surface irrigation and shape livelihood outcomes in the study areas of Nepal and India?

3) How have ground and surface irrigation interventions in Bangladesh addressed structural, institutional, energy constraints? How can these experiences inform interventions in Nepal and India (and vice versa)?

4) What is an appropriate model for the sustainable provision of dry season irrigation utilising both surface and groundwater, and energy efficient, affordable pumping technologies?

5) What institutional innovations are necessary to make this model appropriate to marginal and tenant farmers, including women and potential migrants? How can this model most effectively strengthen their livelihoods and build resilience?

5 Methodology

The project used a participatory action research (PAR) approach to investigate dry season agriculture for marginal and tenant farmers (DSI4MTF), working closely with target farmers and stakeholders. Both technical and socio-economic assessment of the impact and adoption of different practices and interventions was undertaken. In depth case studies as well as quantitative data analysis of cropping practices, productivity and profitability and irrigation performance were used to document impact and change.

Piloting and demonstration was across 35 sites and 6 villages in Nepal (Saptari), Bihar (Madhubani), and West Bengal (Cooch Behar) and 6 villages in the Rajshahi, Pabna, Bogra, Rangpur, Dinajpur and Thakurgaon districts of North West Bangladesh.

The research approach involved four main steps:

- Assessment of sustainable utilisation of available ground and surface water resources for irrigation of dry season crops.
- Research to identify livelihoods, land tenure, water management institutions, gender relations and different farmer groupings and its impact on water management.
- Evaluation of different interventions for improving dry season agriculture. These included biophysical interventions such as introduction of dry season cropping systems under improved irrigation practices and social interventions including collective farming arrangements.
- Capacity building and engagement with local communities and scaling to broader villages and communities.

5.1 Study site selection

Site selection considered both social and biophysical contexts. In India and Nepal selection criteria were strongly focussed on the need to target woman, marginal and tenant farmers, the feasibly of cooperative farming systems, including access to land, as well as availability of water resources and interest of farmers in dry season agriculture. NGO partners engaged in extensive and ongoing negotiation with farmers, initially focussing on availability of land for collective leasing or aggregation of private land for collective farming. Site selection also considered existing or potential for farmer clubs and self-help groups, supply chain linkages and local markets, capacity development and training needs of farmers, and logistics to get access to sites.

Village maps were prepared and on ground data collected to shortlist sites based on a range of bio-physical, socio-economic and logistical criteria. In India and Nepal site selection was completed in May 2015. Appendix 1 documents the selection process and Appendix 2 provides overview maps of the study sites.

In North West Bangladesh collective farming was not evaluated, and the key aim was to better understand the bio-physical, socio-economic and institutional aspects of groundwater irrigation, through intensive monitoring of groundwater irrigation. The focus was on different groundwater access opportunities (deep and shallow tubewells), a range of cropping and irrigation systems and a mix of diesel and electric pump arrangements, and a range of water pricing mechanisms. Sites were selected across the northwest region in each of Rajshahi, Pabna, Bogra, Rangpur, Dinajpur and Thakurgaon Districts with a range of irrigated rice and other crops (such as potato, tomato, wheat and maize).

5.2 Engagement, communication and capacity development

Capacity development, stakeholder engagement and communication was adapted and implemented locally, and guided by a strategy and plan developed at the project inception workshop (Appendix 3). This guided decisions on who, how and what engagement and communication was appropriate at local, district and national scale, and who required capacity development, in what competencies and the associated actions.

Engagement activities included partner meetings, farmer group meetings, training events and formal and informal stakeholder meetings. There were over 450 farmer meetings, 16 stakeholder meetings and 174 training events with woman representation in training events and meetings in Nepal and India sites being 61% of total and across all sites, including Bangladesh 52%.

Engagement was important for capacity building and training of marginal farmers. This included training in production of crops and management of irrigation systems and guiding the evolution of farmer collectives. There was also a focus on market chain development and establishment of linkages with traders. Engagement also supported the evolution of pilot interventions in a participatory manner. Farmers were able to meet regularly with the project team to discuss their experiences of the pilot interventions, draw up key learnings, and identify challenges to be resolved.

Stakeholder meetings provided opportunity for local NGOs, extension personnel and private and government agency representatives to contribute to driving change at a local level and broader scale. This provided opportunities for up-scaling and for broader policy, economic and institutional reforms. Networks were developed through stakeholder meetings to establish links between public, private, village and district institutions.

The processes through which the project team engaged with the farmers and stakeholders was grounded in an Ethical Engagement model developed during the project itself (Mishra, 2016 Report No 6). Project reports can be accessed at the project web site *https://dsi4mtf.usq.edu.au/publications-resources/*.

5.3 Impact pathway, monitoring and evaluation and governance

Project monitoring and evaluation guided by the project impact pathway analysis (PIPA) and Monitoring and Evaluation (M&E) Plan (Appendix 4), which was developed at the inception meeting. Monitoring and Evaluation was based on both quantitative and qualitative assessment, which helped assess impact and progress.

The PIPA and Monitoring and Evaluation plan was reviewed annually and helped participants understand the consequential steps to achieve research outputs and project outcomes, and ultimately project goals. The project PIPA (Figure 1), demonstrates the cause and effect relationships between getting ready, inputs, activities, outputs, and intermediate and longer term outcomes. It shows a series of expected essential consequences (indicators of success) from the project and guided what and when to monitor to assess impact and assist project management during implementation.

A framework of specific evaluation questions about components of the project was used to assess project performance and impact. Summary responses to evaluation questions are provided in Appendix 5.

An overarching project management committee, comprising representatives from each organisation, met regularly to provide project oversight and governance. Regional Coordinating Committees, established to review progress and support planning and management met at least once per year.

Project Impact Pathway (June 2017)

Read me from the bottom up!

Table 1. Improving water use for dry season agriculture by marginal & tenant farmers in the Eastern Gangetic Plains IPA							
Goal	Improved livelihoods for women (WF) & marginal and tenant farmers (MTF) in the Eastern Gangetic Plains through improved dry season irrigated agriculture.						
Longer Term Outcomes 5/10yr	Reduced poverty & increased food security among MTFs with a focus on women farmers.	Improved production through sustainable water and land management (SWM).					
Intermediate Outcomes							
Group/institutional practice change	Groups of WF, MTF and are planning to change water use (WU) practices, institutions have been briefed on policy impacts.	WF & MTF have mobilised and are empowered with increased capacity through group cooperation	Country NGO's, Local Government, Village Development Committees & extension organisations are informed on SWM and collective innovations and policy implications. .				
Key individual practice change	Leading WF & MTF have changed their WU practices and grow dry season irrigated crops profitably.	Successful lead farmers and farmer groups are sharing their WU practices.	MTF and WF have changing tenancy patterns supporting dry season irrigation	Lead WFs are networked to key NGO, agency support people and supply chain organisations.			
Confidence, knowledge & skills change	WF & MTF have confidence in WU & dry season irrigated crop production techniques & negotiate with resource owners.	Country agency water managers, NGOs and extension agents support SWM practices.	Local Government, resource owners and supply chain actors support dry season irrigated crop production and SWM.				
	Partnerships built between project researchers, NGO & local extension staff to support lead WF & MTF & their groups.						
Access to information	WFs, MTFs, local extension, NGO staff, district WU researchers and market chain actors are accessing SWM technical/market information.	WFs, MTFs, NGOs, agency research & extension staff sharing WU project knowledge & experiences.	Innovative technology options for sharing information utilised e.g. mobile telephones, social media etc.	Awareness of dry season WU options increased at local , state and national level, SWM practices demonstrated.			
Initial Outcomes							
Outputs/activities	Lead WF & MTF farmers, resource owners, researchers & extension staff participate actively in demo sites.	Partnerships built between researchers, NGO & agency staff.	Lead WF & MTF trained in WU & dry season irrigated crop practices	SWM techniques & options identified & tested - technically & economically.	Water availability & current use identified.	Water & Land management agencies identified & evaluated for their roles in WU research & extension.	Information on SWM options produced for farmers, NGO & Local extension staff, country agency & project managers.
	Engagement, communications & capacity building strategy & plan produced.	Household vulnerability & socio-economic drivers of communities identified.	Lead WF & MTFs selected & participating.	Demo sites established, NGO & agency extension staff engaged to support sites.	Project management established with M&E & reporting plans.		
Inputs	ACIAR funding & participating country agency 'in kind' contributions made.	Project management & coordination commenced & operational plan & work schedule developed.	Government, NGO & private sector research & extension services partnerships agreed & resources accessed.	Monitoring & reporting templates established.	Participatory operational plan developed identifying schedule of activities by partners.		
Getting Ready	Project proposal, partner agreements, MOUs & timelines agreed. Contracts signed.	IPA, M&E, along with engagement, communications & capacity strategy & plans have been developed & standards for governance, reporting, management (OHS, HR, performance), skills training etc. established with participation of partners.	Partnerships & relationships established & commitments agreed.				

Figure 1: Project impact pathway analysis

5.4 Water resources and sustainable utilisation for irrigation

A village scale assessment of available surface and ground water resources, as well as irrigation systems and strategies was undertaken. Ponds and tubewells were mapped (Appendix 2) and a baseline survey was administered which included irrigation and agricultural production information. The survey covered 2090 households across the 6 villages in Nepal and India (Appendix 6). Owners and users of selected ponds in Saptari, Bihar and West Bengal sites were also interviewed to get a better understanding on pond ownership, access, management and usage issues.

Broader district and village scale, information on temporary and permanent ponds, extent of irrigation and potential for expansion of irrigated crops was collated (Okwany (2016), Report No 21).

Published data on groundwater quality was reviewed focussing on arsenic, fluoride and iron (Rajmohan et al (2017) Report No11). Primary data on pH and EC of the pond and groundwater was monitored on a monthly basis to assess any changes during the year.

Irrigation systems and technology usage was evaluated through field and system measurements and farmer discussions. Detailed pilot study sites were established to develop and test irrigation improvement approaches.

5.4.1 Development of interactive tools

A range of interactive tools and smart phone Apps were developed to assist in field level data collection and irrigation assessment and a number of information sheets and training sheets were developed (Appendix 7).

Mobile phones, particularly internet connected smartphones proved to be efficient tools for sending and receiving information in the field. Simple interfaces were used to capture data, process it and/or instantaneously send it to cloud databases for processing and storage. Figure 2 illustrates data collection, integration and analysis using tools developed for the project.

5.4.2 Monitoring groundwater and surface water resources

Water levels in ponds, tubewells and dug wells were monitored weekly, and daily rainfall and weekly water evaporation was recorded. The mobile friendly applets described earlier have shown much potential and assisted the field officers, who collected the pond and groundwater levels each week, to communicate trends with farmers and prepare an assessment of seasonal trends in both ground water and surface water availability.

Equipment and irrigation infrastructure were purchased by the project and installed at the Bihar, Saptari and West Bengal sites. There was no need to invest in pumps, tubewells, solar systems in Bangladesh as sites were adequately equipped.

A number of aquifer pumping tests were undertaken at the Kanakpatti sites where groundwater was limiting, to assess the impacts of water pumping on aquifer drawdown and recharge. Groundwater potential at this site was also assessed using Electrical Resistivity Methods to better understand the characteristics of local aqifers and optimize tubewell location and operation.

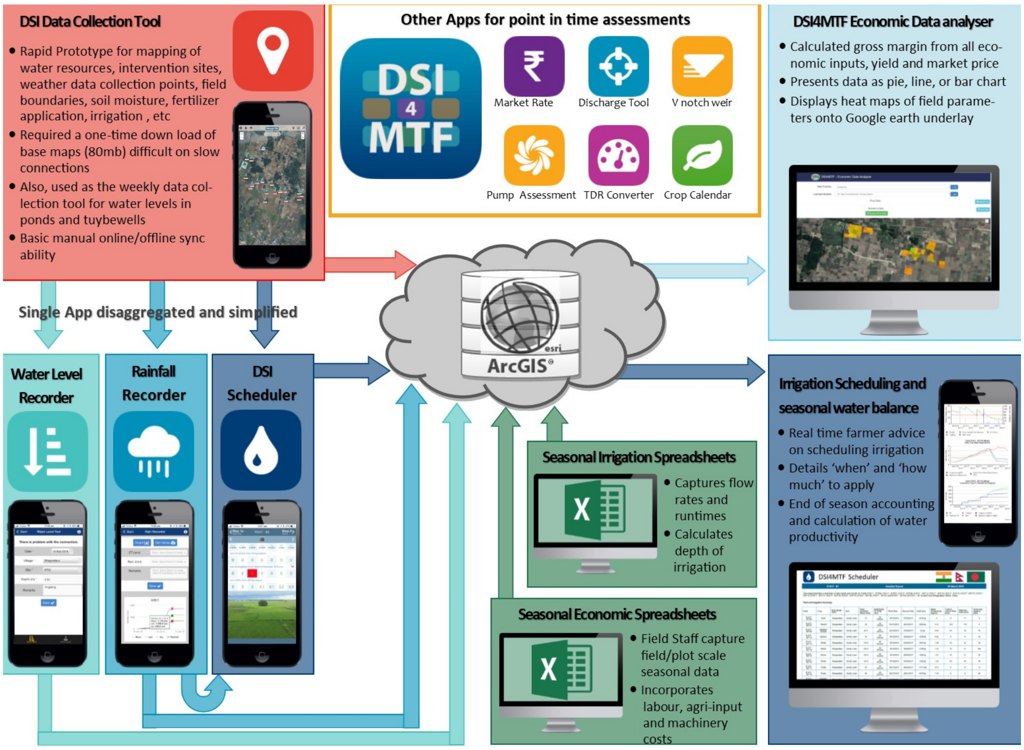


Figure 2: Data collection, integration and analysis using tools developed for the project.

5.4.3 Assessing efficiency of existing irrigation infrastructure

Irrigation system performance was assessed at selected sites. This included pump performance tests, conveyance loss assessment, irrigation application uniformity, and plot water balance assessments.

A range of methods to assist in irrigation scheduling were considered (Appendix 8). These include visual assessment of the plant or soil, soil sampling for volumetric soil moisture assessment, soil moisture monitoring with a range of hardware tools, mini evaporation pans and water balance assessment (e.g. FAO 56). All have different hardware, software, data output, frequency, technological, timing and cost constraints. The project focus was on demonstration trials and not experimental trials, and the main focus was on robust field scale water balance calculations based on FAO56 methods to support improved understanding of adequacy of irrigation management. A mobile phone App (DSI Scheduler, Appendix 9) was developed to support these evaluations.

Due to the perceived complexity, DSI scheduler was found less useful to assist farmers in actually scheduling an irrigation, which was based primarily on experience and observation of the crop and soil and availability of irrigation equipment. It has however been very useful to assess irrigation strategies and their impact on yield and irrigation performance.

Pumping and infield irrigation efficiency assessments were completed for selected systems including diesel, electric and solar pump assessments, drip, sprinkler and surface irrigation system assessments, channel loss assessments, and pond storage assessments. Tests included:

- **Solar pump**: Measuring energy generated and lost through various parts (panels, inverter, pump) of the system throughout the day and as well as comparisons between solar tracking the panel array and fixed array, and clean and dirty panels.
- **Diesel pump**: Determine the cost to pump a unit volume of water and also the effect that different size and length delivery pipe has on the discharge delivered to the field.
- **Drip and sprinkler**: Evaluate the uniformity before and after cleaning emitters, to demonstrate the improvement that results from regular maintenance.
- **Surface irrigation**: Compare depth of irrigation on short and long furrows.
- **Water conveyance**: compare losses in open channel and pipe delivery systems.

5.5 Socioeconomic, structural and institutional constraints to sustainable water use

5.5.1 Analysis of structural inequalities and livelihoods

To ensure that effective socio-economic and institutional interventions could be piloted successfully, it was essential for the team to have an in depth understanding of the socio-economic, gender and institutional context in the region.

A comprehensive review of the history of the region was undertaken, identifying the origins of the present day agrarian formation and assessing recent trends and stresses on agriculture. This provided insights into the agrarian structure, including the different farmer typologies, and the class and caste relations, which serve to reproduce inequalities (Sugden et al (2016) Report No 1). Water management institutions were also assessed through qualitative case study research and the broader economic context was evaluated through analysis of secondary data.

For the sites in Bihar, Nepal and West Bengal where the collectives were to be established, a detailed and comprehensive dataset was developed through a survey of 2090 households in the 6 project villages, covering an extensive set of variables relating to household livelihoods, cropping patterns by plot, productivity and income/expenditure, asset ownership, risk and irrigation practice. This was combined with a series of qualitative tools exploring institutions, market chains, gender and land tenure relations. The comprehensive survey supported assessment of land tenure/management and other social structures, livelihood strategies and water access/demand (see Appendix 6) and a comprehensive baseline report was prepared (Sugden et al 2016, Report No 1).

The baseline survey supported longitudinal evaluation of project sites and collectives, using case studies and focus group discussions. This provides a valuable resource to observe, changes and transformations that take place in the study villages post project.

5.5.2 Gender

To understand gender relations focus group discussion, interviews and literature review data examined how feminization of agriculture and the rise of women-headed households is changing agricultural processes. The team conducted 106 semi-structured interviews, 72 focus group discussions (FGDs), and Participatory Gender Trainings, while a further round of interviews and FGDs were carried out in NW Bangladesh. Intervention farmers, landlords, and staff from implementing organizations were interviewed (Leder (2015), Report No 3).

This study investigated how changing gender relations impact women's access to water and land resources by examining women's empowerment and their perceptions on being a farmer within the context of the changing gender roles in agriculture in the Eastern Gangetic Plains. The research objective was to understand the state of critical consciousness, reasoning and decision-making capacities of particular groups within communities in regard to water access, control and use for agriculture. To strengthen communities' resilience , the interviews and FGDs investigated how environmental, economic and social knowledge and capacity building can be promoted and institutionalized to empower women and marginalized farmers for agricultural productivity.

Through this a gender training approach was developed and piloted with farmer groups. This culminated in development of a training manual and associated training film, "Participatory Gender Training for community groups" (2016) Report No 4.

A documentary on the training manual, titled "Participatory gender training for community groups gender training for community groups", was made and follows community mobilizers as they facilitate the manual's activities and discussions, as highlighted in a project blog article https://dsi4mtf.usq.edu.au/2017/02/ .

5.5.3 Policies and Institutions

For effective water management it is necessary to understand policy and institutional constraints that mediate access to surface and groundwater irrigation. This helps assess how the policy context shapes livelihood outcomes. Such policies, which provide an institutional framework for water management at different levels, were reviewed, with specific focus on irrigation and surface and groundwater management. Literature also provided supportive evidence on key trends and policies (Bastakoti (2017) Report No 2).

Local water management and institutions were also analysed through interviews with key district level officials and focus group discussions at the community level. This helped identify local institutional innovations that are necessary to make various technological models appropriate to marginal and tenant farmers, including women, who comprise the majority farming groups.

5.5.4 Bangladesh comparative institutional analysis

In addition to the gender analysis which already included Bangladesh, further comparative research conducted there on institutional aspects of ground/surface water interventions, helped contrast how the socio-economic and institutional challenges identified in Bihar, West Bengal and the Terai could be addressed through successful irrigation interventions in the Bangladesh context. Case study sites representing examples of institutional innovations were visited and qualitative focus group and interview data was collected. The research highlighted 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 marginal and woman farmer groups. Data was collected through a literature review and qualitative interviews from five villages distributed across Rangpur, Thakurgaon and Rajshahi districts between May 2015 and March 2016 (da Silva and Leder (2017) Report No 17). Gender aspects were also investigated and a Master degree thesis was completed by Sadiq Zafrullah through the Swedish University of Agricultural Sciences on the topic "Gendered Groundwater Technology Adoption in Bangladesh – Case studies from Thakurgaon and Rangpur".

5.6 Evaluation of approaches for access to irrigation water and for collective farming

A range of biophysical and social approaches for dry season irrigated agriculture and collective farming were evaluated at project demonstration sites.

5.6.1 Identifying demonstration sites and interventions

Demonstration sites and interventions within each village were selected in close association with farmers, considering both social and technical constraints and farmer preferences. This process took over eight months and was based on a situation assessment of the current biophysical, social and institutional situation and potential interventions that could be implemented. Initial ideas were discussed with farmers through a series of meetings implementation plans were developed for each site and updated regularly.

Demonstration sites and biophysical and social interventions were agreed with farmers and irrigation infrastructure was deployed between May 2015 and June 2016.

5.6.2 Evaluating biophysical and social interventions

Farmers were provided ongoing training and capacity development. Training covered diverse areas, including crop agronomy, pest and diseases, fertilizer management, crop selection, irrigation technologies and water management practices, collective farming and group operation, gender issues, market linkages (Appendix 10).

Pilot sites were evaluated in terms of crop performance, irrigation system performance and social and institutional development. While the productivity and profitability of the farmers was considered, profitability is not the only driver for these communities. Improved nutrition, diversification and risk and self-empowerment are key benefits from diversified farming practices. Cropping decisions are often about labour, culture, past experience, risk aversion, market limitations and local consumption needs, as well as labour and input cost requirements and less about profit.

5.6.3 Biophysical monitoring and evaluation

Seasonal irrigation demand was determined for pilot sites, using detailed field and crop records and FAO56 based modelling. Economic and bio-physical crop information was collected from all sites across ten cropping seasons between October 2015 and April 2019.

Biophysical and economic data was collected for each plot and used for productivity and profitability assessment, as well as infrastructure investment cost/benefit. Plot by plot information collected included crop yield, selling price, and input costs including labour costs, land preparation, seeding, fertiliser, weed and pest management, irrigation, harvesting and transport. Field officers or assistants were responsible for data collection using hard copy data sheets (Appendix 11) with information transferred onto spreadsheets and uploaded into a web tool, to assist in data analysis and enquiry. For each farmer group or collective on a crop type and season basis, a range of assessments were undertaken, including:

- Changes in cropped area and number of fields cultivated
- Yield (kg/ha) and total production (kg).
- Production costs by field operation or cost type (machinery, labour, agri-inputs)
- Income and expenditure and gross margin

Water balance assessments were also undertaken for selected sites based on the FAO56 modelling and performance of irrigation systems was assessed through a program of pump, water distribution and irrigation uniformity tests.

5.6.4 Socio-economic monitoring and evaluation

The socio-economic performance of the project interventions was evaluated through regular interaction between the project team and farmers. Project field officers played a key mediating role to keep communication channels open. A series of systematic monitoring and evaluation activities were also mobilised.

Firstly, data from the seasonal biophysical survey offered insights into changing cropping practices and productivity improvements amongst marginal farmers. Secondly, data was collected through a series of timed field visits by the socio-economic research team at different points in the cropping cycle between 2015 and 2018. Visits were focused on informally meeting the groups in a focus group setting and collecting key information on challenges, opportunities and group management. Thirdly, a separate spell of focused data collection also took place at the end of the first and second year of cultivation in the winter of 2017 and again 2018. This included 100 semi-structured household interviews and 72 focus group discussions, which analysed the day to day functioning and management of groups, land and labour management and conflict resolution.

Thirdly, a group meeting of farmer group representatives from all 6 sites which was also held in Madhubani in February 2017 to collectively reflect upon some of the issues raised in the interviews and focus groups and encourage debate and cross learning amongst participants.

Finally, a significant source of data was the insights provided by the field teams themselves who were based in each of the sites throughout the three year period. In order to document the learnings of the teams on the ground, they produced three rounds of case studies in year two and three of the project – with 47 collected in total. Separate case studies were collected on each of the chosen themes - household livelihoods, collective action, and access to technology and community engagement. They followed a standard format including the background of what happened, the ‘positive’ experiences from the case study including learnings for upscaling, and the evidence on what could have been done differently, also to inform for future interventions.

5.6.5 Integration through case studies

Integration of biophysical and socio-economic impacts was documented using a case study approach. In total 47 case studies were developed, seventeen of which are being synthesised into a booklet for publishing (“Synthesised Case Studies” (2019) Report No 22). An integrating document allowing analysis across eleven themes is being prepared to support integrated learning from the cases. These themes cover technology and skill development, leadership development, change in attitudes, woman’s empowerment, bargaining capacity, group dynamics, challenge to achieve ownership, ethical community engagement, livelihood security, engagement and linkages with stakeholders.

These case studies formed an integral part of monitoring and evaluation providing qualitative and quantitative data on interventions and the social impact on beneficiary households for each season, using appreciative enquiry methods.

They highlighted how farmers were responding to the interventions, covering positive stories and challenges faced, as well as critically engaging with the process of project implementation and community engagement. The framework used for monitoring and evaluation through case studies is detailed in Appendix 12.

5.7 Facilitating long term scaling of approaches and opportunities

The term scaling is used interchangeably with adoption, transfer and replication. This is an over simplification of a complex social change process that is inherent in the goals of scaling (Williams 2018). A more realistic conceptualisation of scaling is as a process of adaptation and learning, in recognition of the fact that people do not just accept new information, but that it is, reflected, re-interpreted, integrated and adapted to suit their conditions, values, aspirations and constraints (Long 2001). This conceptualisation also recognises that programs and interventions, particularly those that emphasise community empowerment and participation, must be adaptable to the diversity of communities and places in which they would potentially work.

Considering the above conceptualization, three typologies of scaling are identified in the context of DSI4MTF, scaling out, scaling up and scaling deep. These are presented schematically below.

DSI4MTF utilised a wide range of engagement, communication and capacity development strategies to facilitate adoption and scaling. These included focus group discussions, farmer meetings, stakeholder consultation, institutional development and capacity building, participatory planning, exposure visits between villages and training events. The strategy evolved at a local level recognising the differing capabilities of project partners and needs of communities.

Project partners also interfaced with local, district and state agencies, to inform, influence and convince them of project impacts. Seminars and conferences were also a useful forum for broader communications.

DSI4MTF's scaling strategies evolved over time and have taken impact through various routes, the core being community engagement to offer the community a reflective environment to allow the community to collaborate, co-create and adapt.

While DSI4MTF's strategies have supported out-scaling, up-scaling and deep-scaling, the greatest impact has been at a local village level and local institutions and organisations. This is not unusual given the research being undertaken and relatively short time.

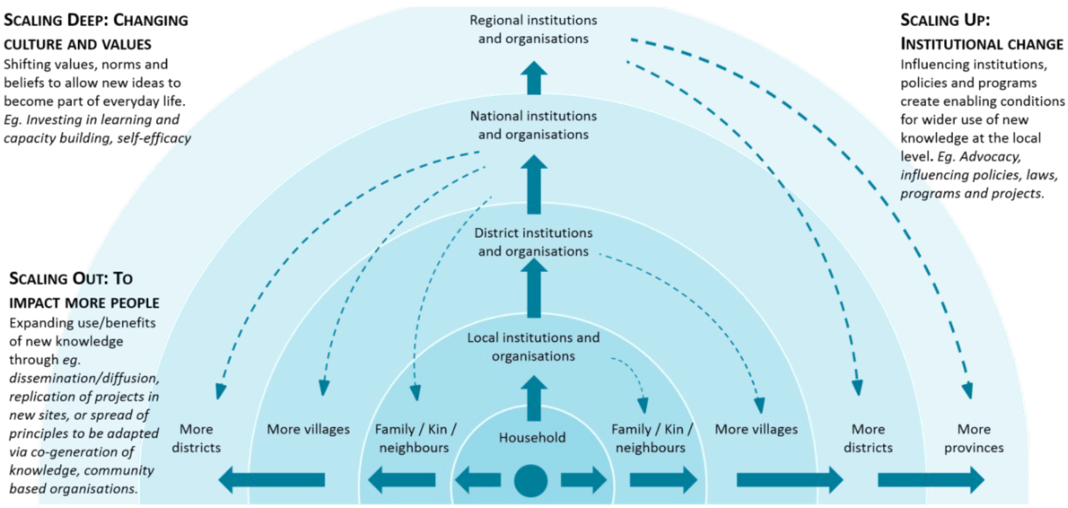


Figure 3: Schematic of typologies of scaling (Adapted from Ridell and Moore (2015) as cited by Williams (2018))

6 Achievements against activities and outputs/milestones

Objective 1: Determine existing water resources and sustainable utilisation for irrigation from tanks and groundwater.

No.	Activity	Outputs / milestones	Achievements / Comment
1.1	**Mapping groundwater and surface water resources**		
	a. Mapping seasonal and perennial ponds b. Groundwater Resources Assessment c. Estimating Irrigation Demand d. Estimating extent of Irrigation e. Water quality	a. Summary tables and maps of ponds, including volume, prepared for target villages and pilot study sites following ground-truthing and loaded in project database. b. Groundwater assessment prepared for each target village and pilot area based on available reports and local piezometric data and loaded into project database. c. Summary tables, maps and report on crops and potential irrigation demand prepared for target villages and pilot sites following ground-truthing, and loaded into project database. d. Summary tables, maps and report on extent of irrigation for target villages and pilot sites following survey and ground-truthing, and loaded into project database e. Literature review completed on water quality. f. Report concluding Activity 1.1	a. Maps and tables of ponds and infrastructure loaded to GIS. Weekly records maintained of pond water level with associated graphs. Field staff use DSI App 'water level recorder' for routine data collection. Survey of 19 ponds completed (8 Madhubani, 4 Saptari, 7 West Bengal) to understand pond water use preferences and usage. b. CSE99 report provided district/village groundwater assessment. Groundwater and pond water assessment prepared for each village (Report No 21). Weekly monitoring of tubewells and piezometers loaded to database for ongoing assessment of ground and pond water resources for each village. Resistivity analysis and drawdown/recharge tests completed for Kanakpatti site based on poor aquifer yields (Report No 19). Monitoring indicates that interventions are having no negative impact on groundwater resources. c. CSE99 report provided information on district scale irrigation demand. Baseline information on crop water requirement and irrigation demand of main seasonal crops determined for each village using AquaCrop (Report No 21). Ongoing seasonal irrigation demand assessed for pilot sites, using detailed field mapping, crop records and FAO56 methods and DSI Scheduler (water balance and scheduling App) or equivalent spreadsheets (Bangladesh). Both irrigation demand and effectiveness (timing and volume of irrigation) are assessed. Information on farmer's performance with respect to irrigation scheduling relayed to farmers through small discussion groups. d. Baseline village survey completed summarising extent of irrigation and infrastructure. (Report No 1). Pilot site irrigation records captured seasonally and loaded into database for use in plot wise water balance calculations. e. Literature review on water quality complete (Report 11). Ongoing collection of EC and pH from monitored tubewells. f. Project Final Report and Technical report chapters (under preparation). Regional modelling of impact of crop expansion and intensification on groundwater is required and proposed as important follow on research.
1.2	**Assess efficiency of existing infrastructure**		
	a. Collection of data on existing water use, cropping patterns and crop demands b. Develop framework to be used to identify and test the feasibility of specific	a. Detailed survey in pilot areas completed of all irrigation infrastructure, method of operation, assumed crop water requirements, irrigation water usage, cropping patterns and production	a. Baseline irrigation infrastructure survey completed for all villages (Report No 1). Irrigation infrastructure details updated annually. Cropping patterns and irrigation requirement and usage assessed seasonally. Cropping patterns/calendars planned with farmers seasonally and documented. DSI Apps tool "Crop Calendar" developed to help farmers assess the potential rotations for maximising cropping. Much effort directed at farmer engagement and training. Selected information presented to farmers in the form of village notice boards (e.g. cumulative rainfall Vs long-term average rainfall, and cropping data (seasonal options, recommended plant and harvest dates).

No.	Activity	Outputs / milestones	Achievements / Comment
	biophysical/technical interventions c. Identify losses and potential gains at each stage of the irrigation system and water balance	b. Framework (assessment methodology) developed to guide selection of technical innovations at each site. c. (i) Storage, distribution and Irrigation system analysis completed for each pilot site for current situation and potential new irrigation and cropping regimes and loaded into database. (ii) Efficiency and cost of pumping documented for a range of existing electric and diesel driven pumps operating in each of the pond sites (iii) Simple seasonal water balance assessment completed for each of the pond sites (iv) Refinement and on-going data collection of actual pond water balance data Report on the current and future infrastructure use and efficiencies of the irrigation system completed Final report on infrastructure assessment incorporating all data collected in activity 1.2 across 3 seasons.	b. Assessment methodology (framework) described in Appendix 1. Selection of technical innovations guided heavily by local partner experience, farmer preferences and technology familiarity and captured in site intervention (action planning) tables. All planned interventions subsequently implemented. c. Ongoing groundwater and pond water level (weekly) records are collected and loaded to the project database using purpose built 'Water Level Recorder App'. Irrigation infrastructure mapped and performance data collected and loaded to database. i. Pilot site water balance ("system analysis") undertaken seasonally at selected sites based on measured inflows and FAO56 modelling. Losses in distribution channels (Madhubani and Saptari) and ponds (West Bengal) assessed ii. Cost of pumping captured seasonally for all sites. Pumping (electric, diesel and solar) and infield irrigation (sprinkler, drip, and surface) assessments completed for selected sites iii. Seasonal water balance completed for selected sites and crops. Analysis of the effectiveness and productivity of irrigation has been undertaken using a purpose built irrigation scheduling App (DSI Scheduler).Simple pond water balance investigations have been undertaken in Madhubani and detailed seepage and evaporation assessments have been undertake for selected ponds in West Bengal. Regional scale water resources (surface and groundwater) assessment (not part of this project) have been included in SRA submitted by CSIRO in 2019. iv. Refinement of processes complete, data collection ongoing. Significant effort given to designing, developing, training for a robust data collection system for all field biophysical data this framework is now well established, and integration of new tool and apps is possible. Digital systems for data collection, while requiring upfront effort, have proved to have substantial timesavings in terms of input and error checking, analysis, and reporting on a range of data. This is an important element of work, Michael Scobie (USQ) has started a PhD looking into the opportunities, and barriers for data collection and decision support tools across a range of biophysical and sociocultural landscapes. The output will be a development framework for improved design and utility of mobile phone tools and decision support systems. This work will be undertaken in parallel with the SRA (WAC/2018/163) in 2019/2020. Technical reporting on infrastructure use and efficiencies ongoing across regions. Consideration given to integration into an ACIAR Technical report or "knowledge harvest" type document. Case studies of technology adoption have also been prepared.

Objective 2: Determine the socioeconomic, structural and institutional constraints to sustainable water use

No.	Activity	Outputs / milestones	Progress against milestones / Comment
2.1	**Analysis of land tenure, gender, institutions and policies**		
	a. Complete questionnaire and focus groups on	a. Survey/Focus groups:	a. Socio-economic survey completed, analysis and write up completed (Report 1).

No.	Activity	Outputs / milestones	Progress against milestones / Comment
	livelihoods land tenure, gender, and institutions b. Analysis of household vulnerability to climate and economic stress and risk c. Analysis of land tenure/relations and other social structures, livelihood strategies and water access/demand d. Analysis of broader economic context and ongoing agricultural trends e. Analysis of water management institutions, both government and non-government f. Analysis of gender relations, migration and irrigation access, and how feminization of agriculture and rise of women headed households is changing agriculture g. Identify different farmer groups according to economic status and current irrigation access h. Identify policy context, including existing irrigation initiatives by government and non-government actors, and seek programmes with which to build synergies i. Publication on land tenure, gender and irrigation access in the Eastern Ganges plain completed	i. Preliminary questionnaire designed and piloted. ii. Questionnaire administered iii. Farmers engaged through participation in focus groups, stratified according to gender. b. Analysis of vulnerability to economic and climate shocks completed based on questionnaire, with farmers categorised according to vulnerability. c. Analysis of land tenure, landlord-tenant relations and its relation to water access and demand completed based on questionnaire and focus group data d. Economic context and agricultural trends documented through secondary literature review e. Water management institutions researched and analysed through focus groups and informal qualitative interviews f. Assessment of gender and male out-migration and impact on agriculture completed using focus group and questionnaire data, and a secondary literature review. g. Questionnaire data analysed to develop useful farmer typology h. Policies on irrigation and ongoing government programmes and initiatives reviewed and documented based on review of secondary sources and dialogue with state/national level irrigation/agriculture officials. i. Data from questionnaires and focus groups compiled into publication on land tenure, gender and irrigation access in Eastern Gangetic Plains	b. Vulnerability report completed (Draft Report 9). Agreement to curtail this area. Some results integrated into socio-economic baseline report to make it more relevant. c. Report on land relations in the Eastern Gangetic Plains and the case for tenant collectives and journal papers prepared. (Report 8). Ongoing control and intervention site data collected to provide an assessment through time of change. d. Report on socio-economic context and institutional constraints to sustainable water use prepared (Project Report 2). e. Report on socio-economic context and institutional constraints to sustainable water use prepared (Project Report 2). f. Report on gendered Access to Water Resources within the Feminization of Agriculture prepared as well as participatory gender training manual for community groups. Reports (3 and 4). Journal paper under preparation. g. Working paper on improving dry season irrigation for marginal and tenant farmers prepared (Report 1) h. Report on socio-economic context and institutional constraints to sustainable water use prepared (Project Report 2). i. Report prepared on farmer collectives to overcome agrarian stress and inequalities, based on questionnaires and focus group discussions. (Report 14)
2.2	**Comparative research in Bangladesh on institutional aspects of ground/surface water interventions**		

No.	Activity	Outputs / milestones	Progress against milestones / Comment
	a. Analysis of institutional development in NW Bangladesh. b. Visit case study sites representing examples of institutional innovations and collect qualitative data c. Identify how land tenure and gender inequalities have impacted the success of these models **d.** Publication on institutional innovations in Bangladesh	a. Secondary data on institutional development in Bangladesh reviewed. b. Focus groups and interviews conducted and data analysed at case study sites. Effectiveness of institutional innovations for equitable water access documented. c. Focus group and interview data from case studies analysed and reported to identify how land tenure and gender has been addressed d. Case study data on institutional innovations will be developed into publication on successes and failures of groundwater management innovations in Bangladesh	a. Secondary institutional data sourced and reviewed and report on agricultural innovations for water security in North West Bangladesh from institutional, gender, food and livelihood security perspectives prepared (Report 17). b. Focus groups established and fieldwork and discussions completed to get an overview of the institutional innovation including its history, key objectives, structure and functioning; and production, socio-economic and other impacts. Reported below. c. Report prepared (Report 17) d. Report prepared (Report 17)
2.3	**Final selection of six sites for implementation of interventions**		
	Final selection of six sites for implementation of interventions	Sites for intervention confirmed for piloting	Final site selection completed May 2015. Process included biophysical, social and logistics criteria, followed by extensive community engagement to assess potential challenges in implementing collective systems and appropriate technical innovations for the target marginal communities. Sites in Bangladesh reduced from six to four for final phase of project.

Objective 3: Determine and evaluate approaches for access to water for irrigation focussing on using renewable technologies and alternate approaches to land tenure, and their impact on livelihoods and resilience.

No.	Activity	Outputs / milestones	Progress against milestones / Comment
3.1	**Identify feasibility of interventions**		
	a. Identify fixed and variable costs of biophysical interventions based on site visits and analysis of secondary sources. b. Utilise existing models and decision support tools (where available) to identify the potential increase in water supply	a. Secondary data and site visit data analysed. Fixed/variable costs documented and comparative report for different interventions prepared. b. (i) Existing water management models and decision support tools assessed (ii) Potential increase in water availability from conjunctive use ponds in each of the pond sites documented. (iii) Potential increase in irrigated area under new cropping patterns and multiple uses identified. (iv) Potential interactive tools identified, developed and evaluated with growers and advisors and then finalised for dissemination.	a. Review report of secondary data prepared (Report 7). Fixed costs and variable costs captured seasonally for each site. Data based established for economic analysis. Seasonal analyses completed. Comparative tables and charts prepared for each site e.g. gross margins, cost of production etc. b. i) Field scale modelling approaches assessed (APSIM, HowLeaky, ClimAnalyser, AquaCrop and FAO56 water balance model SID). AquaCrop used for initial assessment of crop water requirements (Report 21) ii) FAO56 based methods have been used in Bangladesh (Report 18) and have built into a tool (DSI Scheduler refer Chapter 7.4.9 which is used for daily irrigation scheduling and to assess seasonal field level water balance and calculating water productivity. iii) Potential increase in irrigated area under new cropping patterns investigated in conjunction with ii). However, regional hydrological impact of farm-scale water abstraction under different scaling scenarios is required. Recommended for further research under an SRA led by CSIRO.

No.	Activity	Outputs / milestones	Progress against milestones / Comment
	c. Identify how different models of groundwater provision in Bangladesh have regulated electrical energy provision d. Identify potential economic costs and benefits from various social and biophysical interventions. e. Conduct a literature review of institutional innovations in collective ownership of farm resources f. Conduct a detailed gender impact assessment for the range of potential interventions	c. Models of groundwater provision under different energy scenarios in Bangladesh identified d. Analysis to identify potential economic returns for each technology and farmer typology completed e. Literature on collective management and use of land/water resources reviewed, and combined with analysis of Bangladesh data for 2.2 and selected case study research, to identify best practices and potential risks of collective farming/irrigation management f. Potential gender impact of each potential intervention identified and documented.	iv) Twelve tools have been developed and disseminated/deployed as simple App's the tools have been categorised based three on user group, Farmers, Project staff and Engineers. To date, tools primarily used by project officers and engineers. Details of use and potential to be developed. Michael Scobie (USQ) has recently started a PhD investigating the utility of these apps. c. Four sites monitored in NW Bangladesh, representing different agro-ecological zones, and models of groundwater provision. Data on crops, production, and economics of cultivation, socio-economy of the owners, water delivery and water levels collected. Project Reports developed (Report 17 and 18). d. Seasonal biophysical/economic data collected and database established. Seasonal analysis completed including economic costs and benefits. Substantial databases and assessment tools developed using a bespoke platform for this project. e. Reports on institutional innovations in collective farming prepared (Reports 2, 3, 8, 14) Report on agricultural innovations for water security in North West Bangladesh from institutional, gender, food and livelihood security perspectives prepared (Report No 17). f. Report on gendered access to water resources report prepared (Report No 3). Paper submitted to journal
3.2	***Action planning***		
	a. NGOs will undertake capacity building in all villages b. Identify a selection of locales/neighbourhoods within each village c. Stratify target groups into types according to farm size, tenure, woman/male/youth headed, current irrigation use and yields d. Identify the best selection of interventions for each locale and develop final combination of interventions	a. Capacity building undertaken in all communities. b. Locales for interventions selected within villages c. Focussing on the poorest households, farmer group members are shortlisted selecting two groups: women farmers (inc. those from women headed households) and young men d. Farmers engaged to seek feedback on intervention plan and to tailor final package. e. Action plan report completed for each site	a. All Partners active in community engagement and capacity development. Summaries of engagement, training, collective meetings and discussions captured by partners and reported in partner annual reports. b. Locales for interventions selected after extensive engagement with communities. Process described in Appendix 1 c. Selection has taken account of project target households (marginal, woman and tenant). Baseline survey provided profile of villages from which target tenant and marginal farmers selected through engagement by NGO's and potential land available for lease arrangement identified. Beneficiary lists documented. Process for selecting farmers described in Report 14. d. Best approaches and technological and institutional innovations were determined for each site with direct participation of beneficiaries. Number of iterations typically required. Ethical community engagement a fundamental part of our project. Strong linkages with SIAGI project in West Bengal in this regard. CDHI leading our thinking on what constitutes ethical engagement (Report's 6, 10). ***e.*** Action plan reports prepared for each pilot site, comprising summary intervention tables outlining before intervention social, institutional and biophysical situation and planned

No.	Activity	Outputs / milestones	Progress against milestones / Comment
	e. Prepare action planning report with final selection of interventions detailed for each site		social, institutional and biophysical situation, as well as plot wise planned interventions and anticipated budget and proposed cropping calendars. Farmers heavily involved in decision making at all the sites through range of engagement approaches
3.3	**Piloting**		
	a. Determine best facilitation approach for each site (including non-partner government and non-government representatives) b. Final selection of marginal/tenant households, and conduct social mobilisation to create two farmer groups from within this selection c. Establish interventions targeted at farmer groups in each community, with support of the project NGOs d. Conduct separate training for each farmer group before and during establishment of above interventions. e. Assist in market chain development	a. Engagement plan developed and updated for each site. b. Farmer groups established and pre intervention livelihood data collected c. i) Agreed interventions initiated at each site. ii) Equipment purchased and installed and sites reconfigured. iii) Annual evaluation of pilot site in terms of technical performance (water balance, crop production, economics) and social and institutional engagement. d. i) identify target training group and undertake a training needs assessment ii) Develop and deliver training program to stakeholders **e.** Meetings with market chain participants and opportunities documented.	a. Engagement plan developed and delivered for each site. Community engagement primarily through regular farmer group meetings and trainings. Focus group discussions also held (especially gender focussed). Local site-specific adaptation of engagement is essential and ongoing. An engagement manual has been developed from WB experiences (Report 6) and Case Studies are prepared to document examples (Report 22, see also Report A1-3). b. Farmer groups established. Extensive social mobilisation. Baseline livelihood data collected for villages and sites. Draft Case Studies prepared for selected sites to outline interventions (social and biophysical) and impact (Report 22). c. Interventions initiated at all sites all equipment installed. Annual evaluation of pilot site performance underway through seasonal biophysical/economic assessment and irrigation system technical performance. **d.** Training needs updated annually and training program delivered. Documented in Annual reports. **e.** Initial informal market chain linkages established. Focus discussions completed and opportunities identified. Report on assessing value chain opportunities for smallholder vegetable growers completed. (Report 15). Collaboration with SIAGI project who have strong focus in West Bengal in supply chains.
3.4	**Development of Interactive tools**		
	a. Provide capacity building to farmers b. Develop simple, culturally relevant approaches and tools to support understanding and	a. i) Stakeholders engaged at each site to assess existing understanding. ii) Action plan drafted to address knowledge gaps. iii) Training delivered to key stakeholders at each site b. i) Existing tools, platforms and learning materials evaluated and potential tools scoped. ii) Prototype tools developed and tested stakeholders	a. i) Initial discussions held with Partners and stakeholders to assess needs. Discussion at research forums with Partners. ii) Scoping and delivery of a range of software applets that are available to the project staff (and potentially beyond) completed. iii) Partners and field officers primarily responsible for data collection and use of interactive tools. Support provided on an ongoing basis. **b.** Decision support tools used by others in this type of work assessed. Suite of data collection and decision support tools now developed. Tools used weekly at sites in India

No.	Activity	Outputs / milestones	Progress against milestones / Comment
	knowledge of improved irrigation, water and energy management. c. Develop up-scaling training packages including guidelines and flowcharts for delivery in other villages and communities based upon the experiences of the piloting.	iii) Tools finalised, training manuals prepared, training and delivery to advisors and extension agencies. c. Training packages revised and promoted to wider communities as part of out scaling and up scaling.	and Nepal. Extensive technical support and training three times per year during site visits. Potential for wider application of these tools being considered. **c.** Partners in west Bengal have developed crop manuals for a range of vegetable crops in local language. Information sheets developed. Exposure provided primarily via conferences and stakeholder meetings. Further promotion and scaling to wider communities continues..
3.5	**Engagement and capacity development, linking research for development**		
	a. Develop and implement engagement, communication and capacity development strategies and plans b. Conduct continued monitoring of the interventions c. Conduct continued monitoring of the social and institutional impact of the interventions d. Hold bi-annual review meetings to engage with partners and a broader set of stakeholders e. Project monitoring and evaluation framework to provide for adaptive project management and outcome/impact assessment	a. i) Engagement, communication and capacity development strategy developed in consultation with stakeholders. Associated plans implemented and updated annually ii) Capacity building workshops held in each village bi-annually. iii) Networks established and developed through stakeholder meetings and discussions to establish links between public, private and village institutions. b. Annual evaluation of pilot site in terms of technical performance (water balance, crop production, economics) and social and institutional engagement c. Annual evaluation of social and institutional impacts. Reporting of bi-annual data. d. Bi-annual review meetings held e. Monitoring and evaluation reports completed in accordance with project monitoring and evaluation framework	a. i) Project engagement, communication and capacity development strategy developed, adapted and implemented regionally in accordance with priorities. Regional plans updated in partner annual reports. ii). Capacity building and training workshops held in each village in accordance with local planning and documented in annual report. Research partners have provided informal training and development of project staff across a range of topics from general project management to detailed technical data collection and interpretation. iii). Large and expanding network being developed at both a district, national and international level. Stakeholder list continuously developed at a local level. Increased focus on strategic stakeholders and key one on one engagement strategies to assist scaling b. Seasonal biophysical and economic data collected for each plot and used for productivity and profitability assessment as well as infrastructure investment cost/benefit. Water balance assessments undertaken for each site. c. Ongoing through regular (at least once every 2-3 months) field visits by the socio-economic team for qualitative analysis and focus groups with user groups to monitor the success of the collectives. Social and institutional engagement and monitoring is primarily through community meetings and development of case studies. d. Bi-annual review meetings (regional coordination committee RCC and annual meeting) held each year and detailed in trip reports. e. Monitoring and Evaluation discussions held at each Annual Meeting and documentation prepared.

Objective 4: Facilitate long term up-scaling and out-scaling of approaches and alternative opportunities

No.	Activity	Outputs / milestones	Progress against milestones
4.1	**Dialogue with government and non-government institutions to facilitate up-scaling and out-scaling**		
	a. Organise a project workshop in year four bringing together multiple stakeholders	a. i). Policy Briefing paper prepared; ii) Two multi stakeholder workshops completed. iii) Workshop report summarising suggested policy reforms prepared.	a. Multi stakeholder workshops completed in each region during life of project. Policy briefing paper prepared on improving dry season irrigation for marginal and tenant farmers through collective farming.
	b. Promote spillovers with a broader program of training and technical support to selected villages outside of the pilot project areas	b. Training and demonstration to further twelve villages adjacent to pilot study sites of successful interventions.	b. Informal training of adjacent farmers is ongoing but has been ad-hoc. It has nevertheless promoted out-scaling of a range of interventions.
4.2	**Develop and disseminate materials and business models/cases**		
	a. Review data from piloting and identify the key lessons	a. Case studies prepared for each pilot study site illustrating the full range of biophysical and social interventions trialled.	a. Case studies have been prepared for all pilot sites (Reports A1-A3 and 22). These cover themes of household change, technology adoption and engagement approaches and outcomes. Key lessons identified using a range of cross cutting themes for evaluation.
	b. Draw upon the research conducted in Bangladesh to identify ways of ensuring long term sustainability	b. Report and Case studies prepared on Bangladesh institutional and technical experiences and implications for India and Nepal in context of this project.	b. Draft report on Bangladesh institutional and technical experiences prepared (Reports 18).
	c. Develop approaches and business models for combining interventions to achieve an integrated farming system	c. Approaches and business models documented	c. Not achieved: We have document approaches for combining interventions to achieve sustainable farming systems for collectives via Case Studies.
	d. Validate these approaches	d. Case studies prepared for each pilot study site.	d. Case studies have prepared (Reports A1-A3 and 22)
	e. Disseminate information, material and tools to stakeholders	e. i) Policy briefing paper prepared and promoted within government. ii) Training material collated into package and training provided to stakeholders. iii) Decision support tools and manuals finalised, training provided to advisors and extension agencies and tools launched	e. i) Policy briefing paper prepared on improving dry season irrigation for marginal and tenant farmers through collective farming. ii) training material has been developed (gender training manual, engagement processes and practices, five agronomy booklets) iii) Decision support tools do not require training manuals; however, information sheets developed.

7 Results and discussion

7.1 Study sites

7.1.1 Overview

Thirty-five sites were selected across 12 villages between September 2014 and May 2015. Study regions are shown in Figure 4, site maps are given in Appendix 2 and further detail on study sites is given in Appendix 13. Sites comprised small intervention areas, where alternative approaches for irrigation and dry season cropping were demonstrated. In the case of India and Nepal, alternative approaches to land tenure and their impacts on livelihoods and resilience were assessed.

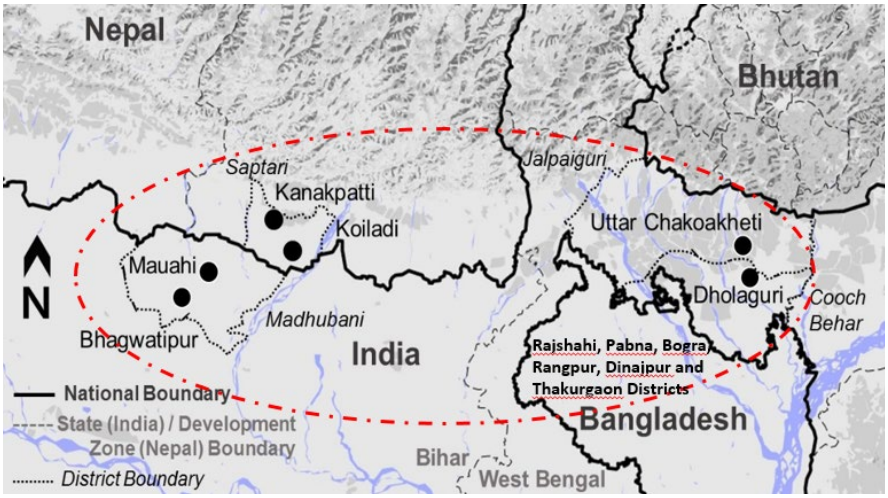


Figure 4: Locality map of study regions

Two villages were selected in Saptari District. Koiladi Village is located at latitude 26.484^{0}N, longitude 86.809^{0}E and two demonstration sites were established with a total area of 1.9ha. Kanakpatti Village is located at latitude 26.637^{0}N longitude 86.700^{0}E and three demonstration sites were established with a total area of 2.3ha.

Two villages were selected in West Bengal. Dholaguri Village is located at latitude 26.428^{0}E longitude 89.493^{0}N and three demonstration sites were established with a total area of 3.4ha. Uttar Chakoakheti Village is located in at latitude 26.547^{0}N longitude 89.401^{0}E and four demonstration sites were established with a total area of 7.2ha.

Two villages were selected in Madhubani. Bhagwatipur village is located at latitude 26.352^{0}N longitude 86.340^{0}E and four demonstration sites were established with a total area of 5.5ha. Mauahi Village is located at latitude 26.442^{0}N longitude 86.298^{0}E and one demonstration site was established with a total area of 2.2ha.

In North West Bangladesh, six villages were selected, one in each of Rajshahi, Pabna, Bogura, Rangpur, Dinajpur and Thakurgaon districts. The project only focussed on the Rangpur, Bogura, Pabna and Thakurgaon districts after the first season of baseline data collection. In total 22 shallow tubewells and six deep tubewells, with a command area of 149ha were selected for monitoring covering 873plots.

Detail on Bangladesh sites, including cropping systems, is given in Section 7.4.7 and Mainuddin et al (2019 – Report No 18)

7.1.2 Crops of the India and Nepal study sites

In the India and Nepal sites, traditional cropping systems comprised of kharif rice, with limited winter cropping using residual moisture. In Madhubani, traditional systems included small areas of winter wheat and summer moong beans, however 95% of the area remained fallow. In Saptari small areas were planted to wheat, maize or mustard in winter, with moong beans in summer, however most land was fallow. Vegetables were cultivated primarily for household consumption. In Uttar Chakoakheti, West Bengal land mostly remained fallow, with only 2-3% of the area cropped through potato or maize during winter months, while in Dholaguri Jute was commonly included in the cropping system with potato as a winter crop. Poor socio-economic conditions and limited irrigation infrastructure resulted in low crop diversification.

The project introduced irrigation infrastructure including shallow tubewells, pumps and irrigation systems, giving opportunity for dry season agriculture and a range of new crops (Table 1 and 2). Technical support and training on irrigation, agronomical practices, pest and disease control, as well as access to better seed and inputs was critical to this transition.

Table 1: Cropping system in intervention sites after project intervention

Crop Type	Saptari						Madhubani						West Bengal					
	S-16	Kh-16	R-16,17	S-17	Kh-17	R-17,18	S-16	Kh-16	R-16,17	S-17	Kh-17	R-17,18	S-16	Kh-16	R-16,17	S-17	Kh-17	R-17,18
Rice		■			■			■			■			■			■	
Wheat						■			■			■			■			■
Legume		■					■			■								
Vegetables	■	■	■	■	■	■	■		■	■		■			■			■
Oilseed			■			■									■			■
Maize	■												■					
Green Manure				■														
Jute													■			■		

1. Where S is summer, R is Rabi, Kh is Kharif.
2. Vegetable crops indicated in Table 2

Table 2: Dry season crops introduced following project commencement

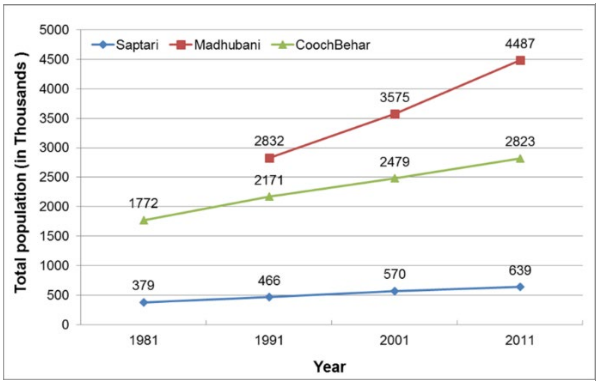
Location	Winter Rabi Crops Introduced	Summer Crops Introduced
Madhubani	Peas, potato, radish, cauliflower, spinach, lentil and wheat,	Chilli, cowpea, cucumber, brinjal, gourd, ladyfinger and moong bean.
Saptari	Cabbage, cauliflower, garlic, onion, brinjal, tomato, potato, radish, coriander and lentil.	Chilli, cucumber, bitter gourd, ladyfinger, pumpkin, zucchini, cowpea, maize, and moong bean.
West Bengal	Rapeseed(mustard), wheat, maize, potato, tomato, cabbage, lentil, garlic	Jute, brinjal, gourd, cucumber, beans

7.2 Socio-economic, structural and institutional constraints

7.2.1 Broader economic context and agricultural trends in Nepal and India study districts

Population and agricultural production trends

Bastakoti (2017 Report No 2), summarised the broader economic context of the study areas based on a literature review, focus group discussions and interviews. The population has increased at varying rates across study districts (Figure 5). Madhubani district has the largest population and highest growth rate. Outmigration of the economically active age group has been a key factor, particularly in Saptari due to Nepal's rise in overseas employment, and has been a key driver for feminization of agriculture in the study districts.



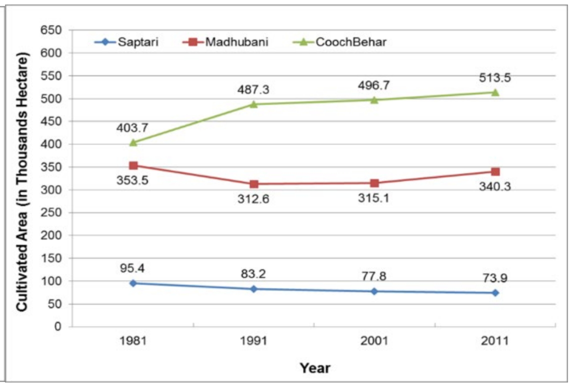
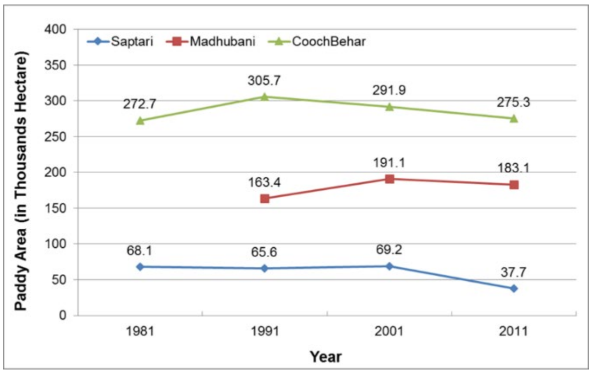


Figure 5: Population trends

Figure 6: Cultivation area trends

Cooch Behar district has the largest cultivated area, followed by Madhubani and Saptari districts. While here has been a gradual increase in cultivation area in Cooch Behar and Madhubani districts (Figure 6), the decline in Saptari district has been driven by urbanization of agricultural land, labour shortage due to outmigration and lack of irrigation facilities. Absentee land ownership has resulted in low investment in irrigation and inputs, resulting in a shift to perennial plantation crops.

In monsoon season, paddy is the main crop cultivated but has shown a general decline (Figure 7). There has been rapid expansion in winter wheat in Madhubani which is not evident in Saptari and Cooch Behar. Changes in cropping patterns, particularly the introduction of commercial crops, has increased the demand for new technologies.



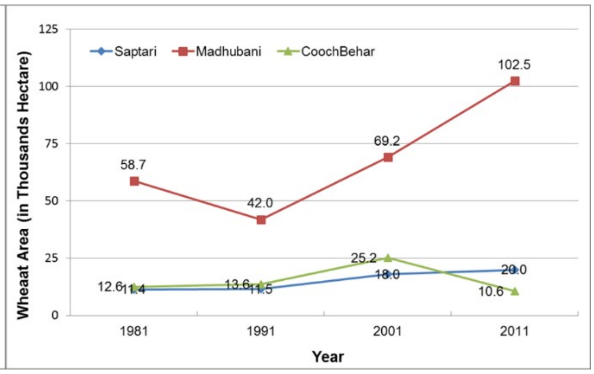


Figure 7: Paddy area trends

Figure 8: Wheat area trends

Agricultural inputs - availability and price

While access to agricultural inputs, particularly seed, fertilizer, pesticides and other chemicals varied across study districts, timely availability, quality of supplies and high price fluctuations of, in particular, fertiliser and seed are major concerns.

Cooch Behar district has higher fertiliser use per hectare, primarily due to greater production areas of vegetables and other input sensitive crops. Input price fluctuations are highest in Saptari district, where distribution systems are not as well organised as in India.

There are a range of input suppliers, including agro-vet traders and cooperatives. Some receive subsidies for input procurement (particularly fertilizer) and other financial incentives, such as loans. Farmers frequently rely on information on fertiliser and pesticide application from these suppliers. Storage and transportation facilities pose challenges in efficient distribution of inputs to farmers.

Price and marketing agricultural commodities

The price of agricultural commodities fluctuates significantly through the year. Variability is low in cereals and legumes and very high for perishable commodities such as fruits and vegetables. In India, there is a minimum support price for most of the agricultural commodities, providing some stability in market price. In Nepal minimum support price has only been introduced recently for a few cereal crops. Despite price support mechanisms and other regulatory measures, the price of agricultural commodities is affected significantly by marketing intermediaries which include collection agents, wholesalers, and retailers. While supply and demand affects price, many traders operate as a cartel resulting in manipulation to pricing and poor farmer bargaining power. Farmers normally set price expectations by comparing with fellow sellers or by asking traders in the local market, they can choose to sell in a different market the price is higher.

7.2.2 Policies on irrigation and water management

Policy and institutional constraints mediate access to surface and groundwater irrigation, thereby shaping livelihood outcomes. Key policies, which have been through many revisions to accommodate socio-economic, political and other changes at state and national level, have been documented by Bastakoti (2017 Report No 2).

For surface water, providing year-round irrigation through development of small scale irrigation infrastructure, has been a key focus. Another major emphasis has been on participatory irrigation management, ensuring active participation of local users through water users' association (WUA). Policies have promoted community-based institutions and acknowledged the key roles of local institutions in managing the small-scale surface irrigation infrastructure, although these are often not well implemented in practice (Karn et al., 2016). The policy emphasis however today is on groundwater irrigation. Subsidies for shallow tubewells and pumps has been an important policy instrument to facilitate its expansion.

Policy frameworks developed in the EGP region have emphasised participatory management of both surface and groundwater resources. The key outcome is formation of water users' committee to ensure active involvement in planning, implementation, and monitoring and evaluation. In line with this a policy environment adopting group/collective approaches through this project seems well suited for improving water management.

Another key policy framework has been the provision of subsidies and support services to enhance the access to surface and groundwater resources. Users are required to follow complex procedure and guidelines to avail such services which are not readily accessible by marginal farmers, particularly women. Facilitating linkages between farmers and relevant government and non-government agencies to ensure they benefit from such provisions has been a key initiative of the project. Further detail has been provided in Appendix 14.

7.2.3 Water management institutions

Local institutions were analysed through interviews with key district level officials and community focus group discussions. While a number of formal/informal institutions exist in each village, they are generally insufficient to significantly enhance access to resources (Bastakoti, 2017 Report No 2). Institutions include the village development committee, water user's committee, village Panchayat, farmer's cooperative or club and self-help groups.

Management of water access is mainly informal and on a first come first served, or priority needs basis. There are typically informal markets to sell water from a tubewell, with charge rate generally based on number of hours pumped and size of pump. For those who cannot access groundwater, public canals are available yet their coverage is limited in the study area. There are also surface ponds yet these primarily support fish farming and farmers seldom access pond water for irrigation purposes.

Some villages have received support from government agencies for installation of tubewells and purchase of pumps. In all villages, except Dholaguri, existing water sources (tubewells and ponds) are insufficient to meet irrigation needs, resulting in large areas of fallow land in the dry season months.

Farmers are generally aware of various government support services, but were unable to access them due to lack of awareness of application procedures and poor local coordination with authorities. While policy and institutional frameworks exist at different levels, and include provision for subsidies and other support, national policies do not trickle down effectively to local levels.

Further strengthening of local institutions was a central goal of the project, and these activities are outlined in section 7.3.

7.2.4 Farmer typology, impact of land tenure/relations and other social structures on sustainable water use

An extensive socio-economic baseline analysis took place in 2015. Drawing upon the census and qualitative interviews described in Section 5.5, and an analysis of secondary sources, this study sought to firstly understand the historical causes of poverty inequality in this region. It went on to analyse the agrarian structure and to develop seven farmer 'typologies' to help the project team understand the agrarian system while also better target interventions. It finally sought to understand what this means for existing access to irrigation (Sugden et al 2016 Report No 1).

History of agrarian change in the Eastern Gangetic Plains and contemporary trends

The character of social inequality and its evolution over time was found to vary across the plains, and the background research conducted for each site selected for the project noted a clear difference between the villages in West Bengal, and the Gangetic heartlands of North Bihar and the Eastern Terai of Nepal. The latter are split between two countries, yet are part of a contiguous cultural region known as Mithilanchal, and they share a common caste structure, economy and language. Mithilanchal includes Kanakpatti and Koiladi in Nepal's Saptari district, and Mauahi and Bhagwatipur in Bihar's Madhubani district.

To understand the root of contemporary inequality however, and the differences between the case study regions, it is necessary to look back to the colonial era tax collection hierarchy. Powerful zamindars extracted a portion of the crop from the peasants to channel to the state as tax and retained a portion for themselves, while also extracting surplus as rent from tenants on their private holdings (Chaudhury, 1964). A similar system was established on the Nepal side of the border in Saptari, although revenue was channelled to the Rana rulers of Kathmandu (Regmi, 1976). In both regions the landlords and their intermediaries emerged into a powerful landed elite. Further east in North

Bengal, the colonial era was dominated by the *jotedari* system (Sarkar, 2015). It differed from Bihar and Nepal in that it was mostly large farmers or *jotedars* who were tasked with the job of tax collection, although it also culminated in significant inequalities.

In the 1950s and 60s, both Bihar, West Bengal state and Nepal saw state implemented land reforms and the abolition of the now largely redundant agrarian tax collection hierarchy. (Adhikari, 2006, Regmi, 1976). Despite the stated objectives, they failed to create real transformations in agrarian relations (Rorabacher, 2016, Regmi, 1976). The inter-linkage of credit-debt relations with land tenure was widespread in Madhubani and Saptari in the 1970s and 80s, increasing the dependence of farmers on landlords, with a number of bonded labour contracts in (Karan, 2003, Rodgers and Rodgers, 2001). Farmers reported how in-kind consumption loans were taken of grain, with crippling rates of interest, including unpaid labour.

In West Bengal state land inequality remained severe into the 1950s and 60s, but there was some positive change from the late-1970s following one of the more successful land tenure reform experiences in the region. *Operation Barga* in 1977 sought not to actually re-distribute land but regulate tenancy. The West Bengal Land Reforms Act in 1977 imposed strict regulations on what constitutes personal cultivation and when landlords can evict tenants, gave tenants permanent and inheritable tenure, and enforced the rent at 25% of the crop. By 1993, more than 65% of an estimated 2.3 million sharecroppers had been registered, facilitating significant productivity increases (Banerjee et al., 2002), and 445,503ha of agricultural land had been redistributed (Bakshi, 2008). However, the operation relied on significant political support by then left-wing government, including a strong network on the ground – conditions which had not been present in Bihar, Bangladesh and the Nepal Terai. In project sites Uttar Chakoakheti and Dholaguri, Operation Barga was successful in breaking up the estates of the larger *jotedars*, and thus inequality in holdings was not as severe as Bihar and the Nepal Terai during the period.

In the intervening years, there were further changes across all three regions (see Sugden et al 2014). This included a wave of rural monetisation and rising consumer culture, coupled with a rising cost of agricultural inputs. Alongside stresses associated with a changing climate such as unpredictable monsoons, heatwaves and cold snaps, agriculture has increasingly become less viable to support a family, and out-migration has become a core component of household livelihoods. In terms of land ownership, there have been some positive changes through some of the bigger zamindars selling off their estates and moving to urban areas, yet concentration of land is still high. With rising living costs, indebtedness has been an increasingly prominent issue, and while debt bondage to single landlords has declined since the 1990s, a range of new money lenders have entered the rural economy to meet the growing demand for cash.

Farmer typologies in Bihar and Nepal

An analysis of the land ownership structure facilitated the development of seven farmer categories, to support the targeting of interventions. The full description of farmer typologies is available in the Sugden et al (2016) Report No 5 and Figure 9 gives an overview of the size of each group.

1. Landless labourers: At the base of the agrarian structure is a large class of landless households with limited involvement in farming. They represent 27% and 34% of households in Saptari's Kanakpatti and Koiladi respectively and 34% in Mauahi, but just 4% in Bhagwatipur where most landless households work as tenant farmers. Agricultural labour remains an important source of income for this group, for which wages are extremely low, at between $1 and $2 per day.

Only some households, usually from the Dalit community, depend entirely on farm labour, with consumption often pushed down to the physiological minimum. Most however, are also engaged in the non-farm economy. Meeting one's subsistence needs entirely from local labour alone is difficult, and as a result both surveys show that a large proportion of landless labourers are engaged in some kind of migration. The highest levels are in Kanakpatti where a substantial 54% of landless labourer households have long term migrants, while 29% have seasonal migrants, usually to Indian cities.

Landless labourers are highly vulnerable to exploitation through usury and frequently take loans from private lenders. The average outstanding debt to money lenders is $375 in Mauahi, $348 in Kanakpatti and $366 in Koiladi – a substantial sum. The average recorded interest rates for outstanding debts varied from 60% per year (5% of total loan per month) in Bhagwatipur, 39% in Mauahi, 43% in Kanakpatti and 47% in Koiladi. In Kanakpatti, some landless labourers even reported paying 72%. The data suggests that landless households are sometimes charged higher rates than land owning farmers, given their limited bargaining power and lack of land to use as ‘collateral’. This group was found to be a priority group to target for involvement in the collectives.

2. Pure tenants: The second landless group are the pure tenant farmers, who represent 22% of the surveyed population across the four villages. They were also important target groups for the collectives, and could possibly bring enhanced farming experience to the groups to the benefit of members who were landless labourers. As one would expect, the three villages with the highest levels of tenancy also have a high proportion of pure tenants. They represent a substantial 27.65%, 27.46% and 21.88% in Koiladi, Bhagwatipur and Mauahi respectively, and a more marginal 6.21% in Kanakpatti. The qualitative interviews found that the vast majority of contracts are negotiated informally through word of mouth agreements between land owners and tenants, and only a small proportion of farmers in Koiladi have formal tenancy rights. Sharecropping or bhaataiya is the most common form of tenancy, and is present on 85% of the rented land in Kanakpatti, 99% in Bhagwatipur and 92% in Mauahi, and a third of the land in Koiladi.

Under sharecropping, the landlord retains half of each crop harvested yet rarely share the input costs, although in Koiladi some contributed to fertiliser costs. In Koiladi, fixed rent tenancy or *tekha* is more common. The advantage of thekka is that farmers can retain the increment in yield due to investment in the land or a favourable monsoon, whereas under sharecropping the landlords always retain half. On the other hand, thekka rents on rainfed land are risky, as even with a crop failure, the tenant would still be expected to pay the pre-agreed consignment of grain to the land owner. For this reason, tenants often preferred sharecropping, particularly if they had no irrigation. This reminded the team that supporting irrigation alongside promotion of fixed rent contracts would be important for the collectives established in this project.

Pure tenants can rarely subsist from tenant farming alone, and it is nearly always supplemented with wage labour to meet their growing cash needs. In all the villages, pure tenants are engaged in agricultural labour like their landless labouring counterparts. Along with landless labourers, these two landless group carry out the bulk of farm labour in the community. In Mauahi, pure tenants and landless labourers together carry out 42% and 44% of the aggregate recorded labour days on others farms. This stands at 29% and 56% for Koiladi and 62% and 14% for Kanakpatti.

In the past, interlinkage of labour and tenancy contracts were common, with landlords also taking ‘labour rents’ (known in studies of feudalism as ‘corvee’ labour) whereby tenants must provide unpaid labour in addition to rent. This reportedly persists in Koiladi, with tenants being expected to provide some days of labour to the land owner on whose plot they cultivate for free, although the research team was unable to collect concrete figures. In the other villages formalised labour rents have declined, although they persist in informal ways. For example, two different landlords for example (including one in a village outside the study area), noted how when his own tenants work for him they provide extra services, such as labouring on his land for lower wages than outside workers, or providing a few hours’ labour for free. Indebtedness is also widespread. In the past tenants would usually take loans from their own landlords, yet today there are now several landlords who offer loans. Average debt to private lenders is even higher for pure tenants than landless labourers, perhaps due to the fact that tenants need to take loans for agricultural inputs. It stands at a considerable $2261 in Kanakpatti, $604 in Mauahi, $488 in Bhagwatipur, and $406 in Koiladi. Migration and off farm labour amongst pure tenants is also an important livelihood strategy, although perhaps due to engagement in agriculture, levels of migration are slightly lower than landless labourers.

3. Part tenants: Another group of tenants are the part tenants, who rent land while also owning small plots. 14.2% of the surveyed population include this group. This group makes up 14.7% of households in Kanakpatti, 15.9% in Koiladi, and a substantial 36.3% in Bhagwatipur. While the average area of land owned is generally small, they are better off than pure tenants in that they have the security of land ownership, which can make accessing credit and resources easier. One's own plot also offers them the full return of their labour, however small.

Nevertheless, the survey showed that in all villages the majority of this groups' land is rented with the 'owned' proportion being on average less than 0.3ha. As a result agriculture alone rarely meets their subsistence needs and most are heavily engaged in wage work for others. Agricultural labour is notably lower than for their landless tenant counterparts, and is only carried out as a 'last resort'. The security of a plot of land may give part-tenants more leeway to wait until they can find access to better paid off-farm work. Migration is important for this group. Debt is also a significant concern for part tenants, and levels of indebtedness are similar to pure tenants. Part-tenants were considered as potential members of the collectives. They have a weak socio-economic status but also have farming experience which could be beneficial for other members.

4. Marginal and small owner cultivators: The fourth group are marginal and small owner cultivators. This group own their own plot of land, yet their farms do not exceed 1ha. However, they can not necessarily meet their minimum subsistence needs off the land. To gain an insight into some of the differences within this category however, the group has been split it into two, including those with less than 0.5ha (marginal) and those with between 0.5ha and 1ha (small). In Kanakpatti the marginal owner cultivators represent 14.7% and small owners represent 13.0%. In Koiladi, marginal and small owners represent 10.4% and 5.1% respectively. In Bhagwatipur they represent 19.2% and 7.3%, while in Mauahi they form 22.2% and 9.4%.

Marginal owner cultivators have an economic status similar to that of many part tenants. The only difference may be due to a smaller household size or better wage labour income, owner cultivation may be sufficient for the families' subsistence needs without them having to recourse to tenancy. The better off of this group, with between 0.5ha and 1ha of land, may still not have enough to support the family through agriculture alone, yet are better off than those who have to rent in land. Farm labour is less common for this group, particularly for those with 0.5-1ha, but levels of off farm labour are higher. Although not subject to the rent burden, this group are heavily indebted to private lenders. Given that many of this group were still land poor and suffered food insecurity and indebtedness they were still potential target farmers for the collectives.

5**. Medium owner cultivators.** This group includes those who own between 1 and 2 hectares. Such farmers generally are self-sufficient on their land, and with investments in irrigation and improved inputs, often produce a saleable surplus. They are a small group, representing just 4.1% of the surveyed farmers, yet they have a strong position in the land ownership structure, owning 18.8% of the cultivated land (see Table 3). This group is present in a significant population only in Kanakpatti, where they represent 17.5% of households. Although they are smaller in number, they still play a relatively more powerful position in the other three villages, and the census suggested they are important employers of farm labour, with off farm income often from salaried or business employment, and limited migration. Given their stronger socio-economic status, this group were not considered as potential target groups for the collectives.

6. Large owner cultivators: This group represent a small minority at just 2% of farmers overall who own between 2 and 5 hectares. This group generally produces a reasonable surplus, and does not labour for others. While most of this group owns land surplus to the requirements of the household, how this land is used, and its link to class relations is variable from village to village. Some prefer to rent out surplus land and use small plots for family consumption. Others prefer to employ labourers on land surplus to household needs and sell the excess produce.

In Kanakpatti, large owner cultivators (representing just five families) own 27% of the land in the survey and 15% of the rented out land. In Koiladi, despite their small numerical population (2%), a substantial 31% of the land in the survey belongs to this group, and they also control a substantial 55% of land reported as 'rented out'. In Bhagwatipur and Mauahi their control over land is slightly lower, at 10% and 13% respectively, with bigger landlords fulfilling this role. They do however, employ a lot of farm labour.

This group also appears to have a substantial income source from salaried work in the case of Koiladi, although it is lower in the other village. Interestingly though, in all villages, while migration appears to be low for medium and even small owner cultivators, it appears to rise substantially for large owner cultivators. The vast majority of 'migrants' from this group involve educated children of farmers who have moved to urban areas for employment, usually in the professional sector. This is due in part to the higher levels of education amongst this group, where university education is often prioritized.

7. Landlords: At the apex of the agrarian structure are the households with more than 5ha of land. Most of this group are 'landlords', known locally still as '*zamindars'* or '*jimidars',* and are generally those households who have had historical dominance in the village, and historically were at the top of the agrarian tax administration hierarchy. The number of land owners with more than 5ha is small, representing less than 1% of the total survey for Madhubani and Saptari combined. However, there are also a considerable number of absentee landlords, who reside in urban centres or even in nearby villages, yet still own land in the community and extract surplus through rent or usury. In Koiladi, a village well known for its absentee landlords, it is estimated from the census data that more than half (51%) of the land belongs to outsiders, while in Mauahi it is 27%.

Those who live in the village and are captured in the survey still own a substantial proportion of the land. In Mauahi, resident landlords own 16% of the land, in spite of being less than 1% of the sample, and 34% of the rented land out land in the survey belongs to them. In Bhagwatipur they were found to own a substantial 41% of the land and 73% of the rented out land. In Koiladi they own just 9% of the land, but this is unsurprising given that absentee landlords are dominant here. Given the large amount of surplus land, these households were targeted to seek land to rent in for the collectives.

Agrarian structure and land tenure today

The census carried out by the research team found that a substantial 81% of the population of the three villages is either landless or owns less than 0.5ha of land (see Table 3). The area of land under tenancy is highest in Koiladi, Bhagwatipur and Mauahi, where it is 77%, 66% and 62% respectively (see Table 4). What is most striking when one considers all the data from the four villages, is that the land owners with more than 1ha represent just 7% of the surveyed population, yet own a substantial 56% of the cultivated land. A full breakdown of the agrarian structure by district is given by Sugden et al (2016)

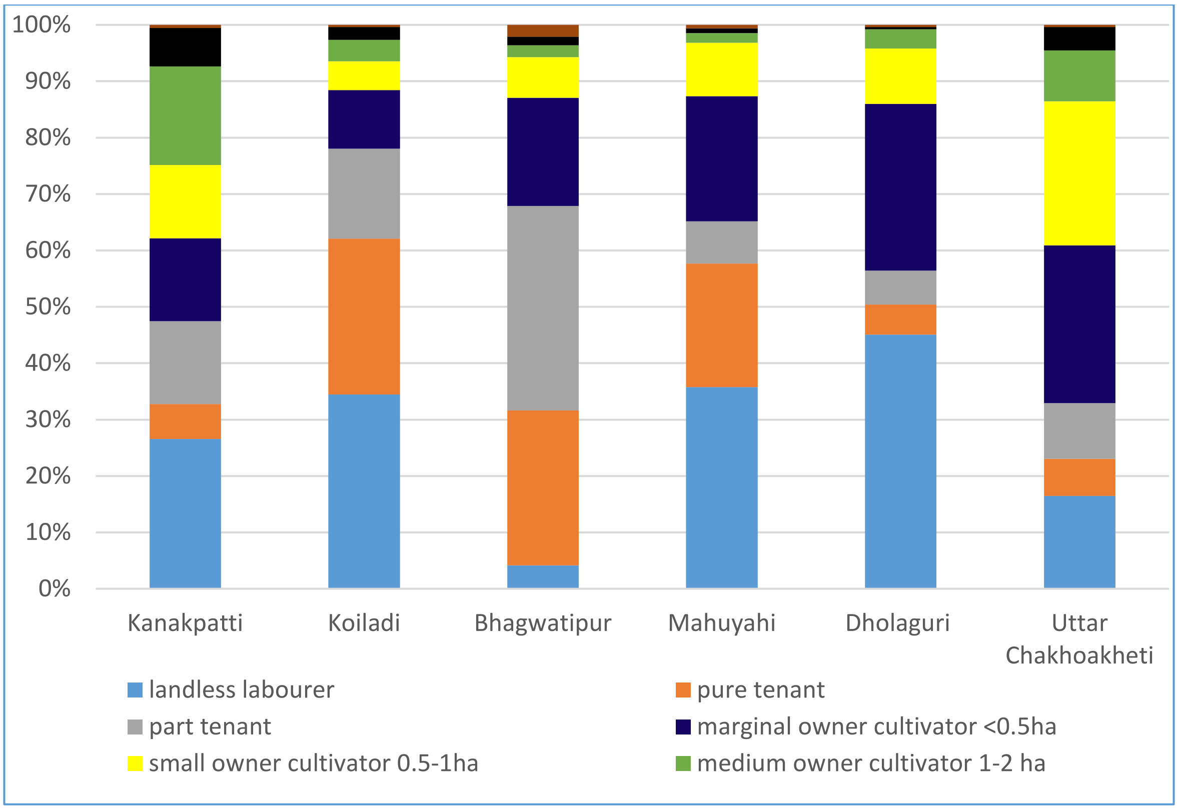


Figure 9: Percentage of farmers in each category Nepal and India study sites.

Table 3: Concentration of land in the survey for Saptari and Madhubani: Kanakpatti, Koiladi, Bhagwatipur and Mauahi

Category	Aggregate area of land owned by this category (ha)	No of households in group	% of total cultivated land owned	% size of group
landless labourer	0	461	0	29
pure tenant	0	347	0	21
part tenant	64	227	14	14
marginal owner cultivator <0.5ha	58	257	14	16
small owner cultivator 0.5-1ha	86	203	18	13
medium owner cultivator 1-2 ha	88	66	19	4
large owner cultivator (>2ha)	98	32	21	2
Landlord	77	11	16	1
Total	471	1604	100	100

Table 4: Ownership of land in study communities

	Total cultivated area (ha)	Total area of land owned by residents of village	Area of land cultivated owner cultivated	Area under tenancy	% area under tenancy
Kanakpatti	129	110	100	29	23
Koiladi	271	132	62	209	77
Bhagwatipur	155	90	53	102	66
Mauahi	193	140	78	119	62
Dholaguri	64	55	54	11	17
Uttar Chakoakheti	141	133	122	28	20

Farmer typologies in West Bengal

Our census found that the agrarian structure in Uttar Chakoakheti and Dholaguri is vastly different from Madhubani and Saptari. Due to the land reforms in the 1970's which broke up the estates of the *jotedars*, there are few large landlords in this region, and small and marginal owner cultivators represent the majority of the rural population, at 19% and 37% respectively (see Table 5). The area under tenancy in Dholaguri and Uttar Chakoakheti is a moderate 17% and 20% respectively (Table 6). It was clear that the lease market could not be an entry point to form collectives in this region and we would need to form groups mobilising mostly existing small owner cultivators.

Table 5: Concentration of land in the survey for North Bengal: Dholaguri and Uttar Chakoakheti

Farmers Category	Aggregate area of land owned by this category (ha)	No of households in group	% of total cultivated land owned	% size of group
landless labourer	0	51	0	13
pure tenant	2	30	1	8
part tenant	14	40	7	10
marginal owner cultivator <0.5ha	34	146	19	37
small owner cultivator 0.5-1ha	61	88	33	22
medium owner cultivator 1-2 ha	41	31	22	8
large owner cultivator (<2ha)	36	13	18	3
Total	188	399	100	100

Table 6: Ownership of land in study communities

	Total cultivated area (ha)	Area of land cultivated owner cultivated (ha)	Area under tenancy (ha)	% area under tenancy
Dholaguri	64	54	11	17
Uttar Chakoakheti	141	122	28	20

Landless labourers: There is a modest population of landless labourers in Uttar Chakoakheti and Dholaguri, at 8% and 19% respectively. Landless labourers work on others farms on average for 142 days a year in agricultural work in Uttar Chakoakheti and 101 days in Dholaguri. Off farm labour however, is more limited. Unlike in Madhubani and Saptari, the burden of debt to private lenders is limited here, and when loans are taken, the interest rates are lower. Migration is high amongst this group. In Uttar Chakoakheti, 5% and 27% of households have seasonal and permanent migrants respectively. It is 4% and 12% in Dholaguri. Their weak socio-economic status made this group a potential target for the project, albeit only if land was available.

Tenants and pure tenants: Unlike in Bihar and Saptari, the tenancy system in North Bengal is very different. Many tenants only lease the land on a seasonal basis, with most farmers cultivating their own land during the monsoon. In Dholaguri, two thirds of tenants pay rents as a fixed cash sum in advance and they vary according to the season for which the land is being leased. This pre-payment system is very different from in Bihar and Nepal where rents are paid after the harvest. For the rabi season for example, Rs2000 per bigha (0.13ha in North Bengal) is paid. For leases during the monsoon paddy season in Dholaguri, a fixed grain payment is sometimes made. Sharecropping is more common in

Uttar Chakoakheti, on just under three quarters of the rented holdings. Unlike in Bihar and Nepal, it is often leased out to farmers of a similar economic status, if for example there is a labour shortage in the renting out household which makes direct cultivation impractical. This group were also potential beneficiaries of the collectives subject to land being available.

Marginal and small owner cultivators: Marginal owner cultivators with less than 0.5ha and small owners with 0.5-1ha form the backbone of the rural population in both communities. The former group represent 31% in Uttar Chakoakheti and 44% in Dholaguri. The latter form 28% in Uttar Chakoakheti and 15% in Dholaguri. Together these two groups own around 52% of the land in the two villages. While they do not experience surplus appropriation through rent or indebtedness they are still relatively poor. However, their income appears to be more dependent on the land when compared to their counterparts in Bihar and Nepal. As a result this groups was considered an important target group for the project, in a model where their own land could be used to form collectives.

Medium owner cultivators: Medium owner cultivators with between 1 and 2 ha are a small group at 10% and 5% respectively in Uttar Chakoakheti. Their engagement in farm or off farm labour is limited, and in Dholaguri none of this group engage in any labour for others. With slightly larger farms, some do buy-in labour, but this is more prominent in Dholaguri compared to Uttar Chakoakheti. Alternative income sources are limited. Migration is particularly significant in the case of Uttar Chakoakheti, where 12 out of 22 households have permanent migrants (54%).

Large owner cultivators: There is a small group of larger land owners with more than 2ha, although only 2 households have more than 2ha. The larger farmers represent 5% in Uttar Chakoakheti and just 1% in Dholaguri. As one would expect, they retain (proportionately) a far greater share of the land, at 22% and 13% respectively, although the levels of concentration are far lower compared to Bihar. They also do not have anything like the same degree of political and economic power as their counterparts in Madhubani and Saptari. This group were deemed unlikely to have sufficient land to rent out to collective groups, as was proposed for Bihar.

Impact of agrarian structure on access to irrigation and technology in Bihar and Nepal

The inequitable agrarian ownership structure in Saptari and Madhubani was found to have a significant impact on irrigation and water access. Below 5% of pure tenants own wells. Landlords are rarely supportive to bear the costs of fixed investments on rented-out land, and few tenants have formal documents, making investment in irrigation infrastructure risky. By contrast, ownership of tubewells amongst part tenants is higher, as they have the security of some owned land, while ownership is widespread amongst better off groups.

It is important to note though that more than ownership of tubewells, it is ownership of pump sets which is essential for irrigation. Pump sets are a considerable expense, and from Figure 10 it is clear that very few marginal or tenant farmers own pump sets in Bhagwatipur, Mauahi and Koiladi, where ownership is negligible for tenants and mostly below 10% for part tenants or marginal owner cultivators. Only in Kanakpatti are there higher levels of ownership. In contrast, the majority of large owner cultivators and many medium owner cultivators own their own pumps.

The implication is that marginal and tenant farmers have to depend on groundwater markets to access groundwater irrigation, whereby they rent a pump set and tubewell from a better off farmer who has his/her own equipment. Over three quarters of part tenants and tenants rent pumps in Koiladi, Bhagwatipur and Mauahi. Rental charges include not only the cost of diesel or electricity but an additional ‘rent’ for the pump set owner. The level of this rent depends very much on the bargaining power the farmer has with the pump set owner. Pump rental charges on average appear higher in Madhubani. This may be due to the fact that there are fewer pump sets in Bhagwatipur and Mauahi with a notably lower pump set to household ratio, leading to a more concentrated water market (see Table 7). Furthermore, water is not always available when required, with farmers often having to 'wait their turn' to use the limited number of pumps in the village. At a time when it is critical to irrigate a crop, such as a paddy nursery, lack of access to a pump can have serious consequences on productivity.

Table 7: Pump set availability by village and cost of pumping

District	village	Avg paid per hour to rent a pump (US$)	Total no pumps	total no hhs	ratio of pumps to households
Saptari	Kanakpatti	1.44	87	177	0.49
	Koiladi	1.42	57	528	0.11
	TOTAL	1.43	144	705	0.20
Madhubani	Bhagwatipur	1.92	23	193	0.10
	Mauahi	1.81	5	626	0.03
	TOTAL	1.85	28	819	0.04

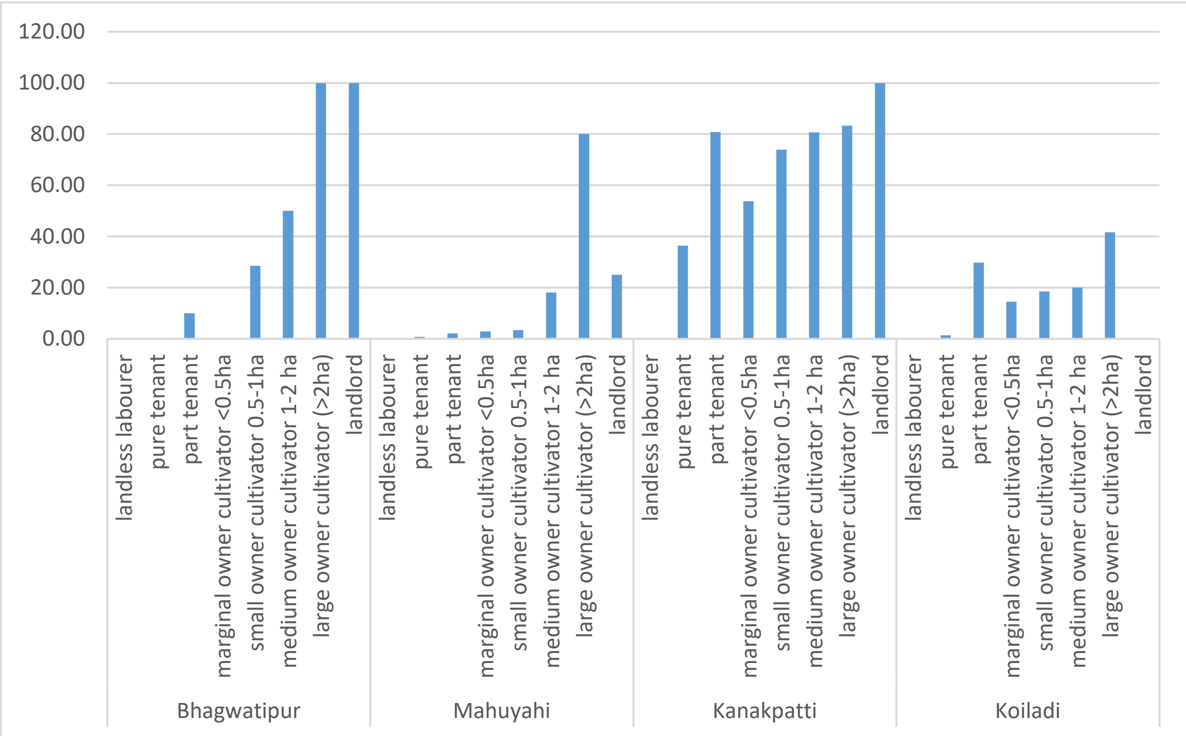


Figure 10: ownership of pump sets by farmer category

It was expected prior to the analysis of our census data that the cost would be a disincentive for farmers to invest on the land during the dry season. However, an analysis of cropping intensity does not show a strong relationship. However, for yield one notices a clearer relationship, although it is not directly linked to one's position in the class structure per se, but whether or not one owns a pump set. In Table 8, it appears that yields of the two main staple crops, paddy and wheat, are closely related to the irrigation source of the plot and whether the farmer owns the pump set, with privately owned pump sets drawing water from shallow tubewells or ponds consistently leading to higher average yields. In fact, plots cultivated by farmers with rented pump sets appear to have paddy yields similar to plots without irrigation at all in Bhagwatipur and Kanakpatti. Our census data suggested that the number of average applications for rice and wheat appears notably higher for pump owners when compared to those without pumps. Not only do the former group have a pump to hand to supply water on demand during any dry spell, they have a greater incentive to use the pump given that they only need to pay the operating costs and not an additional 'rent' for the pump set owner. Pump set ownership as noted above, is connected with one's class position, and the majority of pump set owners are middle to large owner cultivators.

Table 8: Yield per ha of paddy and wheat on land irrigated by different sources

Village	Irrigation source and ownership	**Aggregate yields of paddy per ha**	**Aggregate yields of wheat per ha**
Kanakpatti	owns pump set (STW)	1825	1999
	rents pump (STW)	1555	1287
	owns pump set (pond)	1791	0
	rents pump (pond)	958	1205
	Public canal	1581	1570
	no irrigation	1935	1085
Koiladi	owns pump set (STW)	3204	1729
	rents pump (STW)	2628	1437
	owns pump set (pond)	3682	0
	rents pump (pond)	2735	729
	Public canal	2622	1696
	no irrigation	1932	1313
Bhagwatipur	owns pump set (STW)	2172	1534
	rents pump (STW)	1903	1485
	owns pump set (pond)	NA	NA
	rents pump (pond)	1099	NA
	Public canal	1999	NA
	no irrigation	2198	NA

It is important to not only look at the formal farmer categorization to assess the relationship between economic status and irrigation and cropping outcomes, but also look at the tenure of the land. The biggest differences in both cropping intensity, yields and irrigation use appear to be between plots where the land is owned and plots where the land is sharecropped. It is a well established argument in economics that for each additional unit of investment by sharecroppers, the landlord will keep half, significantly reducing incentives for investment (Marshall, 1907, Nabi, 1986). Focus groups and interviews with farmers highlighted this challenge. Table 9 suggests that yields appear variable in accordance with the tenure of the plot. Aggregate sharecropped land yields are notably lower for paddy in Kanakpatti and Koiladi, and lower for wheat in Koiladi, Bhagwatipur and Mauahi.

Table 9: Aggregate per ha yields of paddy and wheat according on land under different forms of tenure

Village	Tenure	Aggregate yields of paddy per ha	Aggregate yields of wheat per ha
Kanakpatti	owned(cultivated) plots	1842	1471
	sharecropped plots	1465	1815
Koiladi	owned(cultivated) plots	2914	1466
	sharecropped plots	2513	1190
	fixed rent plots	2609	1486
Bhagwatipur	owned(cultivated) plots	1957	1539
	sharecropped plots	1935	1461
Mauyahi	owned(cultivated) plots	2425	1778
	sharecropped plots	2515	1540

Impact of agrarian structure on access to irrigation and technology in North Bengal

The ownership of agricultural equipment was shown to be more limited for marginal and tenant farmers, like in Bihar and Nepal. While there was not a clear relationship between tubewell ownership and wealth, Figure 11 shows how in Dholaguri all the large owner cultivators own pump sets, compared to just 12% for part tenants and 4% of marginal owner cultivators. However, 35% of small and 22% of medium owner cultivators own pump sets. The remainder rent irrigation equipment. In Uttar Chakoakheti, where groundwater irrigation is poorly utilized overall, pump set ownership is very limited across all farmer categories. It costs Rs150 per hour for a diesel pump in the case of Dholaguri. In Uttar Chakoakheti by contrast, there is limited evidence of an active pump rental market at all, and many farmers appear to not irrigate the land at all.

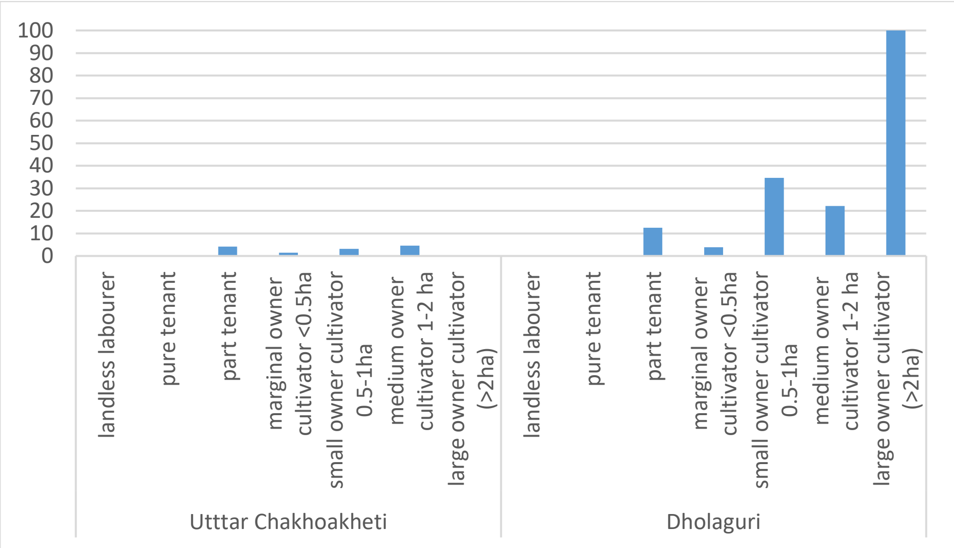


Figure 11: Ownership of pumpsets by farmer category: North Bengal

As in Bihar and Nepal, it is useful to identify whether tubewell and pumpset ownership affects yields. There is only sufficient data regarding paddy to draw firm conclusions. In Dholaguri Table 10 suggests that those with their own pump set yield 3837 kg per ha of paddy, compared to just 32101kg for those with no irrigation. Interestingly, those who were renting pumpsets had even lower yields on average at 2790 kg per ha. It may be the case that these plots are upland fields which require some irrigation, so are less productive than lower lying rainfed plots, particularly if irrigation applications are insufficient. In Uttar Chakoakheti only one household with their own pump irrigated paddy during the year the survey was completed, so it is not possible to draw conclusions about yields. Nevertheless it is clear that plots using no irrigation have lower yields on average when compared to those irrigated by rented pumpsets.

Table 10: Yields per ha of paddy on land irrigated by different source

Village	Irrigation of plot	Average yields per ha
Uttar Chakoakheti	owned pumpset for tubewell/pond	NA
	Rented pumpset for tubewell/pond	1981
	No irrigation	1280
Dholaguri	owned tubewell and pumpset	3837
	rented tubewell and pumpset	2790
	none	3210

Conclusions

It is clear that the project region for DSI4MTF is diverse and complex in terms of the patterns of agriculture and social structures. There are however, striking similarities between the Mithila region which includes the Nepal villages (Saptari) and the Bihar site (Madhubani). Both these regions are characterized by high levels of land inequality, dominance of a small class of landlords, and heavy concentration in the ownership of irrigation equipment which is a constraint for agricultural intensification. The baseline analysis therefore demonstrated strong potential in the region for interventions which can encourage lower cost and more efficient pumping technologies and group ownership of equipment, while also addressing land inequality and fragmentation through farmer collectives on collectively leased land.

In West Bengal by contrast, a very different series of challenges are present. This is a higher rainfall region, and rainfed dry season agriculture has more potential in villages such as Dholaguri and Uttar Chakoakheti. However, there is a limited big farmer class or even landlord class. The lack of a progressive large farmer class at all in villages such as Uttar Chakoakheti mean that there is very limited exposure to new irrigation systems, and even the use of pump sets is rare, with most farmers cultivating a single paddy crop. Even the water market for pumps is limited. In these villages, improving all around access to irrigation was found to be a priority, particularly given that the groundwater is plentiful – not to mention the need to look into cropping patterns which can utilize the residual post monsoon soil water in this high rainfall region. The feasible model of collectivization was however found to be very different, and for this reason the project experimented with the voluntary consolidation of land amongst small holders, rather than collective leasing.

7.2.5 Household vulnerability and climate and economic stress

To better understand what these structural inequalities mean for resilience to climatic and other stresses, a vulnerability assessment was undertaken in 2016. Project census data was analysed in a report by Palanisami (2016) Report No 9.

This analysis computed the farm household income as the total income for 12 months from i) skilled salaried income, ii) crops or livestock product sales (after deducting all input costs), iii) rental income from immovable properties, iv) rental income from agricultural assets, and v) agricultural labour income. The per-capita income was worked out by dividing the total income by household size. Household vulnerability was defined by the probability that the consumption (income) level of a farmer who encounters climatic shocks (such as drought, irregular weather, untimely rain etc.) pushes them below the poverty line.

Two poverty levels were identified for the analysis: a) current income levels of households derived from the sample, and b) World Bank estimates of per capita income of US$ 1.90. A three step generalized least squares technique was used for the estimation of the vulnerability levels of the households.

With regards to the climate related shocks encountered and documented in our census data, drought was the most severe shock encountered by the farmers followed by untimely rain and flood in all the regions. The majority of the farmers encountered a combination of these shocks. In all the regions, farmers responded in many ways to these climatic shocks which included: i) land related, ii) crop related, iii) livestock related, and iv) social activities. In all, these responses included mostly: a) providing supplemental irrigation, b) changing cropping pattern, c) following improved crop production practices, and d) selling livestock to supplement income that was last due to extreme climatic shocks.

Regarding the vulnerability of the households, in the case of the Saptari site, the study found that there are 425 farm households (households) whose per capita income is below the poverty line and 300 households will continue to be vulnerable in the next year also. Further, out of 285 households whose per-capita income is above poverty line, 173 households are liable to be vulnerable next year. In total, about 67 % of the households were found to be vulnerable to poverty in the region. The key determinants of household vulnerability are farm size, maritial status, main occupation and access to credit.

In the case of Bihar, currently there were found to be 594 farm households (69.7% of the sample households) who were below the poverty line and 569 households will continue to be vulnerable in the next year also. Further, out of 258 households whose per-capita income is above poverty line, 232 households are liable to be vulnerable next year. In total 801 households (94%) will be vulnerable next year. The key determinants of vulnerability include household's age, main occupation, livestock possession and access to credit.

In the case of West Bengal, there were found to be 342 households (67% of the sample households) with a per capita income below the poverty line. Out of this, 249 households will continue to be vulnerable in the next year also. Further, out of 165 households whose per-capita income is above poverty line, 33 households were liable to be vulnerable next year. Hence out of 507 households, 282 households (56%) will be vulnerable next year. This means that there will be decline in the number of farmers below the poverty line from current year to next year. The key determinants of vulnerability are farm size, household age, educational level, main occupation, drought and market shock, livestock possession and access to credit.

Regarding the adaptation strategies followed to address the household vulnerability, the majority of the households who responded to drought with crop related responses (such as providing supplemental irrigation, change in cropping pattern and following improved crop production practices) had higher per-capita income compared to households who did nothing. Thus crop related responses provided maximum benefit to offset the negative effects of drought on the vulnerability of households. Although as noted above in chapter 7.2.1, ability to irrigate is strongly linked to pre-existing socio-economic status.

The study highlighted the importance of pilot interventions that yield comparatively higher income from agriculture than the current practices, as illustrated by the results from the case study regions, including mechanisms to cut costs through more efficient irrigation. The vulnerability assessment found that a cluster approach (covering a group of adjacent villages) in piloting of the selected strategies will be more effective as this will minimize the transaction cost of technology adoption. Hence, a package of adaptation strategies should be made available to households and based on their performance, up-scaling can be done through the government agricultural departments and NGOs. It also highlighted that creating awareness and enhancing the skill development activities through capacity building programs is very important in enhancing the adoption levels.

As most of the farmers are facing the risk of rainfall variability, the report suggested that economics of investment in farm ponds and other storage structures (for providing 1-2 supplemental irrigations) needs to be examined in detail. As the investment in the construction of farm ponds and provision of supplemental irrigation through micro sprinklers with solar pumps may be costlier for small and marginal farmers, options for alignment of different government subsidy programs can also be examined.

7.2.6 Gender relations and impact of migration on agriculture

Seasonal and long term male out-migration has become a key component of household livelihoods to meet cash needs as discussed above. Women are increasingly responsible not only for domestic work and labour-intensive agricultural tasks, but also are obliged to enter a new space which was once the male domain. This includes overseeing land preparation and irrigation, as well as the management of inputs and labour.

As the literature on the so-called "feminization of agriculture" has pointed out (Adhikari and Hobley, 2011, Maharajan et al., 2012, Paris et al., 2005), this can be associated with both new vulnerabilities and empowerment depending on the household's economic status and household and community relations. What is a particularly significant concern in the context of the Eastern Gangetic Plains is the hugely increased workload for women, particularly women headed households (Sugden et al., 2016, Hadi, 2001). The out-migration of males creates challenges for women who stay behind. Access to and control over resources such as water and land are strongly connected with gender, class and caste divisions. Gendered norms and behaviour constrain opportunities for women to engage in public and economic activities, which adversely impact opportunities for women to access knowledge, acquire skills and strengthen bargaining power to access resources and sell produce at the market.

We analyse how shifting gender relations in the context of male out-migration affect agricultural practices in the Eastern Gangetic Plains, in regard to (1) agricultural water resources (2) land ownership and tenure (3) the division of labour and work burden (4) agricultural trainings and self-esteem (Leder 2015). Based on diverse and contradictory findings on these gendered struggles, we suggest an intersectional and relational approach by taking class, caste, age and other social differences into account when introducing dry-season irrigation technologies and other agricultural interventions. We criticize binary gender concepts such as the "feminisation of agriculture" for over-simplifying complex and shifting relations within agrarian households and communities (Leder forthcoming).

Methods for gender analysis

As noted above, the separate gender analysis conducted 106 semi-structured interviews, 72 focus group discussions (FGDs), Participatory Gender Trainings (Leder et al. 2016), as well as village resource mappings and repetitive transect walks over a period from 2015 to 2018. The interviews and FGDs were conducted with female and male farmers of different class, caste, religion, ethnicity and age in eight project sites. Focus group discussions were conducted with different farmer groups disaggregated by gender and class (based on land and pump ownership) to understand the impact and perceptions of migration on agricultural practices from a gender perspective. The questions aimed at understanding whether and how agricultural practices, access to water resources and decision-making processes on water changed through male out-migration amongst different farmer groups. The underlying objectives were to create lively discussions to understand negotiation processes on water access and use in agriculture in the context of out-migration.

Gendered access to water

Accessing irrigation takes time and patience, and means discomfort for women as it used to be the task of men. Entering the male domain of irrigation is linked to accessing public space and negotiating usually with other males who own pump sets and tubewells. This challenges gender norms, which women become critically aware about, but also experience as distress:

> *"I have to run after people to get water. People listen more to my husband, he can build pressure, but I can't. As I am a woman, they take it easy. They ignore and neglect me because I am a woman. There is not much to do about it, I have to face it and run four times, if it is like that" (B_I4)*

> *"The one who has a powerful voice gets his field irrigated first, so women whose husbands are out are usually more softly spoken and do not get their fields irrigated" (T_I3)*

However, women develop means to circumvent these challenges by asking and sometimes even paying something extra to male family members or neighbours to negotiate with the pump owner and to arrange irrigation for their fields. This shift of responsibilities from husbands to other men in the family or neighbourhood can sustain or even increase women's dependence on others in the process of male out-migration. Gendered relations are further reinforced as women continue to withdraw from public spaces and do not challenge existing restrictions.

Women are conscious of both the need and their limited capacity to pressurize, and also the rigid structures and their powerlessness to change the gendered norms, which rule access to water. They accept these conditions and act accordingly by approaching tubewell owners more often as they are not valued as much important customers as men. Two reasons were mentioned for this: One woman in Bhagwatipur, Bihar, stated that men usually pay instantly, while women often have to delay paying for irrigation, as they have to wait until they receive remittances, or they even take loans.

Some women in a focus group in Saptari complained that they were often overcharged, on the pretence that they could afford it as they had a husband abroad (Sugden et al., 2015). Some women noted that they do not have the networks and contacts of their husbands and that they feel uncomfortable approaching male neighbours to request the use of a well. For example, in Bhagwatipur, Bihar, one woman stated that men are more mobile and randomly wander around the village and, therefore, they can remind the pump owner more frequently to use the pump than women, who only go once to ask. Men are in contact with the pump owner to discuss other tasks of farming, such as land tenure regulations. This also links to the gendered upbringing of children and signifies the deeply rooted socio-cultural meaning of being male or female, which strongly shapes interpersonal relationships.

Gendered access to land

There are two major issues associated with land ownership and gender. The first relates to how much land the household as a whole has access to. This has important bearings on women in the context of male out-migration, as access to land shapes the overall food and economic security of the household, and can directly mediate women's upward mobility and capacity to make investments to improve the their livelihood in a changed demographic context (Sugden et al., 2014). The second issue relates to whether women themselves are the actual title holders for the land – a factor which can also have a significant impact on women's' livelihoods and access to resources.

With regards to the first issue, the data presented in section 7.2.4 has shown there is considerable variation between households in terms of their overall land ownership – particularly in the highly stratified villages of Madhubani and Saptari. Past research in Madhubani and the Nepal Terai showed that women from larger farming households fare better following the migration of a family member. They have enhanced food security, and cash sent through remittances can be invested not in meeting excess food needs but in productive fields such as micro-enterprises, livestock, or agricultural inputs (Sugden et al., 2014).

Gendered division of labor and work burden

Existing gender roles in agriculture are challenged through male out-migration. In the absence of husbands, some women became more conscious about their capacities ("I realized I can earn money myself when my husband is out"), but also their limitations, as they are dependent on others to irrigate and plough land. Agricultural labour used to be highly gendered, e.g. men used to purchase agricultural inputs, negotiate with traders, plough, and arrange irrigation pumps, while women conduct time-intense but low valued tasks such as weeding, harvesting, transplanting, alongside reproductive labour, such as cooking, cleaning and caring for children, elderly and the sick. In the absence of men, so-called male tasks are often transferred to young boys, the elderly or male neighbours. While remittances may help to pay for basic household needs, out-migration overseas often incurs large debts, which need to be repaid.

Gender relations in agricultural trainings and self-esteem

In order to address gendered struggles over resources and tenure, as well as restrictive gender norms within agrarian households and communities, Leder et al. (2016) developed and piloted a Participatory Gender Training for Community Groups. The training aimed at providing a platform for small groups of farmers to discuss gender norms, roles and relations in their families as well as their community based on visual and communicative learning theories. The training consists of three activities and three discussions in which participants:

1) Reflect on their own perceptions of gender norms in their families and in the community

2) Critically review the gendered labour division in agriculture,

3) Develop argumentation skills to resolve conflicts and evoke empathy by switching genders in a role-play.

Leder et al. (2018) explore how the training promoted enthusiasm, self-esteem and critical self-reflection on changing gender norms under the community's and project staff's active engagement both among participants, and also project staff and community mobilizers.

7.2.7 Innovations in agricultural water management in North West Bangladesh

Compared to the Eastern Gangetic Plains of Nepal and India, a more advanced range of approaches have been adopted in Bangladesh, to adapt to seasonal water stress. This research focused on identifying technologies and analysing institutional and socio-economic conditions of successful agricultural innovations in Northwest Bangladesh, with a view to identifying potential learnings for Nepal and India.

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. Key findings are summarized below and details are provided in de Silva and Leder (2017) Report No 17.

Rice accounted for 93% of the increase in gross cropped area, and 77% of gross irrigated area in the Bangladesh between 1990 and 2010. This and increased yields, due mainly to high yielding irrigated Boro rice varieties, have underwritten Bangladesh becoming self-sufficient in rice. Today, 80% of Boro rice is groundwater irrigated, and supports 57% of total rice production.

Differences in the agro-ecological context impact rice intensification and groundwater use. In areas like Rangpur there is good access to groundwater allowing all year irrigation. In other areas like Rajshahi there are lower groundwater tables and recharge rates resulting in greater water stress in the dry Boro rice season.

Adaptation to water shortages in areas like Rangpur and Thakurgaon have been through deployment of electric deep tubewells (DTW's) which reach greater depths and support three rice crops, full irrigation of Boro rice and supplementary irrigation to Aman and Aus rice. This has been supported by agencies such as the Barind Multi-purpose Development Agency (BMDA). Associated technological innovations include water conveyance through underground pipes and smart card payment systems making irrigation more accessible to, amongst others, women. DTWs have almost halved the cost of irrigating rice, and doubled profits for farmers served by a DTW.

There has been greater emphasis on demand side adaptations in areas where access to groundwater is limited, especially those without access to more reliable DTW supplies. Farmers and agencies are embracing crop diversification and substitution, with greater focus on replacing the summer Boro rice crop with wheat and other high value crops that have potential to reduce crop water demand, and increase farmer income.

Crop diversification and substitution is more prevalent amongst the larger and medium farmers who have more land and investment capacity. Large scale changes in cropping patterns are still challenging, mainly because farmers are not convinced of price stability in local markets, and over-supply remains a risk at local level. Local markets are also plagued by inequality between farmers and buyers (wholesalers, millers) which translates into low purchasing prices. Crop diversification is therefore clearly dependent on broader structural investments in the value chain in reaching its full potential.

Conservation agriculture, to reduce crop water demand (e.g. strip tillage and zero tillage) is a relatively new frontier in adapting to water stress. Although these technologies can reduce irrigation costs by about 50%, and field trials may alleviate risk perceptions, the difficulties faced in supplying high quality labour saving equipment in sufficient numbers is a critical barrier. Consequently, adoption is low, around 10%, though interest levels of farmers suggests more would adopt if the machines are available. In-country capacity for manufacturing good quality machines at affordable prices needs to expand.

Larger landholders are also converting some or all of their land for fish culture. Rising local fish prices makes fish culture 150%-300% more profitable than Boro rice, and at least twice as profitable as any other crop.

Adaptation is a multi-scale, multi-strategy and multi-actor process, and is promoted through the BMDA's structure and multi-sector approach, which includes surface water supply augmentation, tree planting to improve microclimates, agricultural research and infrastructure including roads and markets. The equal emphasis to demand and supply side adaptive measures is important. Reigning back groundwater consumption will require more imaginative approaches than through direct regulation. Collaborative approaches are likely to be more successful in addressing farmer attitudes and perceptions, and in incentivising farmers to adopt such technologies, whilst developing strong output markets for alternative crops to support investments in on-field adaptation.

Electric DTWs have clearly revolutionised groundwater-based rice production overall, and along with the smart card system, are a novel technological advance. However, this can limit access to groundwater by those reliant on shallow tubewells (STW's) and domestic hand pumps. This affects dry season irrigation and crop selection, with potential for inequality between DTW and the greater number of farmers served by STW's.

Future agriculture policy may call for greater demand management, but current farmer perceptions of water security in areas like Rangpur undermines diversification. In Rangpur and Thakurgaon, the primary adaptation measure is the use of more groundwater for Boro rice but also to supplement irrigation for Aman rice. Yet, by re-enforcing water security, farmers see little need to reduce 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 governments 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 Aus 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.

7.3 Collective farming approaches for sustainable dry season agriculture

7.3.1 Collective agricultural and institutional innovations for dry season agriculture

Collective agricultural and institutional innovations

Technical interventions to support sustainable intensification will be unsuccessful if they are not accompanied by institutional innovations, which can overcome structural barriers to adopting new technology and irrigation methods, while also addressing some of the by-products of these challenges – including out-migration and the feminization of agriculture.

There has been recent interest in alternative models of farming which can support smallholders, most notable of which is group farming – whereby collectives of farmers pool land, labour, capital and skills to create larger units of production (see Sugden, 2016, report no 8). The research of Agarwal (2010) paved the way for a new model of group farming, to support marginal farmers in achieving economies of scale in spite of marginal holdings, which increases their bargaining power in the rural economy. It would also allow them to more efficiently manage labour at a time of high out-migration, and strengthen women's leadership. Subsequent analyses have demonstrated the potential for group farms to even out-perform individually owned farms (Agarwal, 2018).

Sixteen groups were formed from mid-2015, later increasing to twenty as new groups emerged. Some emerged spontaneously after observing the success of the other groups. Groups consisting of a chairperson, secretary and treasurer and members numbering from four to ten. Women played a key role. There were five women-only groups, two male groups (including a youth group), with the remainder being mixed. Like conventional farmer organisations they convened monthly meetings and collected regular savings. As these groups were also the channel through which the project irrigation innovations were introduced, the groups received regular training on agronomic practices, pest and disease management, on-farm water management, including farmer exchange visits for cross learning. They also benefitted from sensitization on group functioning, gender and social inclusion. What made these groups different from conventional farmer organisations was the collective approach, which was pursued, which would support more effective introduction of technical innovations, as well as broader sets of benefits for farmers.

The mechanisms to work together were farmer led, and after initially tabling the idea of collective cultivation with the community, it became apparent that flexible models were necessary to take account of the local context.

Four evolving collective models

During the project, four models evolved based on the willingness of farmers to manage different levels of cooperation, the land ownership structure, and their experience with running groups over time.

Model 1: Fully integrated cooperation with leased land: In Bihar and Nepal, tenant farmers, who constituted a significant proportion of the farming population, were willing to engage in high levels of cooperation. Here the Project team, along with the farmers, developed a model whereby groups would lease land collectively on a more favourable fixed rent basis, farm it as a group, and share all costs and outputs.

Model 2: Fully integrated cooperation with own plots: In North Bengal groups were willing to take up a higher level of cooperation, but there was little land for leasing. Group members therefore agreed to consolidate their plots to farm collectively. It is important to note that in both Models 1 and 2, labour and output were shared, the only difference being that the land was leased in Model 1 and owned by group members in Model 2.

Models 3: Medium levels of cooperation with leased land: The wariness of some farmers in Bihar and Nepal regarding the pooling of labour paved the way for models involving *medium* levels of cooperation. Some tenant farmers agreed to collectively lease a contiguous plot of land (as in Model 1) and cooperate for some activities including land preparation (e.g. ploughing), joint crop planning, irrigation and marketing, and sometimes exchange labour during busy spells, but decided to farm their sub-plots individually within the larger group plot.

Model 4: Medium levels of cooperation with owned land: Amongst small landowners in Madhubani (Bihar), a fourth model evolved. Here marginal farmers owning their own fields pooled within one contiguous area were willing to cooperate for land preparation, crop planning, irrigation and input purchase, but not for sharing labour.

These farmer-led groups evolved organically during the Project life cycle, and are discussed in greater detail in Sugden et al (2018, Report number 14).

Benefits of the collectives

Labour management

One of the primary advantages of the collective under models 1 and 2, which pool labour, is the opportunity to save time, a key issue for women in the context of male outmigration, where the work burden has had negative impact on their wellbeing. Key tasks such as harvesting and paddy transplantation generally require large amounts of labour in a short period of time. This burden has productivity implications. For example, under conventional farming systems, delays in paddy transplantation after the early rains due to a lack of labour can result in seedlings drying out. Most women who lack sufficient family labour must hire in some labour during these busy times, although workers are often not available during critical windows, and migration has aggravated shortages of both family and outside labour. The pooling of labour through the collectives helps address these challenges as labour can be mobilised more easily. There can also be a division of labour. A number of members noted that in the past, each farmer would be responsible for tasks such as going to the market to buy fertilizer or to sell vegetables. Now it can be delegated to one member, and remaining group members can engage in other activities. Each member also brings new skills and experiences, i.e. knowledge in the group is also, ‘pooled’ along with the land itself.

Operation of contiguous plot

A second primary benefits of all four collective models is the capacity for several farmers to operate a contiguous plot of a size which optimizes the efficiency of irrigation and land preparation. For households who both own and rent land, it was common for them to operate between 5 and 7 very small plots of land, as they cultivate whichever land is available for rent, which may involve leasing from more than one landlord. Plots were often far from the house, adding to the labour burden, with typical walking time being 15 minutes. Plots themselves were often so small that investment in irrigation or mechanization was unfeasible, particularly when they were scattered in different locations.

The collectives by contrast all consist of a single contiguous plot, and the size is considerably larger than what was previously farmed by individuals. Irrigation has now become more practical and efficient. Moving a heavy pump set between distant plots can add to the time and labour requirements associated with irrigation, and in the case of electric pumps it is not practical if a power source is not available nearby. Crucially, many of the irrigation innovations introduced through the project such as solar pumps and drip systems would not have successfully reached so many marginal farmers had they continued to farm scattered small plots. This is one reason why in conventional agricultural projects, it is often larger farmers who can most easily adopt new irrigation technologies. The process of demonstrating and training in new water saving techniques was also facilitated by the fact that farmers all worked on the same contiguous plot.

Farmers also noted how a larger contiguous plot makes it more economical to use technologies such as tractors to deal with labour scarcity. There are also cost benefits. Farmers noted that when fertilizer is purchased in bulk for the group, as occurs under groups 1 and 2, the cost is inevitably lower, and one only needs to pay for the transportation cost once, not to mention the saved time. Farmers in models 3 and 4 were mostly purchasing their own fertilizer, but there is the potential for cooperation in input procurement also, allowing all to benefit from these savings.

Increased bargaining power

Another important benefit of the collectives piloted in the project, is the potential for the group solidarity to be translated into greater bargaining power with landlords. Collective leases which are pursued under Model 1 and 3 have enabled group members to challenge old power relationships (see Sugden et al 2018, Report number 14). There were several reported instances of the collectives being able to extract concessions from landlords, by building on their group strength and increased confidence. As well as increasing their bargaining power with landlords, as a group the farmers have been able to claim government entitlements which they could not earlier.

Challenges of the collectives

The main challenge of the collectives under Models 1 and 2 arose in labour sharing, and the fact that not all group members were contributing labour as and when required. A lack of incentives to increase the labour input in jointly managed farms has been a long running critique of collective production from the socialist and post-colonial experiences. However, in this case study we cannot assume that farmers were consciously choosing not to work or ‘free riding’. Farmers acknowledged that group farming saved them time to spend on other activities, yet a consistent message from our interviews and focus groups was that they found it difficult to find a time when all members were available, and they struggled to coordinate everyone’s busy work schedule.

This is in part because the group farms are not large enough in land area for members to meet their entire subsistence needs. Some farmers reported a tendency for members to prioritise their own farms outside the collective. This was often for pragmatic reasons linked to the need to coordinate certain activities such as planting when water is available. For example, one respondent noted that if he had called labourers to work on his private plot for irrigation, he needed to finish that work before coming to work on the collective. Failure for members to turn up on time led to delays for key group activities, with a potential adverse effect on productivity.

Some groups in North Bengal were able to weather these challenges, but in Koiladi of Saptari and Bhagwatipur Bihar, these conflicts resulted in four groups shifting from labour pooling under Model 1 to individual plot cultivation under Model 3. Farmers in Koiladi said that although it took them longer overall, they could organize their work between their allocated field in the collectively leased area and their own fields and did not need to coordinate with others. This raises the importance of offering flexible models of collective, which can adapt to changing circumstances.

Comparing the performance of the four models

Several factors appear to affect successful group pooling of labour both under Models 1 and 2 with high cooperation, and Models 3 and 4 with medium cooperation. The first is crop type. For paddy and wheat, farmers in Madhubani and Saptari felt that labour management is relatively straightforward, as everyone is required for a few intensive days during transplanting, weeding and harvesting. This contrasted with vegetable production, which required a less intense but more frequent mobilisation of labour every few days for weeding, irrigating, pesticide application, and harvesting – with the latter often being spread over several weeks as the vegetables mature. Not all groups share this view, however. In North Bengal, the groups cultivated vegetable collectively under Model 2 but then reverted to individual cultivation for the monsoons (as in Model 4). This was due to a cultural preference in the community to be responsible for one's paddy crop, rather than perceived disadvantages of working collectively.

The capacity to pool labour is also connected to the social composition and history of the group and especially with gender dynamics. While most groups belonged to the same ethnic community or caste, the women-only groups in Nepal and Bihar showed a greater ability to work together relative to mixed gender groups. However, these results were not apparent in North Bengal, highlighting that the local history and context is also important. In Uttar Chakoakheti and Dholaguri all groups have successfully pooled labour in spite of the fact that all but one are mixed gender. In these sites, peer pressure and strong cohesion encouraged farmers to come on time, and coordinating work schedules was not raised as such as significant issue. The reason for these differences are likely complex and are further discussed in Sugden et al, 2018 (Report No 14). Firstly, there is a long history of successful collective action in the North Bengal villages, not evident in the other regions. Secondly, North Bengal community has fewer caste divisions compared to the Bihar and Nepal sites, enabling the building of stronger community trust and cohesion. Finally, farmers have fewer plots outside the collective and for most, the land contributed is the family's primary agricultural land – reducing the conflict over time.

Lessons from farmer collective formation

A key lesson is to be flexible and allow multiple models to emerge organically, with varying levels of cooperation. Over time as trust develops or cropping patterns change, the models may also change, or a mix of models may emerge. Whichever model emerge, there are clear gains from cooperation, in terms of time saving, labour use and irrigation efficiency, and improved bargaining power. There are also constraints rooted in time management challenges. There is thus a need to look into alternative solutions such as better accounting of time, or increasing the size of the collectives so there is less conflict between privately leased or owned land and the collective land.

Some may see a possible paradox in that the models of collective leasing can create a dependence on the same landlord-tenant relationships which the models seek to undermine. However, we have also seen the potential for transforming that relationship into a more formal contractual one. In the long term, group solidarity and mobilisation through the collectives could even empower tenants to claim their legal rights to land. There is also strong potential for multiple collectives to band together for cross group cooperation. This could include for example, standardising rents, or in procuring inputs or services, which are beyond the reach of a single group.

7.3.2 Gender impact assessment of collectives, and the new dry season irrigation technologies

Farmer collectives and the introduction of new dry season irrigation technologies are potentially empowering approaches for marginal and tenant farmers, particularly women farmers. Based on our regular engagement as researchers and social mobilizers within this between 2015-2018, we examined the extent to which the establishment of collective farming benefits women, particularly in the five women's collectives. While some results were positive, challenges remained due to the structural gender inequalities, which are deeply entrenched in the Eastern Gangetic Plains.

In Leder et al. (2019), we explore how social relations mediate collectivization processes such as group membership, the (gendered) labour division, and the share of produce. Hence, we found some contradictions between intended benefits of collectivization and their actual functioning. The concept of individual group membership was renegotiated and aligned to existing norms and practices of farming as a household unit. Group members benefitted differently despite the aspired egalitarian approach as labour and benefits were often redistributed on the basis of class and gender. However, in enabling environments with less fragmenting social practices, the collective farming approach turned farming groups towards more equal shares due to their collectivization of labour, land and benefits.

Drawing from feminist political ecology, Leder et al. (2019) identified the following factors mediating these ambivalences regarding the redistribution of labour, land, produce and capital through collective farming: (1) Gendered division of labour and gendered technology adoption (2) social relations across scales (intra-household, group and community relations), (3) intersectionality (e.g. gender, class, caste, age, ethnicity) (4) emotional attachment (to the family and neighbours). We find that unequal gender relations in agriculture, intersected by class, age, ethnicity and caste, can still be reproduced in collective farming, land tenure and water management, and argue that a critical feminist perspective can support a more reflective and relational understanding of collective farming processes, with relevance for future work.

Gendered division of labour and gendered technology adoption in collectives

While the collectives help address labour shortages for women as discussed above, many of the female majority groups still depend upon male household members or male outside labourers for what are considered male tasks such as land preparation, and most importantly transporting and starting the pump, laying pipes for irrigation and digging furrows. A male farmer in Koiladi also noted his ‘concerns’ regarding female work roles, exemplifying the prevailing attitude that certain ‘technical’ tasks such as irrigation fall outside of the female domain. In mixed groups, the rigid gendered division of labour mean that women would sometimes bear a disproportionate burden of the tasks, which fall in the female domain such as weeding and transplanting. Unequal contributions were also manifested by male members sending their wives as ‘substitutes’ and then retaining the output themselves.

With regards to unequal contributions, accounting of labour contributions and benefit sharing could reduce the risk of women taking on an unequal burden, and men who did not contribute equal labour time could compensate the group financially or through a reduced share of the output. More research is required given the difficulties of enforcement, as well as the cultural devaluation of ‘female’ tasks such as paddy transplantation when compared to ‘male’ tasks such as land preparation. In the long term, organizations supporting collective formation will need to prioritize training of women in ‘technical’ tasks within the male domain such as pump operation. This will help to undermine rigid divisions of labour, but will also be advantageous in the case of all women groups, as they will no longer be dependent upon men from outside the group for ‘male’ tasks (Sugden et al. Forthcoming).

The capacity to pool labour was also connected to the social dynamics and history of the group. On a positive note regarding gender empowerment, while most groups were from the same ethnic or caste group, in Nepal and Bihar, the women only groups showed a greater ability to work together when compared to the mixed gender groups. Three out of four groups which abandoned labour pooling under model 1 (Koiladi 1 and 2 and Bhagwatipur 1) were mixed groups, and these were the first to show signs of conflict over the timing of labour. There was relatively less conflict and strong bonds of solidarity (Sugden et al. Forthcoming).

Social relations at household and community level

Social relations and everyday practices are crucial in shaping collective farming practices. We question common interests and equal benefits within communities, groups and households when forming farming collectives, as this brings various responses and struggles related to gender, landownership, age, and ethnicity (Leder et al. 2019).

Intra-household relations can both inhibit and support women's role within collective farming groups. Across groups within the same region, we found differences on the extent to which gender norms on using irrigation technologies were reproduced or challenged (Leder et al. 2019). All cases demonstrate the importance to consider broader social relations across scales, but also individual benefits of collective farming in terms of cash, time and decision-making to understand the degree of more socially just outcomes in comparison to individual family farming.

Intersectionality of gender and class

In some of our case studies, power imbalances due to gender, class (land ownership), education and social networks amongst group members led to unequal divisions of labour and benefit sharing in collectives (Leder et al. 2019). When gender inequalities intersect with land ownership inequalities, as in Dholaguri, West Bengal, and Kanakpatti, Nepal, women had relationally lower financial benefits than male landowners from the produce. To avoid the 'double disadvantage' by gender and class affecting bargaining power, striving for group homogeneity in regards to gender and class requires consideration in future work.

If the division of labour, capital and land distribution and group benefits remain unequally distributed due to unequal gender and class relations, the collective farming approach has not fulfilled its very intention to redistribute land, labour and water resources more justly. Therefore, gender and class relations matter immensely in collective groups, and it is important to reflect these not only prior, but also throughout the formation of groups, particularly since group homogeneity and heterogeneity is highly context-specific. Otherwise, there is a danger that subordinate positions are reproduced due to the internalization of particular (gendered) labour roles (Leder et al. 2019).

Emotional attachment

Emotional attachment among group members and existing commoning practices matter strongly when establishing collective farming, more than household's or individual's socio-economic preconditions and prior farming skills alone. Emotional attachment to the community helped overcome crop failures through mutual encouragement, promoted continuous informal discussions and motivated to continue sharing resources and labour, which are the most important dimensions to keep collectives functioning (Leder et al. 2019).

In order to address gendered power relationships at household and community level, intersectionality and emotional attachment in collective farming, highly contextualized and local approaches implemented and observed by trained staff are required to avoid the reproduction or exacerbation of existing power imbalances in households and communities. We recommend regularly creating spaces for open discussions with group members on gender and other social challenges within groups, as we developed in our Participatory Gender Training approach (Leder et al. 2016).

7.3.3 Assessment of market chain opportunities

Through improved irrigation and collective farming, the project helped introduce a range of new high value, primarily vegetable cropping systems, which generated a marketable surplus. This generated a range of market chain opportunities and challenges. Production–market linkages are important for economic viability, but lack of infrastructure (such as collection centres), low influence on price, small scale of production and inability to penetrate distant markets, as well as high market margins, proved key constraints.

Discussions were held with farmers, farmers' groups (17), traders (32) and input suppliers (16) and service providers (5) at Saptari, Madhubani and West Bengal sites to assess these opportunities and constraints (Bastakoti, 2017 Report No 15).

Input suppliers reported that marginal farmers cannot always pay for purchases and sales are often on credit. Improved access to capital and credit would help strengthen the business. Farmers also reported that high value crop production is especially unreliable with climate, pest, and disease affecting production. Transporting small volumes of produce to nearby markets is also labour intensive. There is a premium price when selling directly to the market, however prices are highly volatile, especially for vegetables. Traders reported that wastage of vegetables is a major problem, given inadequate storage facilities, and markets are poorly managed, with no committee to oversee operations. Price fluctuations and credit availability are also major constraints.

Dialogue between the buyer and trader is limited and formal contracts are not in practice for marketing vegetables. There is limited local knowledge on marketing and processing, given small production scale. Producers are typically interested in access to capital (credit/ loans), market assurances (price and quantity) and maximising selling price. Traders expect to share risks, have quality and quantity assurances and market-led price fixing. These divergent interests often result in conflict and loss of trust. There is little vertical value chain integration for fresh vegetables. While there is good horizontal value chain integration through collectives, coordination in product selling is less advanced.

Key opportunities would flow from strengthening collectives. Improved quality could lead to value addition activities through collectives, such as simple sorting and grading, as well as better credit facilities and logistics for product distribution and sourcing of inputs. Better access to market price information would also assist the groups.

Already, collective marketing through the farmer groups has been effective for models 1 and 2 where there is labour pooling, bringing some benefits in terms of time saving and improved bargaining capacity. For many of the groups not pooling labour under models 3 and 4, production continues to be sold individually by farmers, however if production volumes can be increased there are possibilities for collective marketing through the groups. This may even entail multiple groups cooperating.

The project has supported a range of initiatives to link farmers' groups/cooperatives to traders at different levels. Further focus is required on production planning, to match production with market demand, and to facilitate stronger linkages with traders.

7.3.4 Engagement, communication and capacity development strategies to facilitate maximum adoption

All Partners were active in community engagement and capacity development, although primary responsibility was with the NGO's. Small, marginal, tenant and women farmers were the primary stakeholders, functioning through collectives. Other secondary and tertiary stakeholders included collaborators and service providers, research agencies, government line agencies, and local institutions, such as farmer's clubs and women self-help groups. Strategies to optimize the level of synergy and collaboration with farmers and other stakeholders, and their aggregate impact in terms of scaling and adoption, was founded on the principles of ethical community engagement.

Ethical Community Engagement (ECE)

Ethical community engagement implies that knowledge production is inclusive, and must respect the wisdom and perspective of the communities. There are many issues and challenges in maintaining an ethical engagement process, which takes place in a dynamic socio-cultural and political environment, and has different impacts in time and space. The process helped build constructive relationships, interpersonal trust and embed learning, all requirements for impact and scaling. Engagement was guided by the strategy and plan developed at the inception meeting and was adapted locally. Engagement included a number of strands, which are illustrated in Table 11. There were more than 450 farmer meetings, 15 stakeholder meetings and 170 training events.

Differences occurred in the organization of engagement events across villages and regions depending on local priorities. Early learnings from the project led to the development of a document “Community Engagement - Perspectives, Processes and Practices” (Mishra, 2016, Report No 6). The concept of ECE was further refined and applied by the ACIAR sister project SIAGI and has been an important area of wider impact and scaling, for example through engagement with the ADMIP program of West Bengal.

There has been significant agricultural intensification and diversification across all project villages in response to the engagement and capacity development strategies. A series of Case Studies (Mishra 2016) provide examples. Women, marginal and tenant farmers have developed confidence, new knowledge and skills, and individual and local institutional practice change has been evident. Through ethical community engagement farmers have developed new confidence, skills and capacity for change, a greater tolerance for risk and strong vision for the future.

Table 11: Strands of Engagement

Strands of engagement	Impact
Post inception farmers meeting(s)	Enhancing knowledge and confidence for dry season cultivation. Planning for implementation of new technologies.
Situation analysis	Engagement with farmers to understanding village realities
Focus group discussions	Issue based discussion on different topics and strengthening local institutions and governance.
Stakeholder’s consultation	Insight and action planning with different agencies to encourage convergence .
Institutional development and capacity building	Strengthening the community based organization and engaging towards active participation. Relationship building with service providers.
Planning for technological location	Enhancing community engagement towards technology adoption and proper installation and management of irrigation systems and equipment.
Participatory crop planning	Integrating farmers and advisors ideas for seasonal crop planning.
Monthly meetings	Governance and planning and conflict resolution.
Review workshops and night stays	Reviewing outcomes, assess impacts of interventions and trust building between community and project team.
Exposure visits –between the villages and outside the villages	Enhancing knowledge and confidence. Adopting new technologies and improved relationship between farmers and service providers.
Bi-monthly meetings for peer-group learning and interaction	Learning from each other, for example in aspects of crop, market value, technologies to build confidence to promote dry season crops.
Special events	Participation in events – such as sharing of learnings between villages and countries at Collective retreat, attendance of international women day events.

Capacity building

Implementing the project interventions required changes in attitude, perspectives, knowledge and skills, practices and behaviour. The ethical community engagement approach had a positive influence on changing attitude, and capacity development, through acquiring new knowledge and development of new skill sets. Capacity building has not been uni-directional, in the sense that somebody induced learning and capacity. It has been collaborative and multidirectional through a range of approaches.

Peer-learning: Various technological interventions required specific technical inputs, which were delivered by specialists. Refinement then took place using peer-learning approaches sometimes supported by the specialists and sometimes independently by other persons. This helped learning and scaling.

Exposure: Farmers visited adjacent farmer fields, research stations and participated in different events such as stakeholder meetings, demonstrations and field days. This proved effective in not only adoption but also in improvisation and adaptation to the local conditions.

Field experiments and demonstration: The project encouraged field experiments and the farmers' trialled and compared different practices. This helped adoption, adaptation and scaling.

Participation in open exhibitions and fairs: Farmers participated in field days, fairs and exhibitions during various agriculture seasons. These exhibitions showcased and demonstrate various practices and innovations which provided insights about new technologies, products and processes.

State sponsored capacity building: The project has created a good amount of interest among government departments who have showed interest in approaches and perspectives and have shown interest to implement in broader state-wide schemes.

A large and expanding network has developed at both a district and national level with links established between public, private and village institutions. Lists of key stakeholders were developed locally with focus being placed on strategic stakeholders that could assist in supporting marginal farmers and scale findings.

7.4 Improved irrigation practice for sustainable dry season agriculture

7.4.1 Irrigation from ponds and groundwater

The Sub-Himalayan Terai region has extensive groundwater resources. The water table is shallow and water quality is generally suitable for irrigation purpose. Dry season agriculture for marginal farmers is mainly limited by inadequate irrigation infrastructure. Surface water resources consist of small to medium size ponds and groundwater is accessed using shallow tubewells with a total depth of less than 30m. Tubewells and dug wells are not evenly distributed, and in a number of cases the tubewells were defunct. A number of piezometers were installed to monitor groundwater at the start of the project. Table 12 summarises the pond and tubewells in each village, which are mapped in Appendix 2.

Table 12: Summary of water resources in Nepal/India village sites

Region	Village	Number of ponds in the village	Number of ponds monitored	Number of dugwell/ tubewells in the village	Number of dugwell/ tubewells monitored in the village
North Bengal	Dholaguri	13	6	29	7 +4 Piezometers
	Uttar Chakoakheti	10	3	13	7+3 Piezometers
Madhubani	Bhagwatipur	13	5	20	11 +3 Piezometers
	Mauahi	18	5	4	3
Saptari	Kanakpatti	2	2	54	18
	Koiladi	23	3	22	5

Surface water (ponds)

Palanisami (2011) suggested the potential of ponds for irrigation. Ponds in the study sites were very small, offering limited capacity for irrigation, and are dry in summer due to evaporation and seepage losses. Where ponds can store water, they are usually reserved for more profitable fish production and domestic purposes. While evaporation is a consideration, excessive seepage losses through the banks and base of the pond is the main cause of drying. This is due to poor construction and maintenance of the banks and highly permeable coarse soil textures.

Ponds are generally dry between April-May and fish must be harvested prior to that. In some cases farmers fill the pond with ground water, however this is costly and rare. Pond water level, meteorological, and other environmental data were collected, allowing estimation of evaporation and seepage rates from the pond. Pond water level was recorded weekly in all villages and an example of pond water level data for the period July 2015 to July 2018 for Bhagwatipur village is shown in Figure 12.

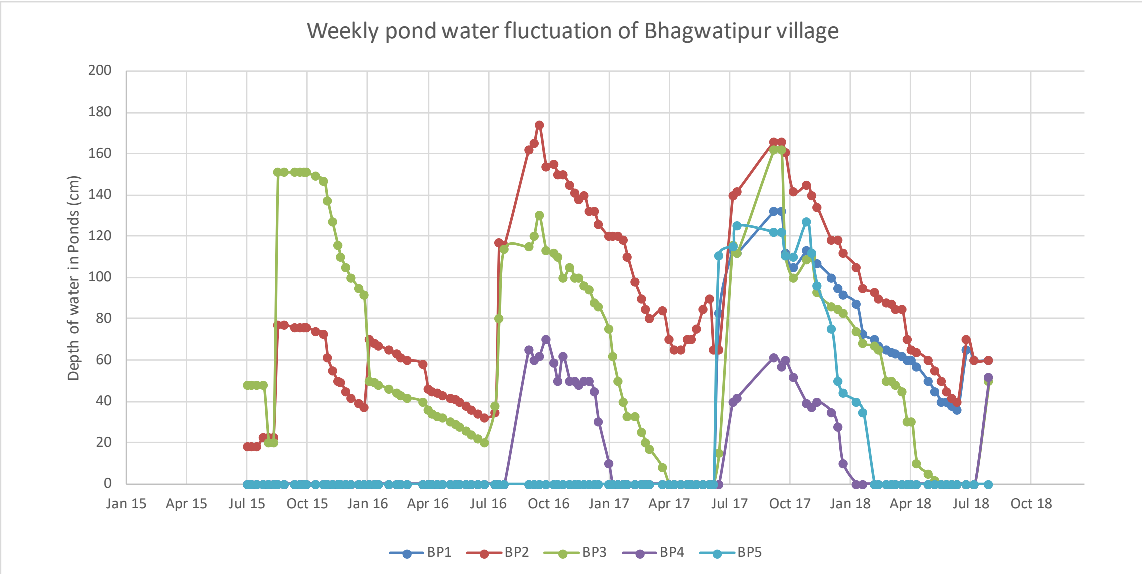


Figure 12: Example of recorded pond water level (Bhagwatipur village)

Trends are typical of other sites showing substantial water loss in the dry season (750 – 1,600 mm), with most ponds near dry between January and April each year. Rainfall and runoff then rapidly fill the ponds at the onset of the monsoon.

Seepage rate is dependent on the materials and compaction and depth of water stored. In West Bengal the soils are lighter than in Madhubani and Saptari, and an investigation was undertaken to quantify evaporation and seepage losses. A pond in Dholaguri village was instrumented with high-resolution electronic pressure sensors, recording water depth hourly. This data was compared to calculated evaporation data to estimate seepage rates.

Figure 13 shows the change in water level in Pond 9 at Dholaguri illustrating the rapid decline in water depth due to seepage and evaporation losses. Periods of rainfall and pumping (shaded periods) are evident, and were removed when determining seepage. Table 13 shows seepage and evaporation loss (mm/day) from DP9 as well as water volume lost (m^3/month). Seepage loss of 4.9mm/day was much larger than evaporation 2.7 mm/day. Seepage loss would provide sufficient water to irrigate an additional 730m^2 of high value vegetables. Consideration should be given to better construction methods including compaction, maintenance, remediation and low cost methods of lining

Figure 13: Water level recorded with pressure sensor in Dholaguri

Table 13: Assessment for pond water losses in Dholaguri Pond 9

Pond	**Surface area (m^2)**	**Total loss (mm/day)**	**Seepage loss (mm/day)**	**Evaporation loss (mm/day)**
DP9	750m^2	7.6 mm/day (171 m^3 /month)	4.9 mm/day (110 m^3/month)	2.7 mm/day (61 m^3 /month)

In Kanakpatti, the average loss through seepage and evaporation, was found to be 5.9 mm/day, and similarly in Koiladi 6.7 mm/day. Most of the ponds in these villages are dry in summer, and there is little irrigation from ponds. Some farmers use ponds to irrigate wheat crops in critical dry periods.

Similarly, in Bhagwatipur and Mauahi, most ponds are dry in summer. The largest accumulated water loss was 135cm in Bhagwatipur pond 3 during the dry season of 2015-16 and 183cm in Mauahi pond 6, during dry season of 2016-17. Seepage from storages recharges groundwater, so the “loss” is not from total available water resource, but does become more expensive for farmers to access pumping from a tubewell.

A survey of 19 ponds helped understand pond ownership, management and maintenance factors. Eight sites were located in Madhubani, seven in West Bengal and four in Saptari. The survey confirmed that ponds are primarily reserved for fish production, religious purposes and domestic and animal use. For optimal fish production, water level needs to be maintained above 1.5m.

There was no irrigation from ponds in West Bengal. In Saptari and Madhubani water was occasionally extracted for emergency irrigation of wheat in Rabi season. Maintenance of government owned ponds was especially poor, while families maintained privately owned ponds. Managing ponds is a challenge, unless privately owned, with disagreement between the users on water access and priority usage.

There is good scope for rehabilitation of ponds to reduced seepage losses. If new ponds are constructed, it is important to size them in such a way that they can cater for the water demand of the dry season crops, and are effective at retaining water.

Groundwater is seldom used to fill ponds, owing to cost of pumping. Solar pumps can be used, thereby reducing pumping costs, however capital cost is prohibitive. At Dholaguri site 2 pond No 9 is filled using a recently installed tubewell which also supplies water to an intensive protected housing structure, growing high value out of season crops, using efficient micro-irrigation (Maitra 2017 Report No 16). In Bhagwatipur at Site 4 and Site 1, ponds are filled from a solar pump, allowing use of water not required for irrigation. This maximises the use of available solar energy and solar pump capacity.

Groundwater

Groundwater was monitored weekly using an electronic sensor and entered in the DSI App 'Water Level recorder' (Appendix 7). An example of the groundwater level data for the period July 2015 to July 2018 for Dholaguri village is given in Figure 14.

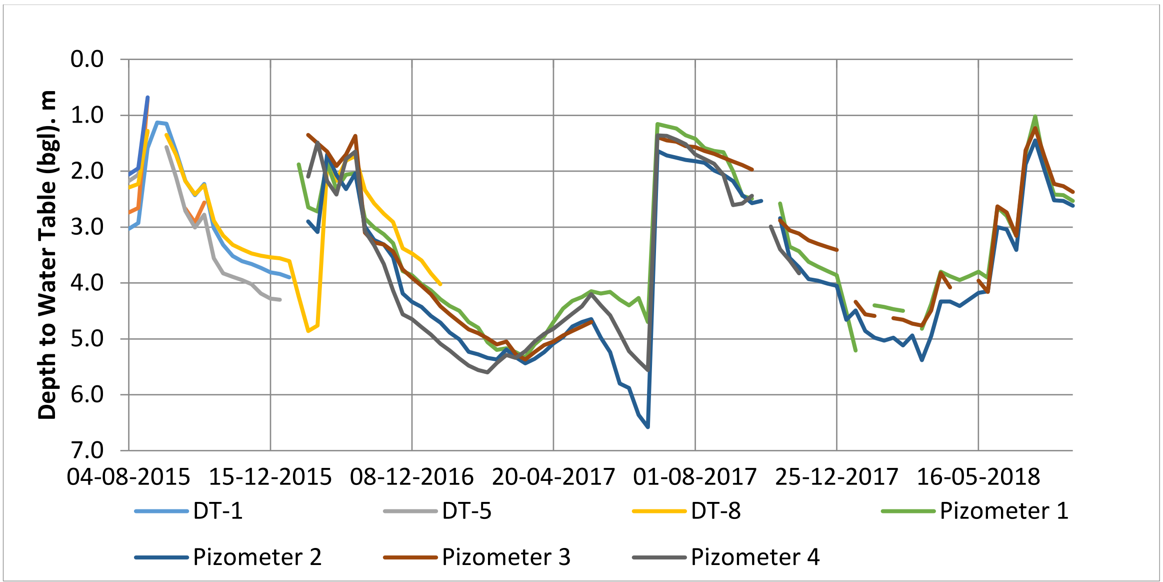


Figure 14: Example of recorded groundwater level (Dholaguri, West Bengal).

The maximum depth to groundwater occurred during the late dry season (February-April) and minimum water depths occurred towards the end of rainy season (July-September). At Dholaguri minimum and maximum observed depth to water table across all sites was 0.7m and 6.6m. The seasonal change in water level was approximately 3.5m. Maximum depth of less than 9m suggests water is within the suction lift of a centrifugal pump. Small inter-seasonal range implies little impact by irrigation. In Uttar Chakoakheti the minimum and maximum depths to water table were 0.5m and 5.3m, respectively. Across all sites pre-monsoon and post-monsoon showers are received during the months of April and September, and the majority of annual rainfall is received during the period May to August. In general, very low precipitation occurs during October to March.

Consistent trends in rise and fall of groundwater were evident across sites. Monsoon rains raise the water table, which then declines, rapidly at first and then slowly as the hydraulic gradient reduces. Another example is given in Figure 15 for Kanakpatti, which shows an initial rise in water level once monsoon rains start and then rapid decrease as Rabi season commences followed by more gradual decrease as water levels fall to lowest levels.

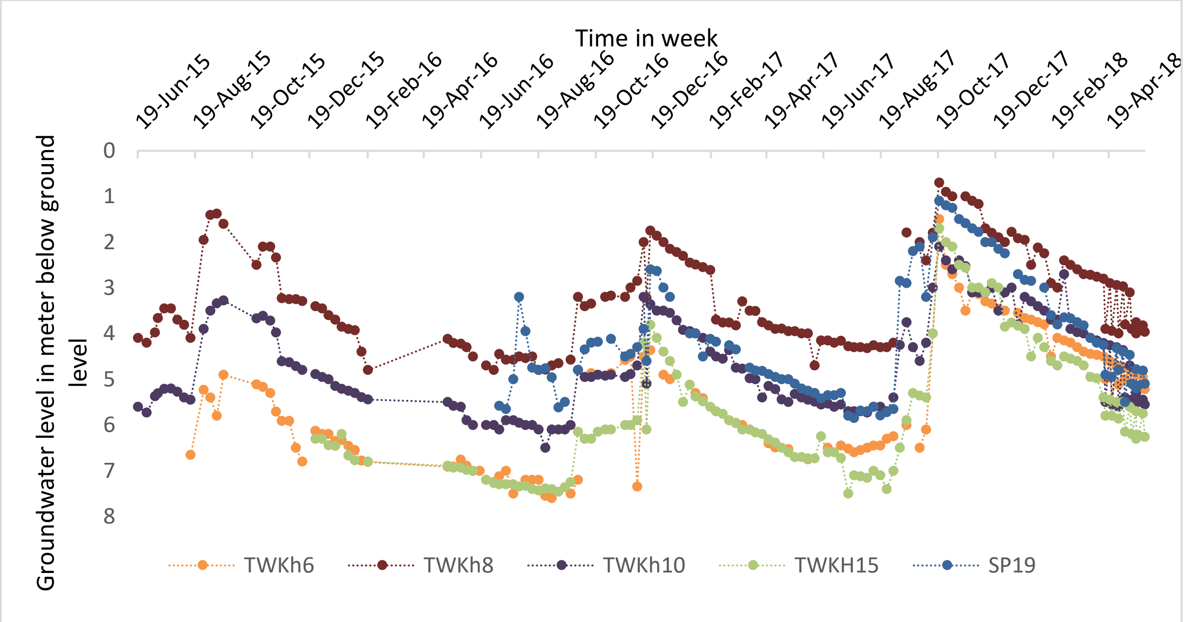


Figure 15: Weekly groundwater level measured at Kanakpatti, Saptari in different tubewells and dugwell.

In Kanakpatti, the water table varies between 0.7m and 7.6m below ground level, with seasonal range of 2m-3m. In Koiladi, the seasonal range was around 1.5 m. The seasonal range in groundwater at Bhagwatipur was between 1.3m and 2m and in Mauahi, 1.2m and 1.8m.

Local measured groundwater levels were consistent with the Indian Governments Central Ground Water Board (CGWB) records for Madhubani district (Bihar) and Jalpaiguri Cooch Behar (West Bengal), reinforcing CGWB report that local groundwater resource in the region is underutilized.

In all villages the groundwater levels did not appear to be impacted markedly by local pumping and generally remain within the practical suction lift of centrifugal pumps. In some cases, groundwater level dropped temporarily below the suction lift of the centrifugal pump following drawdown after a long pumping event. However, with possible large out scaling of dry season irrigated agriculture, pressure on groundwater could increase, such has been found in NW Bangladesh (da Silva et al 2017, Report No 17). Further research on regional hydrological impact of farm-scale water abstractions under different scenarios is warranted and has subsequently been funded by ACIAR (Ref WAC/2019/104).

7.4.2 Water Quality

A review of the occurrence and extend of arsenic and fluoride contamination in groundwater in the study districts was undertaken (Rajmohan et al 2017 Report No 11). Arsenic and fluoride contamination in groundwater is potentially a serious issue and the World Health Organisation (WHO) have reduced regulatory limits of arsenic from 50 μg/L to 10 μg/L for drinking water. While groundwater arsenic contamination is encountered in all three districts, extent and severity is varied and generally within standards. In Madhubani and Cooch Bihar districts information on arsenic in groundwater is scarce and in the Nepal Terai, most of the studies reported that 90% of the groundwater samples have As<10 μg/l.

Fluoride generally occurs at low concentration in groundwater and it is a common constituent of groundwater. High fluoride concentration is impacted by local geology and use of phosphate fertilizers. Other factors such as residence time in the aquifer impact fluoride concentration. Fluoride has significant dental benefits, however groundwater with fluoride content greater than 1.5 mg/l is not advisable for drinking as it can cause serious health issues. Information on fluoride in groundwater is very limited. Fluoride concentration in groundwater in Madhubani and Cooch Bihar districts are generally lower than the drinking water standards (F < 1.5mg/l). In Nepal Terai, data is not available and studies concentrated mostly on major ions, nutrients and some biological parameters in groundwater.

In addition to arsenic and fluoride, iron concentrations in groundwater was also assessed, since iron and arsenic occurrence are interrelated. Groundwater in the studied districts in India contain high iron concentrations which exceed desirable (Fe > 0.3 mg/l) or permissible (Fe > 1 mg/l) limits for drinking water standards. In Saptari iron concentration data was not available. Data scarcity is a major issue in the study districts. High iron contents observed in groundwater suggest that the aquifer is in anaerobic condition, which could favour reduction process and subsequent release of metals and metalloids to groundwater, especially arsenic if it is in the soil or aquifer sediment. Hence, further detailed studies are recommended. Results from various studies also do not correlate very well, which may be due to sampling methods, storage time, analysis procedures. A more detailed study is necessary as a basis for developing suitable groundwater management and mitigation of the arsenic and fluoride problems.

Weekly sampling of groundwater quality was undertaken at study sites, specifically targeting EC and pH, which can impact the yield and quality of crops and soil productivity. Water acidity also impacts fish production. The higher the EC, the less water is typically available to plants. If EC is <= 750 µS/cm there is no limitation, 750-1500µS/cm some limitation, 1501-3000 µS/cm moderate limitation, and >=3000µS/cm severe limitation for use for irrigation. The normal pH range for irrigation water is from 6.5-8.4. High pH's above 8.5 are often caused by high bicarbonate and carbonate concentration. The range of EC and pH recorded are shown in Table 14.

In general results showed that water quality was suitable for irrigation. Extremes in EC or pH were frequently found in open dug wells, which are sometimes used for disposal of rubbish.

Table 14: PH and Electric conductivity ranges in six intervention sites

	Saptari		Madhubani		West Bengal	
Parameter	Kanakpatti	Koiladi	Bhagwatipur	Mauahi	Dholaguri	UC
EC (µS/cm)	45-392	11-451	350-800	80-1150	51-381	47-1146
pH	6.5-10.5	6.5-12.2	7.0-8.0	6.0-8.0	4.4-10.0	4.5-10.1

7.4.3 Irrigation system performance assessment and improvements

Irrigation system performance, efficiency and scheduling are key to increase crop production and reduce input costs, especially pumping cost. A series of trials were conducted across the Nepal and India sites, working with advisors and farmers, to demonstrate how simple tests could help improve irrigation performance. Some examples are provided below.

Pumps

The dominant pump type in Madhubani and West Bengal intervention sites were 3-7 hp diesel driven, end suction, centrifugal pumps. In Saptari many farmers had access to electric pumps. Due to their light weight and portability, 5 hp capacity diesel pumps are most popular among the farming community. Smaller capacity (3 hp) pumps are generally used to pump water from ponds while higher capacity (5 hp) pumps are used to pump water from tubewells with greater discharge capacity. The pumps were typically poorly maintained.

Data on the average number of farmers served per pump indicated that in Bhagwatipur one pump served the needs of 13 farmers whereas in neighbouring Mauahi it was 39 farmers per pump. This highlights the pressure on irrigation pump sets and illustrates that frequently it is not possible for farmers to get access to pumps for irrigation.

Diesel Pumps

Diesel is a major input cost and pump efficiency is impacted by pump design, maintenance and operating factors. The impact of engine speed on volume of water pumped per litre of diesel used, an indicator of pumping and fuel efficiency, was demonstrated in each site. Figure 16 shows trends for four pumps in West Bengal. The arrows show the best engine speed point for each pump. Farmers and advisors were shown how to measure pump flow rate (using flowmeters and catch buckets) and diesel usage. The impact of operating engine speed and discharge pipe diameter on fuel consumption was discussed with farmers to encourage better operation. This simple test was able to identify the optimum engine speed for each pumping situation (combination of the pump, pipes, tubewell and aquifer). Results showed that pumping cost could be reduced by up to 30% simply by finding the optimum engine speed. Collective members were shown that running a pump at low speed was not necessarily the least expensive mode of operation.

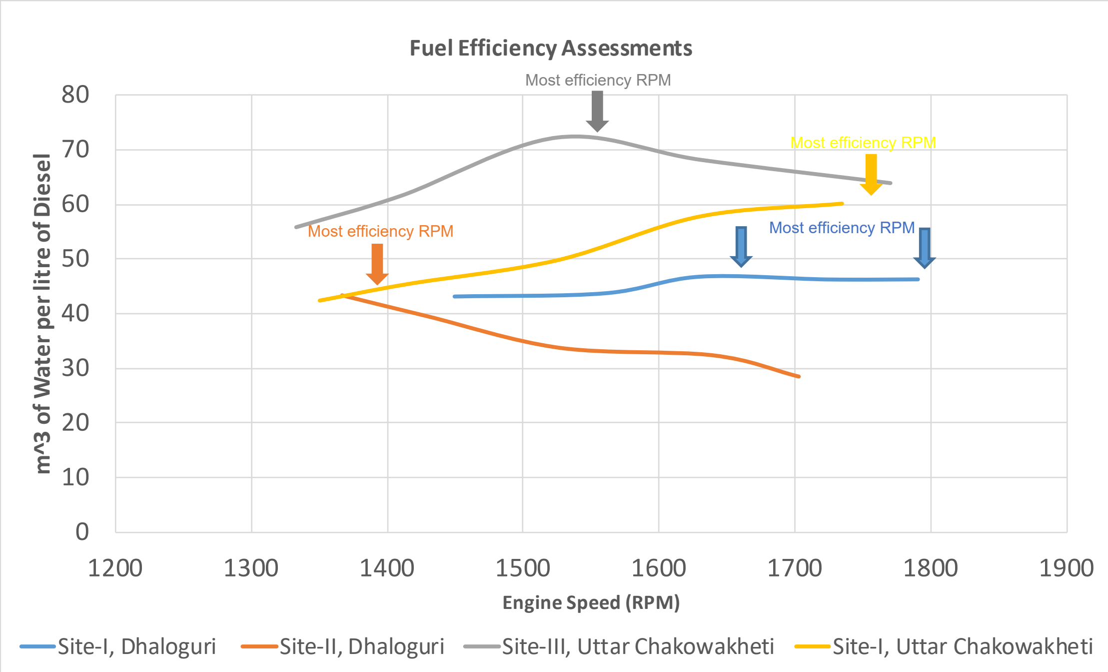


Figure 16: Diesel pump assessment in West Bengal.

Solar Pumps

Electricity and diesel prices, as well as the reliability of electricity supply, impact irrigation reliability and performance. Solar pumping has become an attractive option. Government programs and subsidies are supporting the roll out of these technologies. However, procedural difficulties constrain small and marginal farmers accessing such subsidies. Four 3hp (2.2 kW) solar systems were installed for two collectives in Dholaguri and Uttar Chakoakheti (West Bengal) respectively, while they were also provided to two collectives in Bhagwatipur (Madhubani). Small Sunflower pumps were also provided to the collectives in Saptari.

A number of tests were undertaken to evaluate the performance of solar systems in terms of voltage and current outputs, solar system efficiency, variation in discharge through the season and impact on water pumped and irrigable area.

Seasonal variation in day length and solar intensity impacts pump discharge, is illustrated in Figure 17 for a solar pump at Bhagwatipur. This is a limiting factor when required to irrigate over a 10-hour day, to meet crop water needs. The impact on water yield per day and resulting irrigable area is shown in Table 15. Based on 5 mm/day crop water requirement this equates to an irrigable area of 1.3ha in December and 2.4ha in June. The volume pumped and area served by the 3hp solar systems which typically pump 5l/sec over 5-8hours, is thus small compared to traditional diesel systems. Diesel systems pump 8-10 l/s over a 10hour day, equivalent to 288-360m^3/day and can serve an irrigation area of 5.8 – 7.2 ha. Installation of solar systems is also expensive (Rs 250,000) when compared to a diesel pump Rs 18,500.

The operating cost of a diesel system is however high. The annual cost of using a diesel pump to deliver the same volume of water as the solar system at Madhubani is approximately Rs 100,000. This assumes a solar system pumping 120m^3/day over 250 days, and a diesel pump with discharge (10 l/s) and operating cost of Rs120/hr. This equates to a 2.5-year payback. Further detail on the economics of solar vs diesel systems is given by Rahman (2019).

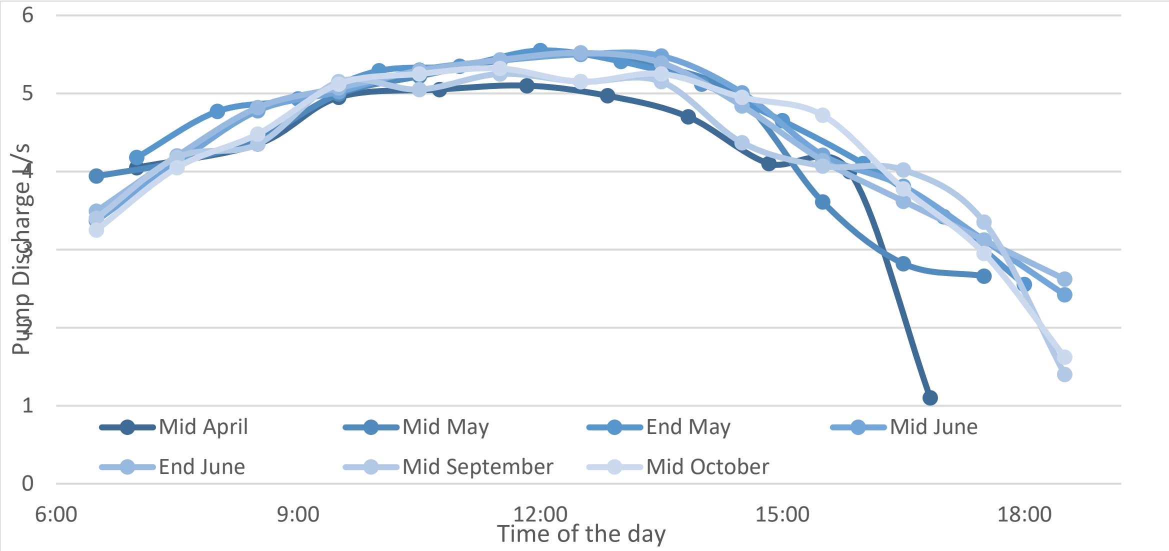


Figure 17: Change in solar pump discharge rate (l/s) between months and through the day.

Table 15: Water availability for dry season agriculture from solar pump

Water yield per day (m^3/day) from a solar pump on a cloud-free day				Irrigable area per day (ha/day) from a solar pump on a cloud-free day (based on 5 mm/day average application rate)			
Sep-Nov	Dec-Jan	Feb	Mar-Jun	Sep-Nov	Dec-Jan	Feb	Mar-Jun
120- 130	75-85	90-110	130-140	2.4 – 2.6	1.5 – 1.7	1.8 – 2.2	2.6 – 2.8

Conveyance efficiency

Water conveyance to fields in the region is typically via small, temporary earth channels. For large fields, farmers have constructed permanent channels that connect different plots. Earth channels have high seepage losses and reduce crop cultivation area. Flexible polythene pipes provide an alternative to earth channels.

Farmer collectives and advisors were shown how to compare the two conveyance methods and take flow readings at the pump and at the end of 100m of earthen channel (through a V-notch weir) and at the end of 100m of layflat polythene pipe on two plots. The irrigation water loss through an earth channel was compared with the reduction in discharge when using a polythene pipe (Table 16).

Table 16: Reduction in discharge at the field through earthen channel and polythene pipe (%)

Conveyance system	Flow rate at water source (l/s)	Flow rate at V-notch and at the end of 100 meter pipe (l/s)	Reduction in flow and conveyance efficiency (%)
Earthen open channel	5.7	3.0	2.7 L/s (53%)
Polythene pipe	5.7	5.1	0.6 L/s (89%)

Discharge was reduced by 2.7l/s when using an earthen channel (conveyance efficiency of 53%) and when layflat pipe was used, the additional backpressure placed on the pump by the restriction of the pipe, resulted in a reduction of only 0.6 l/s (conveyance efficiency of 89%). Results from Madhubani showed the saving in diesel pumping costs more than compensating for capital cost of the piping with a 2 year replacement.

This encouraged several groups to shift to using layflat pipes. Farmers usually use 300 ft rolls of 3” or 4” polythene pipe which costs approximately Rs.1600/- Rs.1900/-. Pipe is sometimes purchased collectively and can be resold as scrap at approximately 20% of the original price.

It was found that there is an increase in water delivery per litre of diesel fuel when using 4” pipe over a 3” pipe, due to reduced friction loss and pumping pressure. The benefit of using 4” hose ranged between 17% and 42% (Table 17) depending on the speed and discharge of the pump. Tests were conducted on a range of pumps under differing conditions

The trade-off between lay-flat hose and channel distribution system is the reduction in water loss when using piping, versus the increased pumping pressure when using piping. This pumping pressure can be reduced by increasing pipe diameter.

Table 17: Comparative study (3” and 4” delivery pipe)

Test No.	**RPM**	**Water Pumped with 1 litre diesel**		**Benefit of using 4” delivery hose**
		3” delivery pipe (300ft)	**4” delivery pipe (300ft)**	
Collective-II, Dholaguri (5 hp pump set)				
1	1600	32.96 M^3	38.59 M^3	17%
2	1500	34.67 M^3	42.31 M^3	21%
3	1400	34.88 M^3	43.09 M^3	24%
4	1300	35.41 M^3	50.54 M^3	42%

In field irrigation system performance

Drip irrigation is often considered to be a highly efficient method for irrigation, and most collectives engaged in vegetable cultivation piloted drip systems. However, if the irrigation system is not installed well and maintained, the performance and efficiency can be poor. The uniformity of water application in drip irrigated fields depends on several factors including operating pressure, extent of emitter clogging, system characteristics, lateral diameter and emitter spacing etc. In addition to system design factors, field topography and soil hydraulic properties are also important considerations. The status of uniformity of water application is generally assessed using uniformity coefficient. Irrigation systems with poor uniformity coefficient experience reduced yields due to localised water stress and/or water logging in various parts of the field (Solomon, 1993 and Clemmens and Solomon, 1997) and can lead to environmental impacts due to leaching of nutrients.

The coefficient of uniformity is the most commonly used indicator the performance of a drip irrigation system and is based on data collected in catch cans across the field (Ortega et al., 2002). Farmers helped collect field data to demonstrate the importance of good installation and maintenance of irrigation systems.

For example, the coefficient of uniformity was calculated for two consecutive years in the same experimental plot. The coefficient of uniformity fell from 91.5% to 80.7% between March 2017 and March 2018. For excellent functioning of drip systems the uniformity coefficient should be greater than 90% (Pitts,1997). The results illustrated the need to maintain drip irrigation systems, with a particular focus on filtration units and emitter clogging.

Sprinkler irrigation systems were also piloted through the project. In this instance the distribution uniformity (DU) was used since it is more commonly used when evaluating sprinkler system uniformity. Results at Madhubani showed an increase in DU of a sprinkler irrigation system from 78.6% in 2017 to 90.9% in 2018. The improvement was due to better operating pressure and favourable prevailing wind conditions during the assessment in 2018. Results helped farmers understand the impact of pump operating pressure and wind on droplet distribution.

7.4.4 Irrigation scheduling

Scheduling is important to optimise the timing and depth of irrigation, and supporting collectives with this was a priority. A number of tools and techniques were evaluated as summarised in Appendix 9. Mini evaporation pans proved useful to demonstrate seasonal changes in evaporation demand. Soil moisture sensors, including Chameleon sensors and tensiometers, helped demonstrate the change in moisture being drawn from different depths. Technical challenges limited the usefulness of these systems for marginal farmers.

Soil moisture budgeting, using FAO56 approaches, and the DSI Scheduler (Appendix 10) allowed integration of, weather, soil and crop information to guide irrigation timing and depth of application. The DSI Scheduler was also used as a storage hub and repository for seasonal irrigation data.

Crop evapotranspiration was computed from solar radiation, temperature, humidity and wind speed data for each site using FAO56 methods. Temperature loggers were installed in each village and other parameters were taken from regional weather sources or long term averages. Figure 18 shows the time series of daily maximum and minimum temperatures and the subsequent evapotranspiration rate in Bhagwatipur village. Where temperature data was missing, long term average data was used to fill gaps.

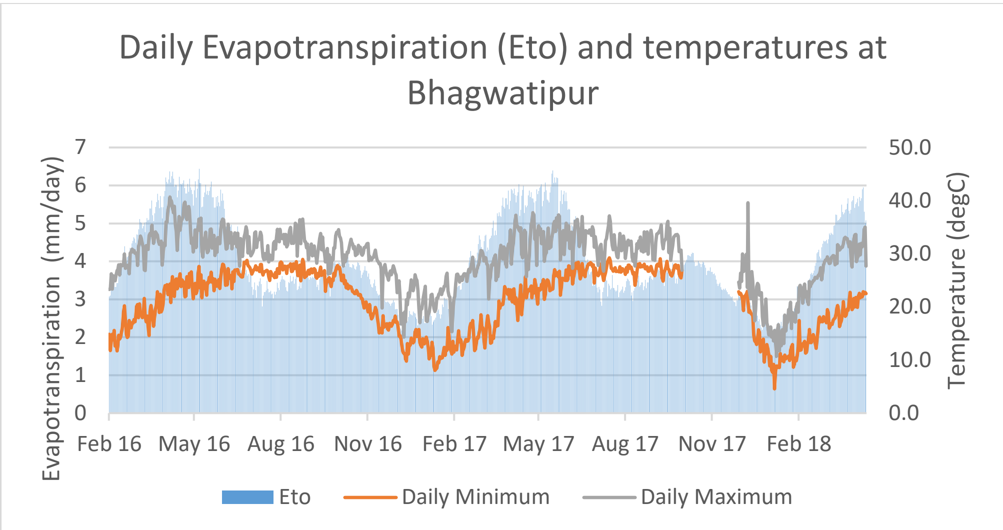


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Figure 18: Daily evapotranspiration and maximum and minimum temperatures at Bhagwatipur village

Figure 19 is an example soil water budget using the DSI Scheduler for field B2F04 (Bhagwatipur Site 2 Field 4). The green line shows the daily soil moisture balance in a wheat crop. The timing of the first irrigation (orange bar) is perfect, within one or two days of the soil moisture depleting to the refill point, an irrigation was applied. The volume of this irrigation was satisfactory (but not perfect, as it did not adequately refill the profile). The second irrigation however was too late and the crop would have been suffering from water stress. Unfortunately, this was compounded as the second irrigation was also insufficient in volume to refill the profile. Maintaining soil moisture is less important in the latter stages of growth for cereal crops where ripening and drying off is required and late rainfall (blue bars) would have had minimal effect on yield. Visualisation of the soil water balance helped interpret whether the timing and volume of irrigation was suitable to meet crop water requirement.

Figure 20 shows that irrigation was well managed for a brinjal (eggplant) crop on field B1F08. Soil moisture was maintained during the growing and fruiting phases of plant development, and then allowed to dry down towards harvest.

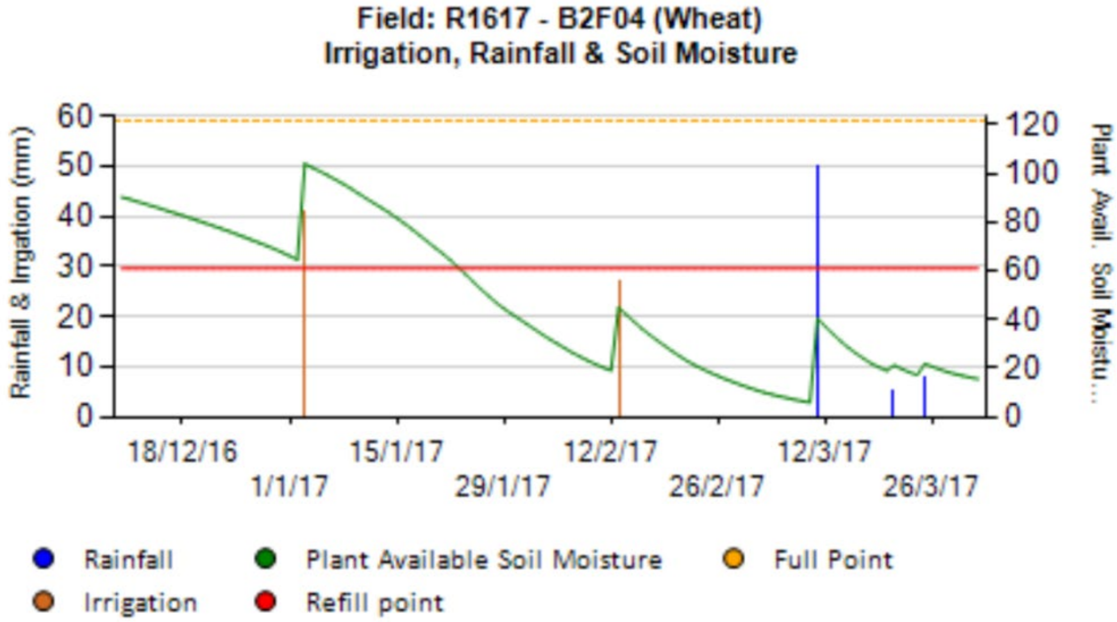

Figure 19: Example of DSI Scheduler soil moisture balance

Figure 21 shows for the same crop cumulative seasonal totals of potential evapotranspiration (ETc), modelled actual ETc (somewhat reduced as this crop was water stressed from late January until harvest) as well as accumulated in season rainfall and irrigation. The crop required 275 mm of water for optimum growth, however, insufficient irrigation created a water stress condition and the crop was only able to utilise 190 mm of moisture. The cumulative total for irrigation and effective rainfall was approximately 145 mm, which means that the crop was able to extract 45 mm of moisture from the soil profile.

The field scale water balance approach described was an important focus of the study and helped advise field staff and farmers, and improve irrigation management and scheduling decisions.

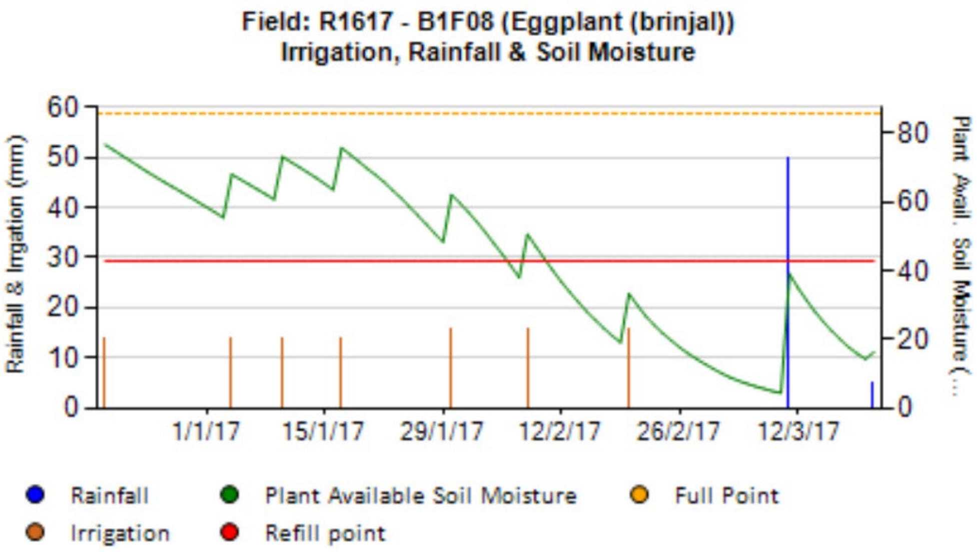

Figure 20: Individual field soil moisture graph, from DSI Scheduler, showing daily soil moisture, rainfall and irrigation applied.

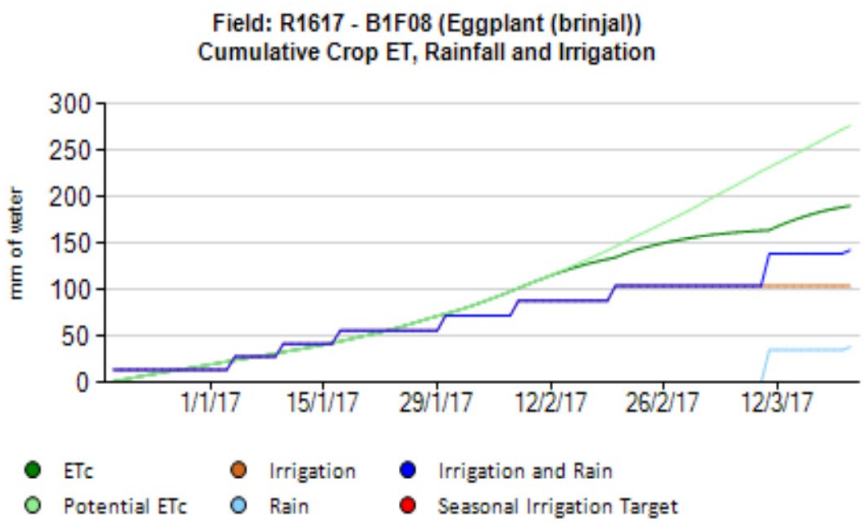

Figure 21: Individual field seasonal summary from DSI Scheduler showing total crop water requirement, irrigation applied and rainfall

7.4.5 Crop water requirement

The water balance approach also helped estimate the irrigation required to meet crop evapotranspiration, as illustrated in Table 18 for a range of crops in the 2016/2017 Rabi season. Red and green shading represents high and low irrigation requirement respectively. The Brinjal crop of B1F08 planted 20/12/2016 and harvested 21/03/17 required 275mm of water to meet potential evapotranspiration (see also Figure 21) of which 39mm was met by effective rainfall and 236mm was required through irrigation. Irrigation water requirements vary based on crop type and plant and harvest dates. For example the radish crop grown for just 55 days required only 135mm of irrigation. There is also a difference in crop water requirement between four wheat crops with a difference in planting dates of 3 weeks.

The water productivity (yield per unit of water), and the extent to which crop water requirements were actually met by irrigation were also determined. Figure 22 shows irrigation, rainfall and water productivity information for a selection of plots in Bhagwatipur for the Rabi 16/17 season. For the brinjal crop of field B1F08, a total of only 104mm irrigation was actually applied by farmers, well below 236mm required. The yield was only 52kg/ha with a low water productivity in terms of yield per cubic meters of water used by the crop.

This information could be used to explore broader trends. Daily soil moisture data was aligned into four growing stages 1) initial, 2) developing, 3) mid and 4) late. Daily soil moisture levels from each of the intervention sites over eight cropping seasons (Kharif 2015 – Rabi 17/18) totalling 1,638 individual crops were modelled to determine the time spent in a water stressed position for all crops (Figure 23**:**), potato only (Figure 24) and wheat only (Figure 25). A general trend was the tendency to over irrigate young crops and under irrigate mature crops.

Figure 23 shows that water stress became more common as the crop developed. Farmers were less likely to allow the crops to become water stressed at the early stages of development. This is likely because young plants require less water and farmers can more easily recognise water stress in young plants.

Figure 24 shows for potato similar trends (more water stress in the later stages of crop growth), however there was a higher proportion of crops stressed in the earlier stages of growth. This is likely due to potato being a newly introduced crop in Bihar and Saptari (potato is very common in West Bengal) and new farmers may not have developed a good understanding of crop water requirements and were not able to recognise signs of crop stress in the early stages.

Figure 25 shows for that water management for wheat crops was relatively good. There were no crops that were water stressed in the initial stages of growth and the extent of water stress in the developing stage is also quite low, but high in mid and late growth stages.

Table 18: Irrigation requirement as a function of total crop water requirement and effective rainfall

Site	Crop	Plant date	Harvest date	Evapotranspiration ETc (mm)	Effective in crop rainfall (mm)	Irrigation required (mm)
B1	Peas	14/12/2016	7/03/2017	251	0	251
B1	Radish	3/11/2016	28/12/2016	135	0	135
B1	Brinjal	20/12/2016	21/03/2017	275	39	236
B4	Brinjal	15/12/2016	1/04/2017	345	44	301
B1	Spinach	14/12/2016	20/02/2017	162	0	162
B4	Spinach	15/12/2016	10/03/2017	240	0	240
B1	Wheat	14/12/2016	1/04/2017	345	44	301
B2	Wheat	6/12/2016	1/04/2017	360	44	316
B3	Wheat	24/11/2016	1/04/2017	390	44	346
B4	Wheat	19/12/2016	28/04/2017	395	51	344
B1	Potato	4/11/2016	4/02/2017	220	0	220
B2	Potato	12/11/2016	6/02/2017	190	0	190
B3	Potato	20/11/2016	5/02/2017	175	0	175
B4	Potato	8/11/2016	4/02/2017	210	0	210
B1	Luffa Gourd	20/12/2016	1/04/2017	305	44	261
B2	Lentil	8/11/2016	5/03/2017	280	0	280
B3	Lentil	5/12/2016	18/03/2017	270	35	235

DSI4MTF Scheduler

R1617 - B1	Detailed Report	18 March 2019

This report provides a summary of data inputs and results for Fields R1617 - B1F06, R1617 - B1F07, R1617 - B1F08, R1617 - B1F12, R1617 - B1F13, R1617 - B1F17 and R1617 - B1F20 at R1617 - B1 located near Bhagwatipur (Bihar, India).

Yield and Irrigation Summary

Field	Crop	Rain gauge used	Soil	Plant Available Water (mm)	Refill Point (% PAW, mm)	Plant Date	Harvest Date	Yield (/ha)	Water Productivity (kg/m3)	Total In-season Rain (mm)	Effective Rain (mm)	Total Irrig. Applied (mm)
R1617 - B1F06	Peas	Bhagwatipur	Sandy Loam	72	50 (36mm)	14/12/2016	07/03/2017	4915 kg	9.1	0	0	0
R1617 - B1F07	Radish	Bhagwatipur	Sandy Loam	36	50 (18mm)	03/11/2016	28/12/2016	6906 kg	25.6	0	0	0
R1617 - B1F08	Eggplant (brinjal)	Bhagwatipur	Sandy Loam	85.5	50 (43mm)	20/12/2016	21/03/2017	52 kg	0.03	55	39	104
R1617 - B1F12	Spinach	Bhagwatipur	Sandy Loam	36	50 (18mm)	14/12/2016	20/02/2017	1934 kg	3.79	0	0	24
R1617 - B1F13	Wheat	Bhagwatipur	Sandy Loam	121.5	50 (61mm)	14/12/2016	01/04/2017	2051 kg	1.14	63	44	59
R1617 - B1F17	Potato	Bhagwatipur	Sandy Loam	45	50 (22mm)	04/11/2016	04/02/2017	11713 kg	12.1	0	0	63
R1617 - B1F20	Gourd (luffa)	Bhagwatipur	Sandy Loam	72	50 (36mm)	20/12/2016	01/04/2017	0 kg	0	63	44	84

Notes

Plant Available Water - the amount of water (mm) that is available in the plant root zone.

Refill point - user defined point at which irrigation should be applied i.e. 20% means that the user is willing to allow 20% of the soil moisture to be removed before applying irrigation.

Water Productivity - units of production per m3 of crop evapotraspiration.

Total In-season rainfall - cumulative total of all rainfall between plant and harvest dates.

Effective rainfall - the amount of rainfall that enters the root zone and is available for the plant to use.

Figure 22: DSI scheduler was used to interpret water productivity kg yield per m^3 water used by the crop (effective rainfall, plus applied irrigation, plus extracted soil moisture).

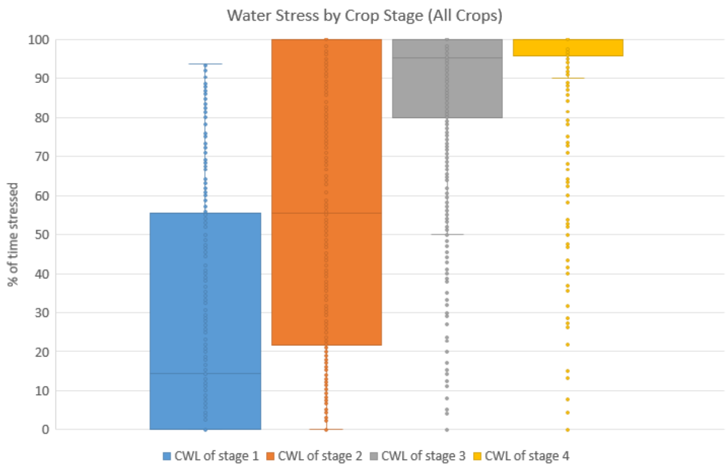

Figure 23: Percentage of time that each crop was water stressed (all crops)

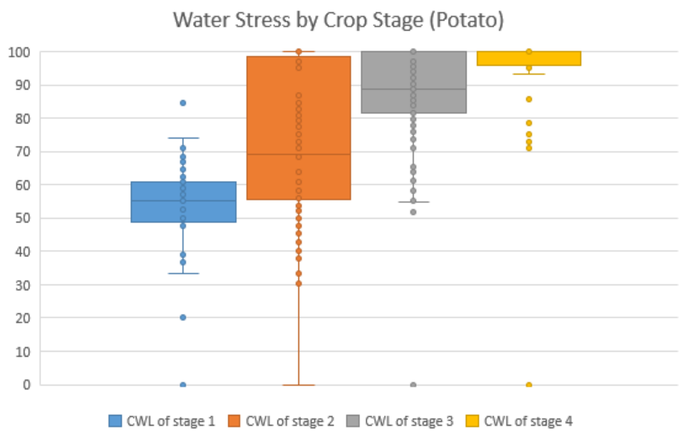

Figure 24: Percentage of time that each crop was water stressed (Potato)

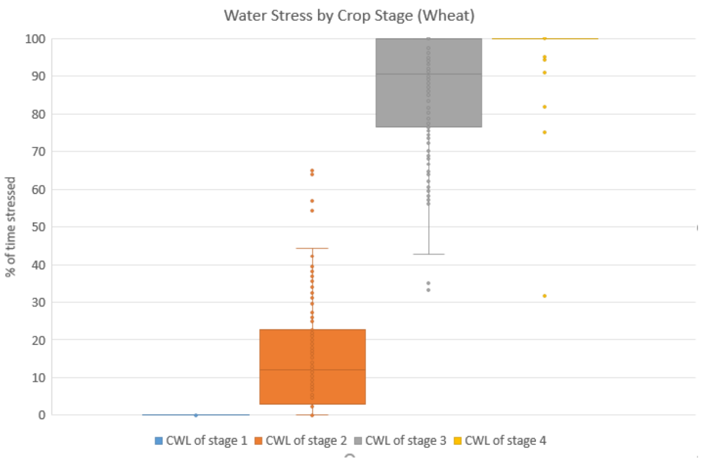

Figure 25: Percentage of time that each crop was water stressed (Wheat)

The water balance approach has helped improve the understanding of crop water requirements across different crops, growth stages and seasons, which is important to manage irrigation scheduling to meet crop water requirements and maximise crop and water productivity.

7.4.6 Economic analysis of collective farming and technological approaches for dry season agriculture (India and Nepal)

Following the establishment of the farmer collectives, seasonal plot surveys were undertaken for monsoon (Kharif), winter (Rabi) and Summer crops, over the period 2015-2019. Data included crop type, area planted, field input costs (agri-inputs, labour and machinery), yield and income. Since marginal farmers were providing data for small plots, there is large margin for error, however reliable broad trends are evident.

Profitability is not the only driver for these communities. Improved nutrition, family tradition and self-empowerment are key benefits from diversified farming practices. Crop choice is often about cultural preferences, past experience, risk aversion, market limitations, local consumption needs, as well as labour and input cost requirements.

Cropping Intensity

Cropping intensity in Nepal and India sites, prior to the project, ranged between 100% and 120% and increased following introduction of a range of dry season crops through collectives (Table 19) to more than 200% across Madhubani sites, between 136% and 229% in Saptari sites and between 136% and 205% in West Bengal sites (Table 20).

Table 19: Dry season crops introduced following project commencement

Location	Winter Rabi Crops Introduced	Summer Crops Introduced
Madhubani	Peas, potato, radish, cauliflower, spinach, lentil and wheat,	Chilli, cowpea, cucumber, brinjal, gourd, ladyfinger and moong bean.
Saptari	Cabbage, cauliflower, garlic, onion, brinjal, tomato, potato, radish, coriander and lentil.	Chilli, cucumber, bitter gourd, ladyfinger, pumpkin, zucchini, cowpea, maize, and moong bean.
West Bengal	Rapeseed(mustard), wheat, maize, potato, tomato, cabbage, lentil, garlic, chilli	Jute, brinjal, gourd, cucumber, beans, taro, elephant foot yam

Table 20: Average crop intensity for project sites across three seasons.

Madhubani					
B1	B2	B3	B4	M1	
238%	212%	225%	248%	214%	
Saptari					
K1	K2	KH1	KH2	KH3	
220%	136%	184%	187%	229%	
West Bengal					
D1	D2	D3	UC1	UC2	UC3
205%	143%	136%	187%	142%	116%

Notwithstanding crop intensification and diversification, production areas and volumes were small, limiting market access and bargaining power. In many cases production by groups was diverted first for home consumption, benefiting household nutrition. There was significant movement between crops and across seasons in response to changing farming and market conditions. Collective members selected crops in consultation with project staff and adapted to a number of challenges, including, pest and disease incursions, access to water, high irrigation costs, labour availability, low market prices, poor market access and poor yields due to early monsoon rainfall.

Yields

Crop yield was highly variable across the 380 plots farmed by the collectives, impacted by many factors, including timing of planting and harvest, weather conditions, timing of irrigation, pest and diseases and fertilizer management (Table 21). Rice and wheat yields were in line with the national India average yield of 2.5 t/ha (rice) and 3.0 t/ha (wheat) and Nepal 3.3t/ha (rice) and 2.5t/ha (wheat). Vegetable yields were highly variable depending on the management skills and degree of input use. In many cases, group members still operate with a subsistence mindset and there is potential to increase yields further with improved agronomy, production systems and inputs.

Table 21: Typical yield of selected crops (t/ha)

Crop	Madhubani	Saptari	West Bengal
Rice	2.0-4.0	3.0-4.0	2.0-5.0
Wheat	2.5-3.5	2.2-2.6	1.8-3.5
Lentil	0.6-0.8		
Moongbean	0.3-0.4		
Cowpea	2.3-3.0		
Bittergourd	1.5-3.5	2.0-2.5	
Tomato		9.0-11.0	9.0-15.0
Okra	3.0-6.0	2.5-2.9	
Chilli			
Maize		2.2-2.7	2.0-4.5
Zuchini		7.0-9.0	
Jute			2.0-2.8
Mustard		0.7-0.9	0.6-1.1

Market prices

As indicated above, profitability was impacted by poor local knowledge of product marketing, volatile prices, poor market price information and low prices paid by vendors (intermediary). For example in Madhubani vegetable prices during 2017 were between 30% and 60% lower than in 2016. High prices for early season vegetable crops in 2016, resulted in expansion in 2017, which was sold at depressed prices, due to oversupply. Prices obtained at local markets were often much higher than paid by vendors to farmers. In 2017, Bitter gourd prices at the market was Rs 30-60/kg compared to the Rs14/kg paid to farmers. Vendors paid Rs12/kg for ladyfinger, which sold at the local market for Rs30-40/kg. In Madhubani, only people of low socio-economic status and caste traditionally sell at the market, and farmers were not initially prepared to engage in direct selling for this reason. This has changed as farmers see the potential to maximize profit by bypassing vendors.

In Saptari prices paid to farmers also varied within and between seasons (Table 22). Prices for tomato, potato and mustard from three local markets near project villages and at Kathmandu demonstrate volatility (Figure 26). Local project staff collect market price data using a Market Rate App developed for the project. This information can assist farmers in market selection and price negotiation. Similar high variability in selling price, between and within seasons, occurred in Dholaguri and Uttar Chakoakheti.

Table 22: Typical prices paid to farmers in Saptari (NPR/kg)

Season	Zucchini	Mustard	Potato	Tomato	Wheat	Rice
16/17	25-30	100	20	10-40	27-105	20
17/18	20	80	20-40	30	25-75	18

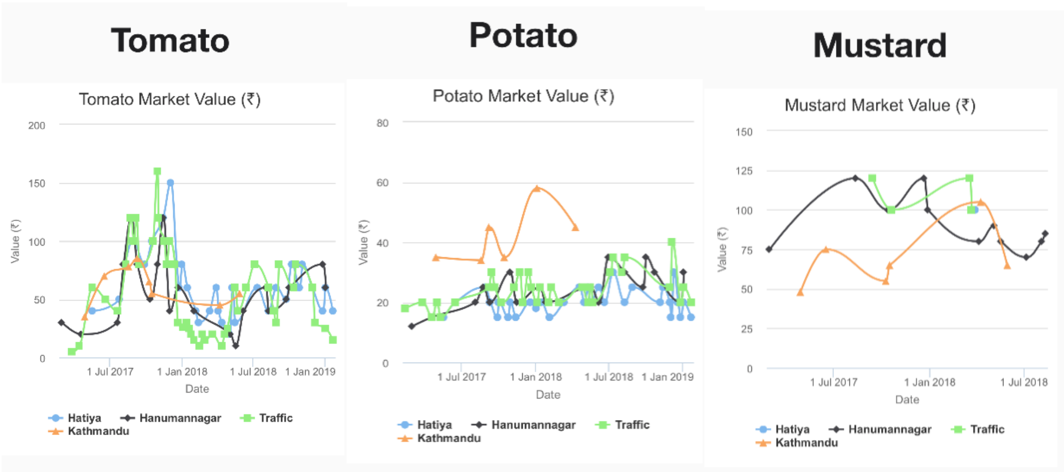

Figure 26: Market prices collected at local villages using the Market Rate App

Production costs

Profitability can be improved by reducing input costs, while maintaining productivity. The contribution of agri-inputs (seed, fertiliser, pesticide), labour, and machinery (primarily land preparation and irrigation equipment) to total production costs is provided in Table 23. For Madhubani sites, agri-inputs represent 39% of input costs, labour 33% and machinery 28%. This varied between seasons. For rice production in Kharif season labour was the most significant cost.

In Saptari and West Bengal the proportion of costs attributable to labour were high in both summer, under labour intensive vegetable production, and in Khariff season, under rice production. For dry season vegetable crops, agri-inputs become an important cost component. Machinery was generally the lowest contributor to cost of production owing to low level of mechanisation.

Table 23: Percentage of input costs attributable to agri-inputs, labour and machinery.

	Madhubani		
	Agri-Inputs	Labour	Machinery
Summer Season	39%	28%	33%
Kharif Season	31%	46%	23%
Rabi Season	49%	17%	34%
Combined Seasons	39%	33%	29%
	Saptari		
Summer Season	30%	57%	13%
Kharif Season	25%	55%	20%
Rabi Season	47%	35%	18%
Combined Seasons	33%	50%	18%
	West Bengal		
Summer Season	12%	57%	31%
Kharif Season	13%	68%	19%
Rabi Season	56%	32%	11%
Combined Seasons	35%	47%	18%

Economic returns

Table 24 shows seasonal income, expenditure and gross margin (Rs/ha or NPR/ha) for combined sites in Madhubani, Saptari and West Bengal. Profit margin (gross margin as percentage (%) of income), is also indicated.

Profit margin typically ranged between 20% and 60%. There was large variability, between sites and seasons, driven by the complex mix of crops, seasonal productivity and market price.

For example, profit margin ranged between 8% and 41% in Madhubani. In Saptari, profit margin ranged between 30% and 59%, and was highest in Rabi season and lowest in kharif season. There was also a reduction in gross margin per hectare in summer season between 2016 and 2017.

In West Bengal, the negative profit margin in summer 2016 was due to large loss in summer paddy in Dholaguri, whereas in Uttar Chakoakheti, where only jute was grown, there were significant profits of 43-54%. In subsequent summer seasons, only jute was grown in Dholaguri, which was highly profitable due to its stable return over the last few years. Rabi 2017-18 was profitable in both villages however in Rabi 2016-17 farmers faced a loss due to poor farm gate price of potato in both villages and low price of wheat and mustard in Uttar Chakoakheti.

Table 24: Income, expenditure and gross margin (Rs/ha or NPR/ha)

Saptari				
Seasons	Income (NPR/ha)	Expenditure (NPR/ha)	Margin (NPR/ha)	%
1.1 Summer 16	140,507	82,922	57,585	41%
1.2 Kharif 16	101,914	67,259	34,655	34%
1.3 Rabi 16/17	130,929	53,563	77,366	59%
2.1 Summer 17	74,689	49,691	24,998	33%
2.2 Kharif 17	83,364	58,120	25,244	30%
2.3 Rabi 17/18	122,949	49,931	73,018	59%
Madhubani				
Season	Income (Rs/ha)	Expenditure (Rs/ha)	Margin (Rs/ha)	%
1.1 - Summer 16	13,206	12,201	1,006	8%
1.2 - Khariff 16	45,798	34,830	10,968	24%
1.3 - Rabi 16-17	43,823	25,712	18,111	41%
2.1 - Summer 17	14,525	10,983	3,542	24%
2.2 - Khariff 17	46,820	35,818	11,002	23%
2.3 - Rabi 17-18	40,369	27,028	13,341	33%
West Bengal				
Season	Income (Rs/ha)	Expenditure (Rs/ha)	Margin (Rs/ha)	%
1.1 - Summer 16	100,243	-101,399	-1,156	-1%
1.3 - Rabi 16-17	50,776	-70,539	-19,764	-39%
2.1 - Summer 17	82,157	-45,304	36,853	45%
2.2 - Khariff 17	52,752	-32,299	20,453	39%
2.3 - Rabi 17-18	92,582	-58,361	34,221	37%
3.1 - Summer 18	83,387	-37,634	45,754	55%
3.2 - Khariff 18	50,067	-35,325	14,742	29%

The introduction of dry season irrigated vegetables has shown potential to improve financial return, food security and nutrition. For example at Dholaguri in West Bengal profit margin for vegetables ranged between 17% and 67% (Table 25).

Table 25: Vegetable productivity and profitability in West Bengal

Dholaguri **Crop**	**Yield (kg/ha)**	**Cost of cultivation** **(Rs./ha)**	**Gross income (Rs./ha)**	**Net return (Rs./ha)**	**Profit margin (%)**
Tomato	14655	60785	73275	12490	17%
Cabbage	17385	52495	78233	25738	32%
Chilli	6525	45820	110925	65105	58%
Taro	9085	45295	136275	90980	67%
Elephant Foot Yam	8780	64385	193160	128775	67%
Uttar Chakoakheti **Crop**	**Yield (kg/ha)**	**Cost of cultivation (Rs/ha)**	**Gross income (Rs/ha)**	**Net return (Rs/ha)**	**Profit margin (%)**
Tomato	9600	56100	43200	-12900	-29%
Brinjal	9452	78500	113424	34924	31%

Some crops such as Elephant Foot Yam had high input cost but yielded highest return 67%. Crops like cabbage and tomato have high biomass production but lower return, 32% and 17% respectively. Chilli provided a return of 58% off a low cost of cultivation. Experience differs across sites. Yields of crops in Uttar Chakoakheti, where farmers have had less experience in vegetable production, were lower and while Brinjal was profitable tomato had a negative return.

Profit margin for crops between 2016-2019 in Madhubani, was generally above 25% and was positive for all crops except chili and sponge gourd due to poor yield (Figure 27). Profit margin for crops from 2016-2018 in Saptari, was generally above positive and in many cases exceeded 40%, but was negative for okra, maize and lentil (Figure 28). In part improvements may reflect the collectives improving their cultivation techniques over time, although other changes were likely connected to price and climatic-ecological factors.

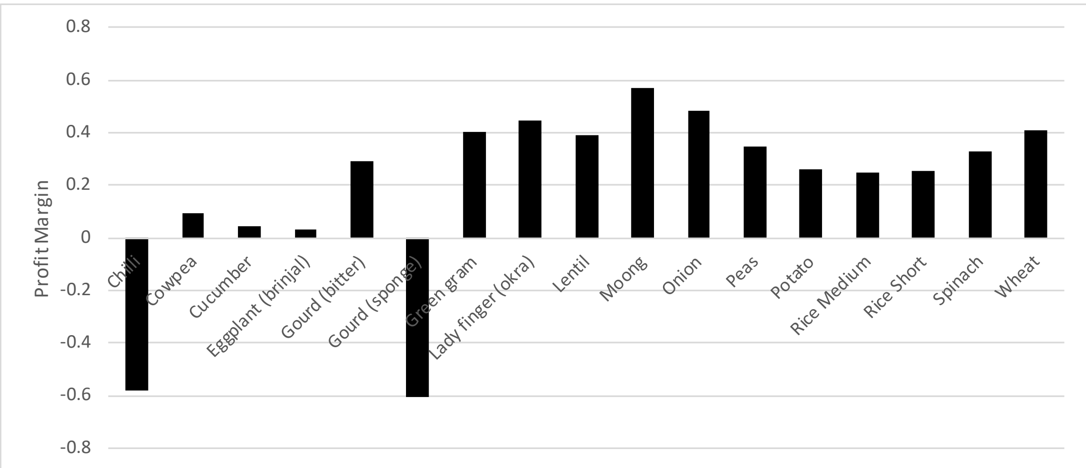

Figure 27: Aggregate profitability for 17 crops from 2016-2019 in Madhubani

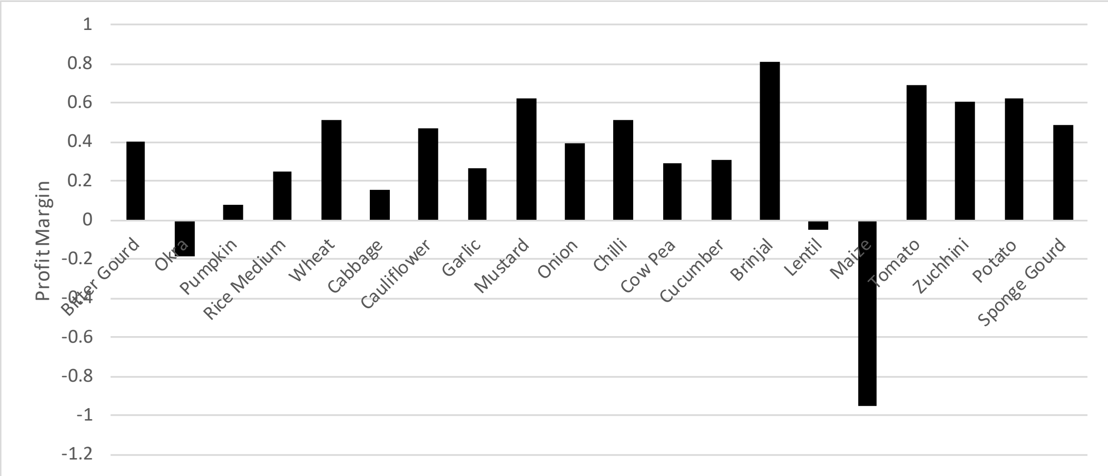

Figure 28: Aggregate profitability for 20 crops from 2016-2018 in Saptari

Improving production systems

Introduction of short duration paddy

In West Bengal, medium-long duration rice varieties such as MTU 7029 are traditionally grown, taking 145-155 days to mature, which delays sowing of the Rabi crops. A new drought and disease resistant variety Anjali with shorter days to maturity was introduced to the collectives in both Dholaguri and Uttar Chakoakheti. Despite generally lower yield, Anjali matured earlier, allowing early sowing of Rabi vegetable crops which farmers preferred. Previously farmers had to harvest jute early to free land for rice planting. With Anjali, jute could be grown to full term with an early Rabi planting.

Zero tillage in wheat and mustard

Poor productivity of wheat and mustard in West Bengal is sometimes attributed to delay in sowing, due to preceding medium and long duration rice varieties, and difficulty in tilling wet soil conditions. Zero till (ZT) was introduced to the groups for wheat/mustard, allowing early seeding into residual moisture. Productivity can increase with ZT, as it is possible to sow the crop in mid to end November (15 to 20 days earlier) in rice fields, without any land preparation. Localized placement of fertilizers and chemical weed control in ZT drilled crops helps further towards better performance. During Rabi, 2016-17 farmers introduced zero tillage wheat in Dholaguri and in Rabi, 2017-18, wheat and rapeseed-mustard in Uttar Chakoakheti, using zero tillage technology.

In wheat, productivity levels were encouraging and the cost of cultivation was reduced significantly. Zero till helped to advance the sowing time by 2 weeks, which had a direct influence on crop performance. Herbicide usage replaced manual weeding, which reduced cultivation cost. The benefit-cost ratio increased from 0.67 to 1.15 when conventional tillage was replaced by zero till. Zero till also had a positive impact on mustard production, with a benefit-cost of 1.98. In some cases, a poor crop stand was achieved under zero till mustard due to excessive depth in seed placement. Notwithstanding this crop failure, farmers showed resilience, and continued zero till successfully, due to labour cost savings, timeliness and reduced irrigation water requirements.

Liming in Jute

Jute is a major pre-Kharif crop of the village Uttar Chakoakheti and Dholaguri, however productivity has been low owing to the occurrence of the stem rot pathogen (*Macrophominaphaseolina*). Soil acidity is one of the pre-disposing factors of stem rot, which is aggravated by high pre-monsoon showers and high humidity, which cause rapid multiplication of the pathogen. Liming at 2.5 t/ha for correction of soil acidity resulted in reduction in the infestation of stem rot pathogen by between 42% and 47% and increase in yield between 6% and 43%.

Introducing new technologies

Protected production houses

Two polyhouses having dimensions of 12m x 4m (48m^2) were constructed in each of Dholaguri and Uttar Chakoakheti, in West Bengal, and both were handed over to women's collectives to manage. The polyhouses comprised a bamboo pole structure covered with 200 micron UV stabilized polyethylene sheeting and 50% agro-shade netting, with a cost of Rs 18,000 for each structure. Protected housing provides a controlled micro environment, with enhanced production, water savings through drip irrigation, and production of high value crops, all year with premium quality and market prices. Crops included cucumber, capsicum, coriander, cauliflower and spinach.

It took time for farmers to become acquainted with these production facilities. An initial cucumber crop failed. Thereafter good returns were found in out of season vegetables. The benefit/cost ratio (net return divided by cost of production) was found highest for Coriander leaf (10.6 to 12.8 respectively) and lowest in Capsicum (6.2 to 3.9). Efficient water savings, high yields and selling price were key drivers for these successes.

Damage due to high winds occurred at one site in Uttar Chakoakheti highlighting that robust design is critical. Farmers in Dholaguri have subsequently self-financed additional structures based on their positive experiences.

Solar pumping – economic considerations

A range of irrigation technologies were demonstrated amongst selected collectives in India and Nepal, as discussed in section 7.4.3. Technologies included diesel, electric and solar pumps, sprinkler and drip irrigation systems, conveyance piping as well as micro irrigation in protected production houses mentioned above.

Electricity and diesel prices, as well as the reliability of electricity supply, impact irrigation. Solar pumping has thus become an attractive option. Government programs and subsidies are supporting the roll out of these technologies. However, procedural difficulties constrain small and marginal farmers availing such subsidies.

Results from fourteen solar system assessments in Saptari which were outside the project, showed that solar pumps need to be operated at a system capacity utilisation factor (CUF) of greater than 45% (>700hrs in Saptari) to be competitive with a diesel pump (Renewable World (2018) Report No 20). The CUF represents the amount of time the solar system is used for irrigation, as a percentage of potential pumping time (a function of day light hours and bright sunshine days), and is used as an indicator of solar system viability. The CUF would need to be 90% to be competitive with an electric pump. The payback of a solar system in Saptari would be 4 years when compared to a diesel system when the CUF is 70%.

In Saptari high capital cost solar systems hinder uptake and for small scale farmers it is difficult to access subsidies. While solar systems do not require much maintenance, service centres are more remote and less accessible. The study showed that 80% of farmers surveyed used solar systems for inefficient surface irrigation (paddy and furrow) and only 20% for drip irrigation. Thirty percent of farmers using solar pumps were irrigating only traditional rice crops while 70% had introduced vegetables in the dry season.

Figure 29 shows the cost per unit water for solar, diesel and electric pumps in Saptari. There is a high cost per unit water pumped, at low volumes for solar systems, given high capital cost. This cost per unit water pumped reduces quickly as utilisation increases based on limited operating costs. Electric and diesel systems have relatively high operating costs, low capital cost, and a flatter cost curve.

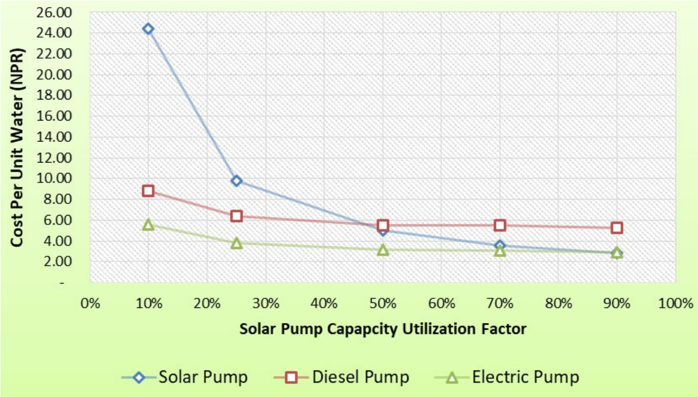

Figure 29: Cost per unit water for different pumping technologies

To maximise the benefits of solar pump systems, cropping patterns need to be optimised to introduce high value (high production and good market price), water efficient crops, using efficient irrigation technologies such as drip, sprinkler or well managed short furrow systems.

For the Saptari collectives, a number of small sunflower pumps were introduced. These have only 80 W capacity and deliver 0.3l/s for a 5m water table depth. The capital cost is low, only NPRs 50-000 to NPRs 60,000, and farmers are successfully irrigating small areas of vegetables using drum kit drip irrigation systems or short furrows.

While savings in diesel pump operating costs justify investment in solar pumps by collectives, a key consideration is the CUF and ability to generate and pay back the high capital cost. This is linked to the area irrigated, cropping intensity through the year, value of crop produced, and efficiency with which water is applied to the crop.

For example in Madhubani the project invested $21,800 in irrigation infrastructure across the four sites of total area 5.5ha. The annual gross margin for the combined sites over period 2016-2018 was $3,384, which suggests a 6.5-year payback on equipment. Payback varied between sites depending on specific infrastructure, costs and profits. Subsidies on solar pump systems, up to 80% in India, further improve economics. To achieve a commercial return on solar systems, the area cropped must be maximised with efficient irrigation systems, achieving good yields, coupled with high value crops.

7.4.7 Interactive tools for improved water management

Mobile phones, particularly internet-connected smartphones are efficient tools for sending and receiving information in the field. Simple interfaces can capture data, process it and/or instantaneously send it to cloud databases for processing and storage. These tools reduced the time delay for data transfer, from the field to the office, and potential transcription errors.

The project successfully developed a range of prototype tools to assist the project staff to capture field data and display results to farmers and advisors. Some of the tools provide one-way transfer of data, to support field staff to collect and send information from field sites. Others provided quick calculations and direct feedback to a query, with no data storage. The remainder were a combination, capturing information and performing calculations and sending data to a cloud database to build a time series dataset for analysis of trends, and help in assessing future scenarios.

Appendix 7 provides more detail on the decision support tools, which are listed in Table 26 with a brief explanation of their function. Figure 30 illustrates the Cropping calendar tool which provides a scenario based assessment of the potential cropping rotations in a given year.

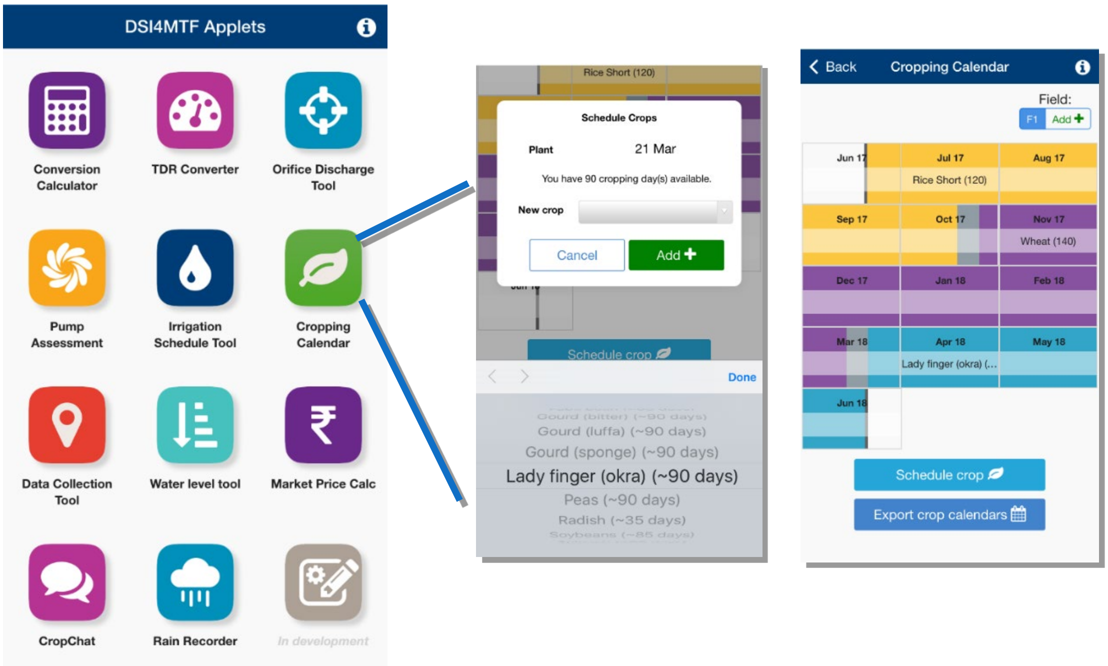

Figure 30: Example of one of the DSI Applets (Cropping Calendar)

Table 26: Listing and function of the DSI Applets.

Tool	Function
Conversion Calculator	Converts units of area, weight and currency from SI/ Australian/US units to local measurements and currencies
TDR Converter	Converts the millivolt reading from a MP406 probe into volumetric soil moisture based on a calibration curve
Orifice Discharge Tool	Calculated the flow rate from a pump using a velocity head and the orifice equation
Pump Assessment Tool	Calculates the cost of pumping (Rupees per kL). Captures assessment data and compare one scenario with another
DSI Scheduler	Uses FAO56 methodology to calculate an irrigation schedule. Also records rainfall and irrigation applied
Cropping Calendar	Scenario based assessment to determine the potential cropping rotations in a given year
DSI Data Collection Tool	GIS data collection of fields and monitoring locations (ponds, tubewells) for real time relay to cloud database
Water Level Tool	Simple tool for capturing real time pond and tubewell levels and water quality data
Market Price Calculator	Allows users to collect data and watch produce market prices at the nearest 4 markets
Rainfall Recorder	Simple tool for the collection of site specific rainfall
Crop Chat	Forum for discussing agronomy and irrigation technical problems between the field and the advisors

7.5 Irrigated Agriculture in the North West region of Bangladesh

7.5.1 Background

Bangladesh has seen remarkable agricultural development over the last few decades and gained self-sufficiency in rice production. Production of rice has increased from 11.6 million tonnes (152 kg/capita) in 1977 to 34.7 million tonnes (222 kg/capita) in 2016. There has also been significant increase in production of other crops such as wheat, maize, vegetables and fruits. The overall cropping intensity for the country has increased from

149% in 1977 to 190% in 2012 (BBS, 2018) with an increasing proportion of land, being double- or triple- cropped. Agriculture has been a leading contributor to poverty reduction in Bangladesh since 2000 (World Bank, 2016).

This growth in intensity was driven by increased cultivation during the dry season, made possible through phenomenal growth in irrigation over the last 3 decades. Total irrigated area has increased from 1.52 million ha in 1983 (18% of the net cultivable area) to 5.4 million ha in 2013, (63% of the net cultivable area). This growth was driven by rapid increase in the adoption of shallow tubewells and groundwater supplies 80% of the total irrigated area.

The northwest region has the most intensive use of groundwater; over 97% of the total area is irrigated (2012-13) by groundwater. The region produces 34% of the country's total rice, 60% of the total wheat, and more than two-thirds of the total production of potato and maize. This region is considered the food basket of Bangladesh. In recent years, there have been serious concerns about the sustainability of groundwater use in the northwest region. Many studies (Samsudduha et al., 2009; Rahman and Mahbub, 2012; Aziz et al., 2015) show that groundwater levels are falling and that the use of shallow aquifers for irrigation in the area is unsustainable.

Due to the concerns of the sustainability of groundwater use, the Government of Bangladesh intends to decrease dependence on groundwater by increasing use of surface water for irrigation (Government of Bangladesh, 2010), increase productivity of water and also reduce pumping through crop diversification; replacing Boro rice with other non-rice crops particularly wheat (Government of Bangladesh, 2010).

Northwest region is part of the Eastern Gangetic Plains (broadly, Bihar and northern West Bengal in India, the Terai in Nepal and Northwest Bangladesh) within the Ganges Basin. Eastern Gangetic Plains are believed to have significant potential for intensification of agricultural production and to offer underutilised opportunities to improve livelihoods of smallholder farmers. Northwest Bangladesh has been more successful in tapping into this potential than the biophysically similar neighbouring states in India, and Nepal Terai (Kirby et al. 2013) which raises the question about the nature of social and institutional constraints to rural development holding back smallholders in India and Nepal.

The objective of this study was to provide a historical and current state (productivity, economic cost and benefit, irrigation water use, etc.) of irrigated agriculture of the northwest region of Bangladesh. This was done through analysing the historical trends in area, production and yield of the major crops grown in the region, historical trend in the development of groundwater irrigation and intensive monitoring of the groundwater irrigation by STW and DTW in 7 selected locations across the region. In addition, the project demonstrated to the farmers and provided training for efficient irrigation practices such as alternate wetting and drying (AWD), use of polythene pipe for irrigation water delivery, effective water management in the field, and introduction of recent high yielding varieties (HYV) of rice to increase productivity.

7.5.2 Methodology

For historical trend analysis, district scale data was collected on crop area, yield, production, and irrigated area of the major crops available from the Bangladesh Bureau of Statistics (BBS) and Bangladesh Agricultural Development Corporation (BADC) in the region covering 1980 to 2015. The project selected 22 shallow tubewells, STW (6 operated by electric motor and the rest operated by diesel engine) and 6 deep tubewell, DTWs (electric motor operated). The study focussed on six sites (Tanore, Ishurdi, Sherpur, Mithapukur, Kaharol, and Thakurgaon) in the districts of Rajshahi, Pabna, Bogura, Rangpur, Dinajpur and Thakurgaon. Rajshahi and Thakurgaon were DTW sites. All plots under the command area of the STWs were monitored. For the DTW, the command area of 3 outlets in each DTW was selected for monitoring and data collection. In the 2016-17 crop season, the Tanore and Dinajpur sites were discarded and a site in

Badarganj in Rangpur district was added. Irrigation in Badarganj is through solar powered tubewell. Nine STW (3 electric, 6 diesel) were monitored in 3 sites (Ishrudi, Sherpur, and Mithapukur). Details are given in Appendix 13.

Experiments were established to evaluate technological interventions like polythene pipe distribution systems for reducing conveyance loss, alternate wetting and drying (AWD) system for reducing field scale water supply and adoption of HYV Boro rice for improving land productivity in 4 selected sites (Ishrudi, Sherpur, Mithapukur and Thakurgaon) during 2016-17 and 2017-18. This provided some crop and water management training for improving the crop and water use.

All field activities were recorded, including name of the farmer, ownership, area in decimal, cropping patterns, years of cultivation, land type, soil type, crop grown, date of seeding, date of transplanting, date of flowering etc. Input used (amount of seed, fertilizers, herbicides, pesticides, irrigation, labourer etc.), costs and revenue, and output achieved (crop and biomass) in the cultivation were also recorded. The discharge of the irrigation units was measured during the initial, middle and later part of crop growing season. The discharge rate and irrigation time of the specific period was used to calculate amount of irrigation water applied in each irrigation.

7.5.3 Observations, results and discussion

Detail results are given in the companion report by Mainuddin et al. (2019), Report No. 18 and Maniruzzaman et al. (2019), Report No. 23. Rice is the predominant crop grown in all sites. Of the total 336 plots monitored in 2015-16, rice was cultivated in 235 plots (35.05 ha). Wheat, maize, potato, lentil, mustard, cauliflower and okra are grown in the remaining 101 plots (13.05 ha) across six sites. Approximately 27% of the total area was under non-rice crops in 2015-16. In 2016-17, 195 plots were monitored in these 5 locations (26.15 ha) of which only 10 (1.54 ha) were with crops other than rice.

Historical trend in irrigation

There was phenomenal growth in irrigation development over the last 3 decades. According to the Minor Irrigation Survey Report prepared by BADC under the Ministry of Agriculture, total irrigated area has increased from 1.52 million ha in 1983 (18% of the net cultivable area) to 5.45 million ha in 2015 (61% of the net cultivable area) (Figure 31). This growth was driven by the i use of groundwater through rapid increase in the adoption of STWs as shown in Figure 31. The number of STWs has increased from 93 thousand to 1.55 million during this period. The number of deep tubewells (DTWs), which also pump groundwater, has increased from about 14,000 to about 37,000. There was almost no growth in use of surface water for irrigation (0.9 million ha in 1983 to 1.22 million ha in 2015. Currently, about 80% of the total area (4.22 million ha) is irrigated using groundwater sources.

Irrigation, more specifically groundwater irrigation, is not uniform over the whole country. Northwest region is the most intensively irrigated area of the country. Currently, 83% of the net cultivable area (NCA) is irrigated in the northwest region compared to the 61% at the country level. Despite having 30% of the NCA area of the country, the region has more than 40% of the total irrigated area. Of the irrigated area 97% is irrigated with groundwater (Figure 32). On average, there are more than 28 STW and 1 DTW per 100 ha of cultivable area of the region.

There are serious concerns about the sustainability of groundwater use, particularly in the Barind area (western part of the northwest region). Shamsudduha et al. (2009), Jahan et al. (2010), Rahman and Mahbub (2012), Qureshi et al. (2015), and Hasanuzzaman et al. (2017) show that groundwater levels are falling in the Barind Tract and that current abstraction is unsustainable. Shamsudduha et al. (2009), Kirby et al. (2015, 2016) and MacDonald et al. (2016), conclude that the use of shallow aquifers for irrigation in some areas, particularly in the Barind tract is unsustainable.

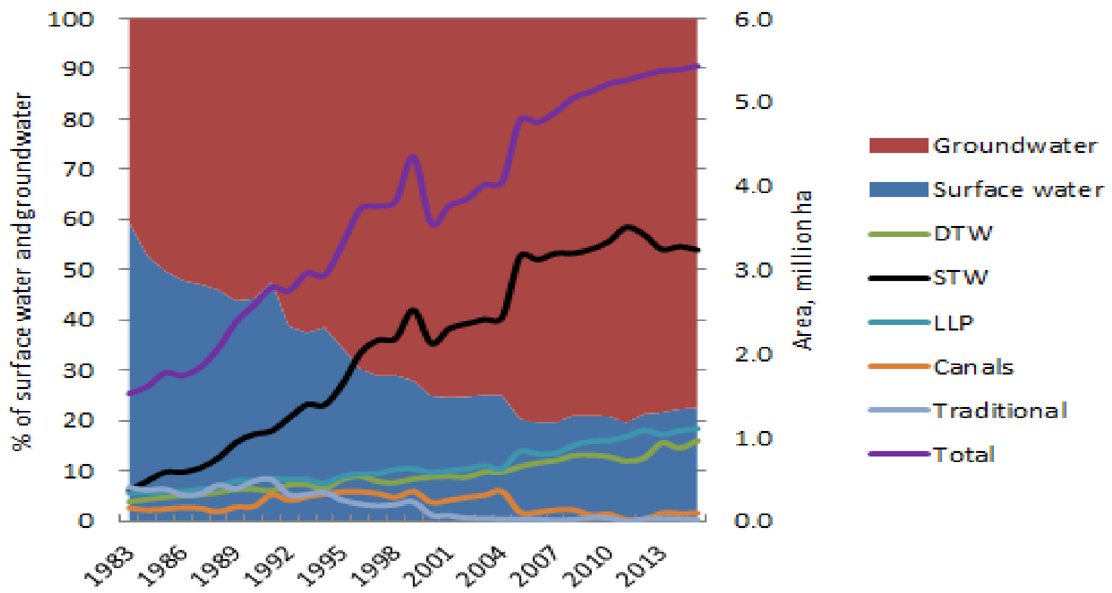

Figure 31: Area irrigated by different technology and source of water in Bangladesh (data source: BADC data)

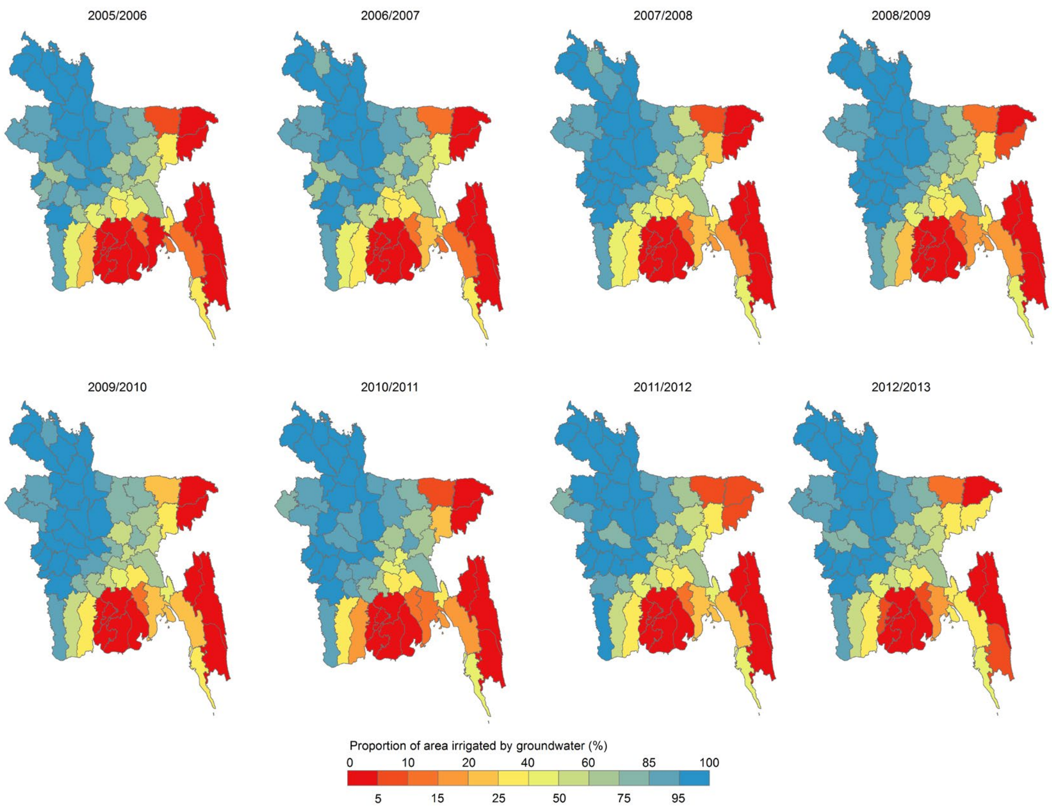

Figure 32: Proportion of net cultivable area (NCA) irrigated by groundwater during 2005–06 to 2012–13 (data source: BADC)

Cost, benefit and yield of rice and other crops

Six different rice varieties were grown in the sites. They are Hybrid rice, BRRI dhan28, BRRI dhan29, *Minikit*, *Kajallata* and *Jirashail*. BRRI dhan28 and BRRI dhan29 are the dominant varieties (about 50% of the plots). It is clear that certain varieties are dominant in certain locations. Farmers consider many factors such as local climatic conditions, total duration, market condition, availability of the seed, crops grown before or after rice, prospective net economic benefit, etc. while choosing a variety to cultivate. Transplanting of rice started in late December and is completed by the end of February in 2015-16. Most of the plots (81%) were transplanted during the period of 16 January to 15 February. In 2016-17, 93% of the plots were transplanted during this period.

Figure 33 shows the variation in total paid-out costs of different input categories per ha for the plots monitored for the crop years 2015-16 and 2016-17. There is significant variation in the total paid-out cost from location to location. Average irrigation cost was 16,459 Taka/ha in 2015-16, which represents higher proportion (23%) of total, paid-out (TPC). This is followed by the harvesting (crop cutting, transporting and threshing) cost (e.g., 22%) and fertilizer cost (17%) of TPC.

Total cost, gross benefit and gross income varies due to location, type of tubewells and varieties of rice cultivated (Table 27). Total cost, gross benefit, and gross income significantly differ among the locations, types of pumps used for irrigation and varieties of rice.

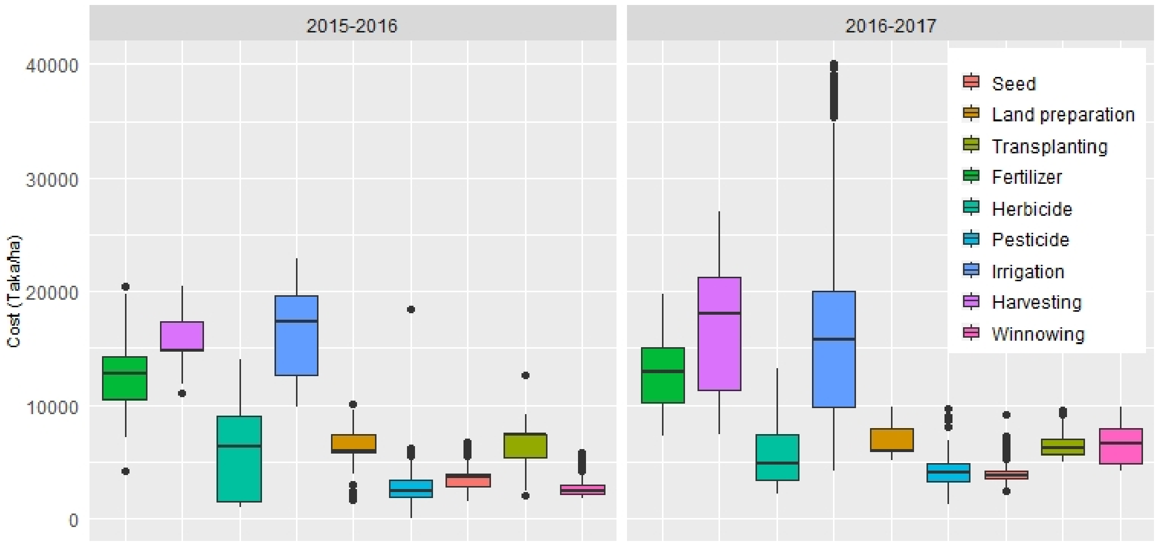

Figure 33: Variation of total paid-out cost for different inputs for growing rice

There are significant variations in the average yield of rice due to location, and the varieties cultivated as shown in Table 27. This variation is mainly due to the variation in cultivation of different varieties at different locations. The potential yield of rice is different for different varieties. Hybrid rice has the highest potential yield, followed by BRRI dhan29, BRRI dhan28 and other varieties (Minikit, Kajallata, and Jirashail). Among the varieties, in 2015-16, the average yield was highest (7.39 tonne/ha) for Hybrid rice, followed by BRRI dhan29 (6.72 tonne/ha), and BRRI dhan28 (6.14 tonne/ha). According to BRRI (*Adhunik Dhaner Chas*), the average expected yield of BRRI dhan29 and BRRI dhan28 are 7.5 and 6.0 tonne/ha respectvely. The average yield achieved in these plots was very close to the expected yield. In general, there is a decreasing trend in yield with the delay in transplanting for BRRI dhan28 and BRRI dhan29. The age of seedlings is also a factor in the yield of rice. It seems the higher the age of seedlings, the lower is the yield for BRRI dhan28 and BRRI dhan29.

Table 27: Number of plots, and mean of land area, yield, cost and profit for the plots by location, varieties and pump type

Item	2015-16					2016-17				
	No. of plots	Yield tonne/ha	Total paid out cost, Taka/ha	Gross benefit Taka/ha	Gross income, Taka/ha	No. of plots	Yield tonne/ha	Total paid out cost, Taka/ha	Gross benefit Taka/ha	Gross income, Taka/ha
Location										
Ishurdi	50	6.55	79,532	102,981	23,449	39	6.99	105,436	174,092	68,656
Kaharol	24	5.93	61,174	78,169	16,995					
Mithapukur	69	6.92	70,134	96,982	26,848	62	5.50	78,821	134,762	55,941
Sherpur	52	5.00	69,588	93,387	23,799	46	4.43	79,646	109,574	29,927
Tanore	22	5.04	76,373	106,663	30,290					
Thakurgaon	18	7.24	77,940	108,833	30,893	18	6.70	67,222	138,154	70,932
Badarganj						20	6.29	68,029	129,741	61,713
Pump type										
STW-Electric motor	80	6.62	70,975	107,640	25,317	74	6.11	90,558	152,923	62,365
STW-Diesel engine	115	5.89	71,519	96,291	23,000	73	5.00	81,662	121,492	39,830
DTW-electric	40	6.03	77,078	94,519	30,561	18	6.70	67,030	138,154	71,124
Solar power						20	6.29	68,029	129,741	61,713
Variety										
BRRI dhan28	57	6.14	66,559	88,074	21,515	48	5.33	74,468	125,903	51,435
BRRI dhan29	61	6.72	78,231	103,949	25,717	43	6.81	84,429	151,708	67,278
Hybrid	43	7.39	72,582	100,344	27,762	28	6.06	78,836	143,397	64,561
Jirashail	22	5.04	76,373	106,663	30,290					
Kajallata	21	4.87	71,880	91,076	19,196					
Minikit	31	5.09	68,034	94,952	26,918	66	5.18	88,154	131,223	43,068
Date of transplanting										
January	107	5.87	72,780	97,219	24,439	60	5.35	86,416	131,612	45,196
February first	104	6.49	73,683	100,579	26,896	113	5.92	80,831	138,965	58,134
February last	24	6.05	63,971	83,995	20,025	12	6.18	70,624	139,218	68,593

Of the non-rice crops, maize, wheat and potato were the dominant crops in the monitored sites. The average total paid-out cost of production, gross benefit and gross income gained from the cultivation of rice, maize and potato are compared in Figure 34. Compared to rice, total cost, gross benefit and gross income for potato were 59%, 128%, and 326% higher, respectively in 2015-16. In 2016-17, these were 6, 46, and 106% higher. Potato is the most profitable with higher investment (much higher in 2015-16 compared to rice) followed by maize (57,957 Taka/ha and 86,859 Taka/ha, respectively for 2015-16 and 2016-17), and rice (25,076 Taka/ha and 54,254 Taka/ha). Wheat was cultivated in 2015-16 season. Most of the plots had very low yield due to the outbreak of blast disease. The gross income was very low; in fact, some farmers were not even able to recover the cost. Though potato has much higher gross income than rice and maize, the risk of growing potato may be higher.

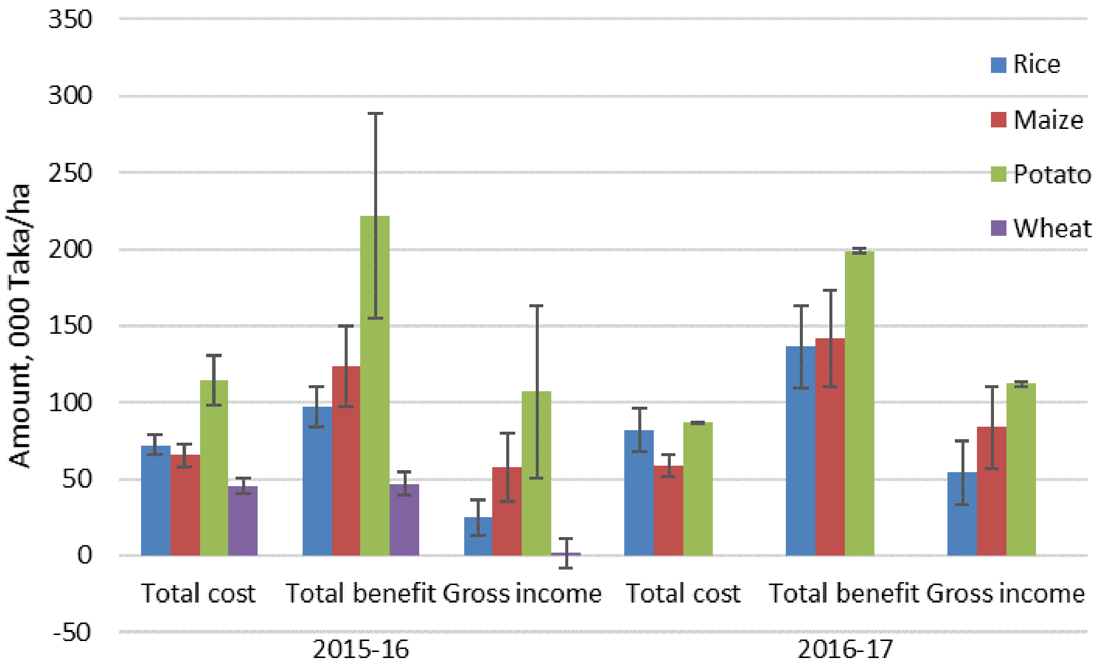

Figure 34: Total paid out cost (total cost), total benefit and gross income of rice for 2015-16 and 2016-17

Irrigation water requirements and use

Irrigation water requirement of rice varies due to its geographical locations, climate variations, soil properties, varieties of rice cultivated, and the time of transplanting. To compare the irrigation water supply with the requirements for full yield potential, the irrigation water requirements for rice at different planting dates for all sites were determined using a soil water balance model. Figure 35 compares the average water supplied and the estimated requirement. In 2015-16, actual supply was less in all plots compared to the estimated requirements in Ishurdi (-23%). In Sherpur and Kaharol, actual supply was very close (-2%) to the estimated requirements; in some plots water supply was slightly higher and, in the others, actual supply was slightly lower. In the other three sites (Mithapukur, Thakurgaon, and Tanore) actual water supply was considerably higher (60%, 37%, and 36%, respectively) in all plots compared to the estimated requirements. In 2016-17, actual water supply was reasonably close to the estimated requirements in Mithapukur (7%), Sherpur (4%) and Badarganj (3%) (Figures 35). Water supply was higher in Ishurdi (36%), and Thakurgaon (57%).

There is general perception that farmers apply excessive irrigation water (http://www.ipsnews.net/2018/12/farmers-bangladesh-waste-800-liters-water-produce-1-kg-paddy/, Rahman, 2018). The results of this study do not support that perception at least for the STW area. For the STW irrigated area the results suggest that farmers are very careful and wise in applying water in the field. There are some over application in the DTW areas, however, the scale of over irrigation is not as high as perceived.

Figure 36 shows irrigation water supplied to the plot to produce one kg of rice (unhusked) for all the plots for the years 2015-16 and 2016-17. No plot used 3,000 lit or more water. As shown in Figure 35, the average water used to produce one kg of rice less than half of 3,000 litre. So, the general perception of overuse of water to the extent of 3,000 to 5,000 lit to produce a kg of rice is nowhere near the reality in the field for groundwater irrigation. As we discussed earlier, due to high price of water, reduced availability, and experience of the farmers, farmers are very wise in supplying water to the field. Over the years, the yield of rice increased linearly (Mainuddin et al. 2015) while the actual water supply may have been reduced which is also a contributing factor in the lower water use for producing rice.

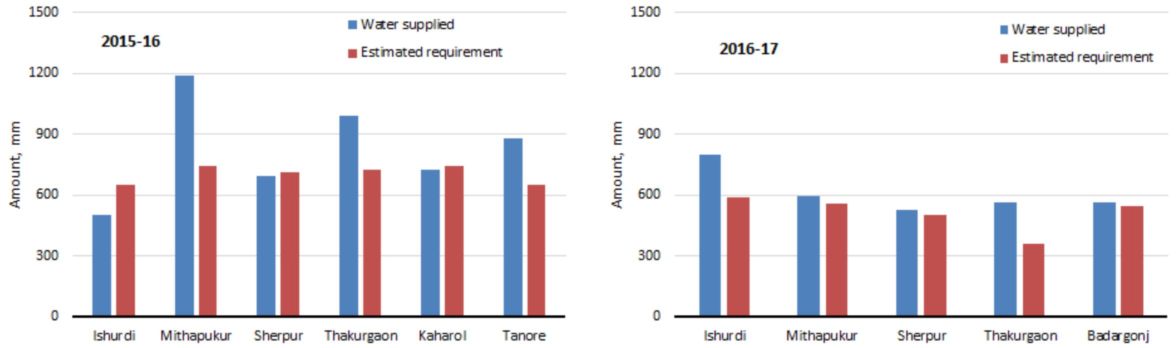

Figure 35: Comparison of average irrigation supplied and requirements for rice at different locations

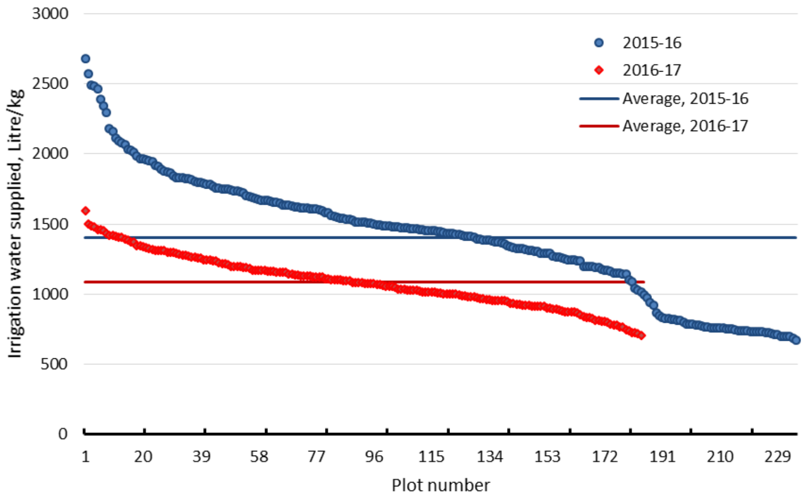

Figure 36: Irrigation water supplied to grow a kilogram of rice

Not all water supplied to the rice field is actually consumed by the plants. Evapotranspiration is the real loss from the field. Seepage from one field goes to others and used by plants. Rice fields are contiguous, separated by narrow and low height bunds. At the single plot level, seepage in and out of the field more or less balances each other. Only the plots at the edges of the whole area may lose some water to the adjacent ditches or used by the plants and trees along the roads.

Percolation from the rice field is not really consumed by the plants and is not lost from the system. Percolation returns to the aquifer as recharge. Irrigation water is extracted from the aquifer below the field in the northwest region in the dry season. Decline in groundwater creates space for recharge during the monsoon months. Percolation from the rice field recharges the aquifer in the dry season. Withdrawal of water is more than the recharge to the aquifer by percolation, and is not visible in the water level hydrographs. Without that recharge, water level would have dropped further below that observed. Percolation could be loss from the system if water is pumped from other sources (such as rivers) for irrigation in an area where groundwater is not used due to some limitations (such as unsuitable water, saline aquifer, extraction of water not economically viable). This is not the case in the groundwater irrigation system of the Eastern Gangetic Plains.

Actual water used to produce rice is the actual evapotranspiration during the cropping period. In 2015-16, maximum potential evapotranspiration was 545 mm for BRRI dhan29. In that year lowest yield of BRRI dhan29 was 4.76 tonne/ha. The actual water used to produce 1 kg of rice was 873 litre. In 2016-17, maximum potential crop evapotranspiration was 497 mm for BRRI dhan29 and the lowest yield was 6.68 tonne/ha; requiring 1,344 lit of water to grow a kg of rice. These results clearly indicate that the perception of actual water use (potential crop evapotranspiration) or water supplied to the field to grow 1 kg of rice is far from the reality in the field.

Figure 37 compares the economic water productivity of rice, maize and potato (4 major crops grown in the region) for 2015-16 and 2016-17. The economic water productivity of rice was significantly lower than that of maize and potato .In 2016-17, economic water productivity of potato was several fold higher than that in 2015-16 due to higher production, higher price and less amount of water used.

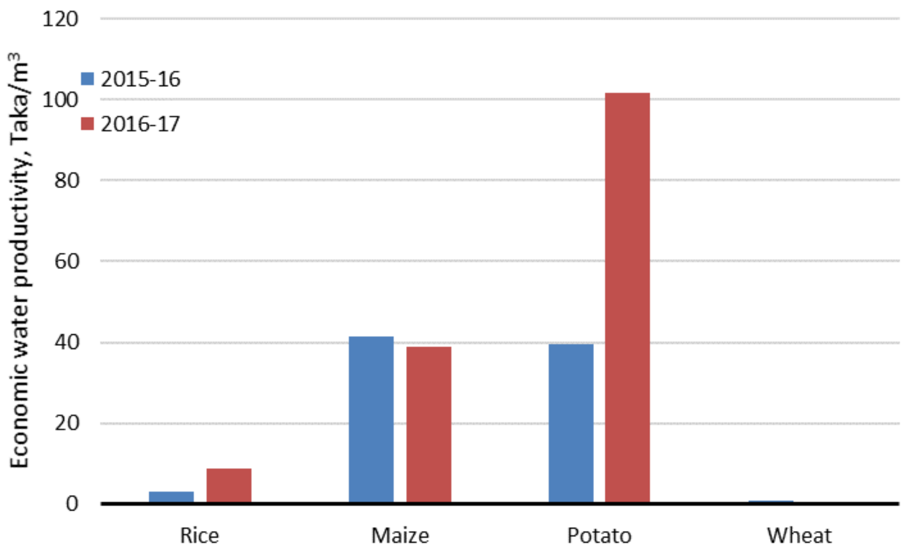

Figure 37: Comparison of economic water productivity of rice, maize, potato and wheat

7.5.4 Technological interventions for reducing irrigation cost

The amount of irrigation water required if conveyed by polythene pipe compared to earthen canal varied from location to location depending on the soil texture (Table 28). The study results indicated that use of polythene pipe reduces irrigation water pumping and consequently reduce the pumping cost. Sen et al. (2018) conducted a study on the irrigation water losses in earthen canal and found that under natural condition earthen canal conveyance losses varied from 35-40%. Hossain et al. (2016) and Maniruzzaman et al. (2000) showed that plastic pipe distribution system successfully minimized 92 – 95% of water loss that occurred in earthen canal.

The time of irrigation requirement per unit area (decimal) up to certain depth of irrigation was varied from location to location based on soil type and discharge of the pumps as shown in Table 28. This clearly shows that polythene pipe irrigation water distribution system not only reduce pumping of irrigation water but also irrigation time compared to the earthen canal. The reduction in irrigation time as well as amount of irrigation water also helped to reduce the irrigation cost.

The results (Table 29) from the AWD experiments shows that the amount of irrigation water applied was less in AWD plots than the plots with farmers' practice (FP). AWD is reported to reduce water inputs by 23% (Bouman and Tuong, 2001) compared to continuously flooded rice systems. Djaman et al. (2018) reported that the AWD irrigation management at -30 kPa resulted in increasing rice yield, rice water use and nitrogen use efficiency and reducing the irrigation applications by 27.3% in comparison with continuous flooding. Carrijo et at. (2017) also reported that mild AWD or field water level did not drop below 15 cm from the soil surface, yields were not significantly reduced in most circumstances and the water supply reduction was about 23.4% relative to continuous flooding. The reduction of irrigation by AWD practice has saved time of pump operation. This ultimately saves fuel for pump operation which has contribution in reducing greenhouse gas emission.

Table 28: Irrigation water and application time reduction by polythene pipe compared to earthen canal water distribution system at different STWs during Boro seasons of 2016-17 and 2017-18.

Location	Water supplied (mm)		Reduction in water supply (%)	Irrigation time (min/decimal)		Reduction in water supply (%)
	Earthen canal	Polythene pipe		Earthen canal	Polythene pipe	
2016-17						
Pabna	847	719	15	19.8	16.7	15
Bogura	515	408	21	34.2	27.1	21
Rangpur	641	502	22	38.3	30.2	21
Mean	**633**	**507**	**20**	**33.8**	**26.9**	**20**
STD	**137**	**123**	**2.6**	**7.6**	**2.3**	**2.7**
2017-18						
Pabna	659	481	27	15.0	10.9	27
Bogura	574	456	20	25.8	20.7	20
Rangpur	752	554	26	46.0	33.5	27
Mean	**698**	**520**	**25**	**35.8**	**26.4**	**25**
STD	**118**	**71.7**	**3.5**	**16.6**	**11.4**	**3.9**

Table 29: Reduction in water supply by AWD method over farmers practice (FP) in different locations during Boro seasons 2016-17 and 2017-18

Location	Irrigation applied (mm)		Rainfall received (mm)	Total water used (mm)		Reduction in water application by AWD (%)
	FP	AWD		FP	AWD	
2016-17						
Pabna	812	635	328	1,066	890	22
Bogura	398	338	196	594	534	15
Rangpur	756	635	377	1,133	1,012	17
Thakurgaon	651	541	202	853	743	17
Mean	**660**	**542**	**268**	**936**	**818**	**18**
STD	**180**	**141**	**94**	**245**	**212**	**4.4**
2017-18						
Pabna	813	716	244	1,057	960	12
Bogura	623	526	202	825	728	15
Rangpur	794	665	243	1,117	989	16
Thakurgaon	568	491	134	702	625	13
Mean	**708**	**609**	**227**	**935**	**836**	**14**
STD	**116**	**105**	**85**	**177**	**160**	**2.7**

Considering reduction in water supply and pump discharge by AWD, approximately 12 liters diesel fuel was saved per hectare of land irrigation. For the polythene pipe water distribution system diesel fuel saving was 32 liters/ha. The combined effect of polythene pipe and AWD water management, per hectare reduction in fuel use was about 44 liters, which is equivalent to 440 kg CO_2 emission (Haque et al., 2017). AWD irrigation was very effective to reduce (23-36%) seasonal CH_4 flux compared to continuous flooding (Hossain et al., 2019).

7.5.5 Conclusion and key messages

Northwest Bangladesh is the most intensively cultivated region of the country. The average cropping intensity in 2012 was 205% compared to the national average of 190%. The average yield of rice is higher in the NW region. Area under Boro rice has been stable over the last few years, while the maize area has increased rapidly mostly at the expense of other non-rice crops.

Groundwater is the main driver of the phenomenal growth of irrigation and productivity. Currently, 83% of the net cultivable area is irrigated in the northwest region compared to the 61.2% nationally. In the northwest region, 97% of the total irrigated area is irrigated by groundwater. Groundwater levels are falling in some regions below the suction limit of shallow tubewell pumps.

Initial drivers for the change in cropping system was availability of irrigation and improved research, training and extension services. Expansion in maize and other crops is mostly driven by market demand, availability of water, risk (e.g. climate, disease, market), economic profit and price fluctuation, and adoption of commercial farming systems.

Total cost, gross benefit and gross income varies and is impacted by type of pump used, and varieties of rice and transplanting dates. Cost of irrigation was as high as 35% of the total production cost of rice. Average cost was 25% in 2015-16, and 20% in 2016-17. Different price models (e.g. area based, fixed charge based on area plus diesel by the farmer, crop sharing, etc.) are used.

There is a significant variation in yield between location and varieties. Hybrid rice and BRRI dhan29 produced higher yield. Variation in yield is less in BRRI dhan29. For own consumption it could be better to grow hybrid rice or BR-29 as the yield is higher. Jirashail, Minikit, and Kajallata are low yielding but can be more profitable (depending on the market). Yield and net benefit varies from plot to plot and location to location but in general rice is profitable, contrary to popular belief.

Potato is the most profitable crop, but initial investment is very high. Maize has similar initial investment to rice returns much higher profit. The risk of growing potato may be higher.

General perception is 3,000-5,000 litre of water is required to grow a kg of rice. Results showed that average water required was 1,402 litre and 1,086 litre to grow a kg of rice respectively in 2015-16 and 2016-17. Contrary to the general perception, farmers are in general efficient in applying irrigation to crops particularly when using STW. DTW sites have some oversupply.

Percolation rate from the rice fields is on average 3 mm/day. Percolation recharges the aquifer during the irrigation season. Water saving measures, such as alternate wetting and drying (AWD) result in less pumping costs and have economic and environmental benefits but do not save groundwater. AWD was shown to reduce irrigation water supply by about 14-18% in Boro rice cultivation.

Use of polythene pipe for irrigation water distribution was found effective in minimizing conveyance loss of irrigation water. This save about 20-25% irrigation conveyance water and saves irrigation time by 25%.

7.6 Scaling to maximise impact

7.6.1 Facilitating Scaling

The project recognised three typologies of scaling, scaling out, up and deep. Scaling strategies used by the project, and pathways to impact are illustrated below (Table 30).

Table 30: Scaling strategies, pathways and impact

Scaling typology	Pathways and trajectory	Impact
Scaling –out	• Creation of new collectives • Peer-group sharing and learning • Market linkages • Stakeholders consultation	• More areas, more households. • Spread and adaptation in more villages and more families • Strengthened value chain • Changing value and belief system –from individual to collectivism
Scaling –up	• Stakeholders consultation • Sharing with state and non -state agencies • Collaboration with the state and non-state agencies • Policy analysis • Sharing with larger agencies • Support emanating from different schemes from different state-non state agencies	• More physical coverage • Wider-partnership with state and non-state agencies • Multiple support to the DSI4MTF programs and strategies • Inclusive value chain • Farmers income and aspirations grow • Culture of collaboration develops and expands • Inter-institutional trust strengthened • Social capital
Scaling –deep	• Ethical –community engagement • Qualitative analysis • Stories and narratives captured and shared across • Participatory planning • Inter-village sharing and reflection • Sharing with larger players –say ADMI • Demand for entitlements articulated and made –caste certificate	• Culture of collaboration and cooperation enters the otherwise indifferent social dynamics • Aspirational buoyancy • Risk taking and trialling • Entitlements articulated and presented with positive response

Scaling out

Scaling out represents the spatial spread of the knowledge and impacts including perspectives, strategies, methods, tools and institutional development. In terms of spread, it can represent scaling across households, villages, administrative units, development blocks, districts, regions etc. The spread may take a formal as well as an informal path.

Examples of scaling included expansion of dry season crops in surrounding project villages, based on the learning from project demonstration sites. One example has been the establishment of two new collectives in Uttar Chakoakheti, and two in Mahuyahi (including a youth group), which emerged spontaneously after neighbouring farmers observed the activities of the project.

Through the project, farmers developed better linkages with supply chains and government line departments and knowledge partners, which has supported out-scaling. For example in Saptari the Ground Water Resources Development Board, following a stakeholder workshop in November 2017, has installed four new tubewells in the local village. In West Bengal the government has supported the installation of 8 shallow tubewells with electric pumps covering 80 to 90 marginalized farmers and eight new

Water User Associations (WUA's) are now being supported to manage the irrigation water and technologies collectively. These linkages were facilitated by the greater organisation provided by the collectives.

Local business models to link input suppliers, markets and famers are starting to be initiated. These include the establishment in Saptari of community business facilitators (CBF) who link farmers with suppliers. Options to develop sustainable rural organisations around commercial pockets that link small producers to government and the private sector are being considered. Collectives can potentially serve as vehicles for training and access to agricultural inputs and markets with linkages to rural collection centres. Ways to link collectives under a broader sustainable institutional base with greater authority need to be considered.

In Madhubani, a state level meeting was organized to raise awareness of the project with Chief Secretary of Government of Bihar (GOB), Director (Agriculture, GOB) and other stakeholders and plans are being developed to provide greater support to marginal farmers though subsidies and access to services and support. There has been success in out scaling and more than 47 farmers outside the pilot sites are now being supported in vegetable cultivation.

Scaling up

Scaling up, represents the integration of the impacts, protocols and processes of the interventions into existing policies and practices of the state and non-state institutions. The institutions are influenced by the programs, processes and impacts of the interventions and integrate them into policies and practices, as an enabler for expanding impact.

Policy integration takes time and is beyond the likely achievement of a four-year project. Notwithstanding, given both state and non-state agencies are important players in policy formulation, many meetings, seminars, conferences and focussed presentations were used to reach, influence and convince officials of the impacts of the project. Hosting more than 16 formal multi-stakeholder meetings was part of this engagement strategy.

There were some notable successes. In particular, the project's ethical community engagement perspectives (Mishra 2016, Report No 6) have been shared with the Government of West Bengal, through its Accelerated Development of Minor Irrigation (ADMI) project, and following a series of meetings ADMI are seeking to implement these concepts into their broader programs.

Scaling deep

It takes time for communities to adopt and adapt to the emerging perspectives and impacts of an intervention. People reflect, evaluate, compare , integrate and adopt various learning which are in conformity with their existing frame of reference, socio-cultural norms and practices and belief system related to the issues.

Community beliefs, value system, norms and practices may be dysfunctional in dealing with the existing issues, which the intervention could be trying to address. Scaling out and up may add to the volume and quantity but may not attract due attention and commitment in the face of non-compatible values and cultural beliefs (Mishra 2019 under preparation). Dependency, for example, is a dysfunctional value system and the communities preparing to achieve economic and entrepreneurial independence must first learn to shun dependency and start believing in self-help. Changing cultures and beliefs are considered difficult but the experiences of the project suggest that they can be influenced using stories (narratives) and co-creating scenarios and ideas from various interventions.

The project has documented, through Case studies ("Synthesised Case Studies", 2019, Report No 22) many examples of how a process of deep reflection and engagement has resulted in communities adopting and adapting to new perspectives of dry season agriculture. Field notes and documents such as Mishra et al 2017, Report No 10 have shown how, in communities, a culture of indifference has changed to active participation, and dependency into action.

Analysis of the scaling and impacts

The above typologies have strong overlaps and interdependence. While scaling out and scaling up are more in terms of physical and spatial spread, scaling deep may offer the necessary cultural glue to keep the impacts intact and internalized (Mishra 2019). Cultural change requires reflective and collaborative space where changes are perceived objectively, examined and analyzed for and subsequently, owned and internalized collectively. Ethical community engagement (ECE) perspective ensures this space. ECE offers recognition of the worth of everybody concerned, enlarges scope for participation, and ultimately leads to joint celebration and development of self-efficacy. The project has been a precursor to ECE, and continues to offer an appropriate space for critical reflections, collaboration and mutual appreciation alongside its ACIAR SIAGI sister project.

Activities supporting scaling

To support scaling the project disseminated information, reports and training material and developed tools and case studies to demonstrate a range of technical and institutional innovations for improved water management and dry season production. Training materials covered gender, engagement practices and crop agronomy and included release of five technical bulletins in vernacular language at the 2016 annual meeting. These were distributed amongst farmers, and covered cultivation techniques for a range of crops in the Terai. The participatory gender training manual ("Participatory gender training" 2016 Report No 4) continues to be used widely as a resource in training programs and webinars.

The project facilitated out-scaling of interventions to neighbouring communities through ground level dissemination activities with farmers. This has resulted in the adoption of improved agricultural practices in some adjacent fields and villages.

Case studies are a primary mechanism to disseminate key project learnings. Cases cover individual household livelihood improvement, community engagement and collective action and adoption of technology. They capture learnings, both positive and negative and a document summarising, on a thematic level, key findings has been prepared.

7.6.2 Policy reforms

Findings in Bangladesh have illustrated that water use efficiency by farmers is much better than widely believed and impacts on groundwater are not as bad as expected. This has significant policy impact and this information will be communicated once results are finalized through policy briefs and stakeholder workshops planned. There is need to understand the impacts on groundwater of expanding dry season agriculture, and different crop selections, as well as multiple water sources, not fully dependent on groundwater.

Results from India and Nepal sites indicate there is much potential to promote dry season cropping using non-traditional crops and especially high value vegetables, however water efficient practices need to be promoted and market development and price volatility needs to be managed. Policies and its implementation need to support training, extension and access to information for marginal farmers through government and the private sector. The project has demonstrated a range of technologies for improved water management, and tools for local water resource monitoring. Stronger engagement with government and incorporation into water management programs would support wider adoption of these approaches.

Collectives have the potential to transform agrarian relations in the Eastern Gangetic Plains. Grassroots organisations seeking to replicate the model need to ensure effective management of labour, mindful of past experiences, and consider the establishment of larger farms offering food security to members, so dependence on personal plots and conflict over time is reduced. Cropping choices also need careful consideration in terms of suitability for collective action. There is also the need for an institutional spine to bind collectives, replacing the need for NGO support in the long term. This could take the form of a federation of collectives, which could be a focal point for technical and institutional support and even marketing or negotiating with external stakeholders. Participatory gender trainings for community groups ("Participatory gender training", 2016, Report No 4) help provide a platform for both collective groups and project staff to critically discuss how gender norms, roles and relations affect dry-season irrigation, collective labour management and land cultivation practices.

Governments also have a key role in creating the conditions for out-scaling. This is through incentivizing the adoption of a collective approach by increasing awareness of the benefits to collectives, allocation of budget for local NGOs to support group formation and operation, making it easier to access subsidies as a group, through a simplified application process and providing access to agronomic training for marginal farmers.

Governments can also expand access to land and tenure security by identifying public land, which can be set aside for the poorest farmers to establish collectives, integrating the establishment of collectives into plans for future land reforms or redistribution. They could also support groups using leased land (model 2) in receiving tenure security for their plots.

There is also role for the government to work with the non-governmental sector to provide budget for NGO's to provide trainings on the management of collectives as well as agro-economic skills and empower leader collective farmers to act as a knowledge hub for wider communities. Crucially, the collectives can potentially emerge as a powerful model to introduce farming innovation into communities, rather than the dominant approach which tends to depend on better off 'model farmers' to showcase new technologies.

8 Impacts

8.1 Scientific impacts – now and in 5 years

The project has confirmed its main underlying premise: that the combination of innovative social interventions, such as the formation of farmer collectives as a vehicle for innovation, coupled with judicious introduction of appropriate tried and tested biophysical interventions (high value crops, cost effective irrigation) can improve the livelihood of marginal and tenant farmers. This is a major achievement, which has important development implications and makes this project highly relevant to food security and poverty alleviation in the EGP.

8.1.1 Interdisciplinary and multi-partner research knowledge and skills

The project has been unusual in marrying the scientific skill sets of researchers in social sciences, irrigation and water management, and community engagement. This has resulted in successful implementation of interdisciplinary and cross-institutional research across a diverse project team including science focussed government agencies, socially focussed NGO's and diverse academic researchers.

Some partners seek research recognition only in traditional disciplinary publications and their organisations do not recognise outcome and impact achievements. For others impact is more in terms of on the ground engagement and change. While different organisational cultures challenge integration, the project proved effective in integrating diverse types of data and outputs from partners during data collection and reporting. This has enhanced the research approach and capability of all partner organisations.

8.1.2 Viability for marginal farmers engaging in dry season agricultural production

The project generated a large and complex dataset, including an extensive baseline census of household livelihoods and water use, and the collection of plot wise biophysical and socio-economic data throughout cropping cycles. This was combined with in depth monitoring of the interventions through the regular collection of qualitative case studies. This has provided an improved understanding of the livelihoods of marginal farmers using dry season agricultural production systems, and the interventions needed to make this possible.

Trials in West Bengal have shown the positive impact of liming on jute yields and data collected will provide a good research-validation document. Anjali, a short duration paddy variety, is a good gap crop prior to planting other Rabi crops. Zero tillage technology in wheat, maize and mustard has also shown advantages over conventional tillage with productivity and resource-use-efficiency and profitability improvements.

Improved knowledge of crop diversification, through Rabi and winter vegetable cultivation, has increased crop intensity and profitability, with better understanding of crop rotation options and agronomic practices. There is potential for protected housing for cultivation of high value out of season crops. Improved water management practices, including reduced furrow length irrigation of potato, water conveyance though plastic pipe, and timing of irrigation have been demonstrated, and understanding of opportunities and constraints of solar pumping systems and drip irrigation systems has increased.

Successes from the formation of collectives of marginal famers has led to better understanding of the potential for these approaches in addressing labour scarcity, weak bargaining power and poor economies of scale for farmers who wish to intensify. These models are now being adopted in neighbouring communities.

8.1.3 Bangladesh water efficiency results

In Bangladesh, results from detailed plot scale trials informed broader scale modelling initiatives being conducted under the SDIP2 program. Findings in Bangladesh have illustrated that water use efficiency by farmers is much better than widely believed and impacts on groundwater are not as bad as expected. There are opportunities to communicate this information through policy briefs and stakeholder workshops.

8.1.4 Participatory monitoring of water resources and irrigation systems

The introduction of appropriate app-based data collection tools, complemented by a concerted effort in training and capacity building of partners, has improved the accuracy and timeliness of data collection, specifically around irrigation system performance and water resource monitoring. With further refinement, there are opportunities to promote these tools for wider use in other ACIAR projects and programs.

8.1.5 Ethical community engagement

Ethical community engagement processes evolved as the project matured. Early research into community engagement perspectives, processes and practices, became a precursor to approaches, which have been a foundation for our SIAGI sister project.

8.1.6 Gender training

The project developed a better understanding of how changing gender relations affect women’s access to water and land resources by examining women’s empowerment and their perceptions on being a farmer, within the feminization of agriculture in the Eastern Gangetic Plains. Through this, a gender training approach was developed and piloted with farmer groups. This culminated in development of a training manual and associated training film, “Participatory Gender Training for community groups. Critical Discussions on Gender Norms, Roles and Relations”. The collectives themselves also provided a model with huge potential for gender empowering agricultural intensification, and the field research identified mechanism to better unleash this potential and address equity constraints.

8.2 Capacity impacts – now and in 5 years

8.2.1 Confidence knowledge and skills change

There has been significant capacity development of farmers, driven through group meetings, training events and continuous onsite technical support and social mobilisation. Farmers participated in exposure field visits and farmer exchange visits oriented to technical and institutional capacity building, which resulted in substantial change in confidence, knowledge and skills.

The capacity of project partners has strengthened, particularly in delivery of research for development projects with a social-biophysical interface. In-country partners confirmed substantial growth in internal capabilities and capacity, especially in project management and data collection and the research process. The interface between technical and social aspects of research was a challenge but most partners significantly advanced their capacity in this area. Many partners had limited prior experience in this type of participatory multi-focus and social-technological linked project.

Formal research training opportunities and scientist exchange were unfortunately limited in the project. Dipika Das was awarded a John Allwright fellowship, and has registered for a PhD at USQ and is using gender perspectives to explore women’s participation in agriculture focusing on women smallholder farmers’ bargaining power in agricultural value chains. Sadiq Zafrullah completed a Master degree thesis through the Swedish University of Agricultural Sciences on the topic “Gendered Groundwater Technology Adoption in Bangladesh –Case studies from Thakurgaon and Rangpur”.

ACIAR event funding was received in 2016 to host a workshop in Madhubani to facilitate capacity development and sharing of experiences from collective farmer groups across 8 villages. This built confidence and knowledge across groups and provided cross regional sharing.

Improved confidence of woman, marginal and tenant farmers has been documented in numerous case studies, while adoption of dry season cropping and collective farming has been impressive. At some sites, farmers have demonstrated a greater confidence to take on risk and are investing in expanded production based on learnings from demonstration sites.

8.2.2 Individual practice change

Farmers have adopted new agricultural, water and technological management practices and migrated from predominantly rice based cropping systems to multi crop systems (including vegetables) with cropping intensity increasing from around 100% to over 200% in most sites.

Farmers adopted new irrigation management practices, through the introduction of new technologies such as solar or sprinkler / drip systems and through improved water management practices, using ridge and furrow irrigation, lay flat piping for better water distribution, and controlled water application. Farmers expanded their knowledge of agronomic practices such as seed treatment and fertiliser placement, use of weedicide, composting, mulching, raised bed cultivation and tray nursery cultivation.

Farmers participated in irrigation system assessments resulting in a better understanding of the need for regular maintenance and monitoring. While traditionally, irrigation is considered a man’s responsibility, women have started operating irrigation systems at intervention sites. For example, women are using sunflower pumps, drip kits, and are applying fertigation to crop through drip irrigation system. Women are also starting to take responsibility for farming decisions and operations highlighting the importance of gender inclusive technologies.

Dry season agriculture has expanded into surrounding fields in the village. In some sites farmers are contributing to infrastructure maintenance costs, however since profits are still relatively low, surplus funds are often used for other household expenses. There is therefore some risk in sustainability of infrastructure such as solar and drip irrigation after project completion. It is likely though that increased scale and profitability over time will improve long term sustainability. There is need for ongoing training and support and better linkages to local institutions and service providers to ensure this.

Participation has been consistent at local farmer group meetings (typically held monthly) with demonstrated interest to learn and evaluate new dry season agriculture. The level of confidence varies but has grown in all cases. Local dissemination of information, farmer to farmer, has been most effective. There is evidence of local out-scaling of cropping systems and technologies based on sharing of experience from demonstration sites.

While gradually improving profitability and productivity is widely observed as farmers’ skills develop and technical problems are resolved (see data above), where losses have occurred these have primarily been due to crop failure because of pests and disease, unseasonal weather and market failure.

8.2.3 Institutional and group practice change

In most of the sites, farmers now have a greater capacity to work collectively at a range of levels, from the stage of input procurement up to marketing. Farmers have adopted a range of collective farming models, which have evolved organically over the last three years and have been documented to better understand their trajectory. There sometimes reluctance in the early stages for collective farming systems under intensive dry season vegetable crops until confidence and trust has developed.

Resource owners and landlords in Madhubani and Saptari who have often shown little interest in tenant practices other than extracting rent, have seen value in collective farming systems and mutual trust has developed between both sides. In some instances, there have been problems in the relationship with tenants, generally a result of local disputes on access to land, tubewells and ponds, often associated with caste divisions.

Collective (group) practice change has been significant and generally positive. However, institutional practice change, through policy or government extension programs, is not widely evident. Local out scaling through neighbour farmer interest is occurring and there are some examples of agencies and departments upscaling and out scaling soil water management practices but these are localized. Sustainability of these groups will require stronger local institutions and better linkages with markets and service providers. This will require a greater scale of production. Food security, livelihood and production/profitability has improved for most farmer groups following project interventions.

Out scaling is starting to occur at a local level by neighbouring farmers and landlords are becoming aware of experiences and opportunities. This has required input from local partners who have provided support to broader interest groups. There is greater dialogue between farmers and landlords for the first time which has had positive outcomes.

There have been significant benefits to woman farmers who comprise 60% of the farmers in the Nepal and India sites, however in some cases established woman leaders have benefited over other woman farmers. Unequal power relationships still occur in some mixed woman/men groups with negative effects in particular on women’s labour burden.

Continuation of groups after the project will depend strongly on ongoing NGO presence and further development of leadership in local farmer groups. Strengthening of local institutions to support the small collectives, in terms of market access, input supplies and agricultural support services will be critical – in particular through the development of an institutional ‘spine’ to bind the collectives together.

Dry season crops have improved productivity and profitability however there has been increased risk through higher value specialized crops. Agronomic practices and market prices have been critical. Collective farming has been a challenging concept for many of the communities, especially at labour intensive times for critical crops (e.g. vegetables).

8.2.4 Policy implications

The inception meeting recognised the importance of engaging with policy makers and implementers. Sixteen stakeholder meetings and many private discussions were held with policy makers/implementers and local and state officials. It is not possible to quantify the impact of these engagements at this stage.

Project design and delivery has however not been optimal to consolidate findings beyond local level stakeholder engagement. However, local implementation and scaling should ultimately lead to better policy recognition.

While project impact is largely localized, it has started to interface with local agencies and departments who are now supporting farmer groups. This includes provision of subsidies and support for inputs (e.g. seed and fertilizer) based on the registration of collectives as well as installation of new tubewells and pumps as part of government programs.

Registration of farmers with the government department is a prerequisite for support. This often requires land ownership. Support for marginal farmers is now possible through registration as a group and this is being facilitated by local NGO’s, a potentially transformative change for landless tenants and women without land in their name.

A key policy message has been the transformative role of local collective farmer institutions for effective water management in the Eastern Gangetic Plains – particularly at a time when most new technologies are disseminated through better off ‘leader farmers’ who are expect to spread ideas to their poorer counterparts. This project reverses this model by using the marginal and tenant farmers as the entry point for new systems, with the contiguous plots and larger group making up for scale limitations. A policy note was developed and is available on the project web site. The brief outlines the conditions for out-scaling the model and the role of government through incentives for collective farming, expanding access to land and tenure security, and facilitating linkages with the non-governmental sector who can provide support services for marginal farmer collectives.

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

Within the project groups and pilot sites, there has been demonstrated increase in income from new cropping systems and irrigation practices, and increased food security. This is a considerable contrast with the pre-project situation, when farmers were engaged in subsistence oriented paddy cultivation with limited winter wheat farming. Economic benefits will likely continue to increase as farmers become more familiar with new agronomic practices and irrigation practices. Nevertheless, farmers have an additional source of cash, and this is particularly valuable for women who are most active in the groups. Poor market access, oversupply and low prices have occasionally affected farmers. Crop selection has evolved as a result of these experiences, and even when crops are not sold they bring nutritional benefits for households when consumed.

For example in Madhubani cropping intensity has increased from 110% to >200%, with yields up to 50% higher than previously. There is further scope to increase cropping intensity and profitability especially through better market access and higher product price. Farmers are making better crop choice decisions based on recent experiences on income, market demand and pest and disease impacts. Farmers are recognising the potential for furrow, drip and sprinkler irrigation to meet crop water requirement with less water than used when flood irrigating bays.

In Bangladesh, farmers have demonstrated greater awareness of the importance of water resources management and an interest in water saving irrigation practices. Farmers are adopting improved agronomic practices including use of younger seedlings, improved varieties, application of balanced fertilizers, biological control of insects, and water saving irrigation techniques such as alternative wetting and drying and polythene pipe water conveyance.

In Saptari farmers now have savings and credit facilities through the collectives, with interest earned on savings and loans used primarily for agricultural inputs and household activities. Farmers are now negotiating with market actors and landlords and are generating increased profits. The farmers are showing greater confidence in the operation of irrigation technologies and close linkages with ward representatives have developed.

In West Bengal economic impacts are already evident at most sites at both individual and community level with farmers adopting collective farming practices. Farmers are more aware of the importance of profitability and not just productivity and their market intelligence has improved. The best mechanism for profit sharing amongst the collective group members is still evolving. Introduction of furrow and basin methods of irrigation has resulted in saving of irrigation water and techniques like zero tillage, mechanized paddy transplanting, and better water management have led to reduced cost of cultivation and higher profit – interventions which have been made possible by the land consolidation brought about by collective formation. Local institutions such as collective groups and farmers club have evolved and there are now better relationships between tenant, poor and rich farmers. Neighbouring farmers are also coming forward to trial new crops under collective arrangements. The project is promoting environmentally friendly agriculture and farmers are using compost fertilizers and vermi-compost. The economic impact is increasing slowly and farmers are gaining knowledge on crop selection and maximizing financial benefit. Even with crop failure farmers are remaining confident and learning from failure to implement new approaches.

8.3.2 Social impacts

There has been strong evidence that through collectives, the confidence of farmers has increased and their ability to negotiate with landlords has been strengthened. Farmers have begun mobilizing access to government services, including provision of irrigation infrastructure through government programs and access to subsidised production inputs such as seed and fertiliser. For example in Saptari, three farmer groups pooled efforts to access subsidies for seed and fertilizer which are only offered to cooperatives with a minimum of 20 members. Links between government agencies and farmer groups have been strengthened through a number of coordination meetings, stakeholder meetings and associated field visits. Collectives are evolving with a new group even forming in response to a landlord at Koiladi discontinuing a lease. A significant achievement was the establishment of four new collectives, largely on the initiation of the farmers themselves, who had observed the successes of the other groups.

In many instances while larger farmers have access to information and benefits of government schemes, marginal farmers do not. Through group mobilization and support marginal farmers are increasingly becoming part of the dialogue with the government and stakeholders. This represents a significant achievement.

The project has opened up opportunities to undermine entrenched caste relations. In villages such as Mahuyahi where divisions were rigid and landlords rarely leased land to Dalits, a group from that community are now leasing land, and the women who lead this group are now making key decisions in crop choice and management. They were even been able to join forces with the youth groups to negotiate a reduced rent (see Sugden et al 2018, Report 14).

In West Bengal the promotion of collective farming approaches has had a significant social impact in Uttar Chakoakheti, home to Adivasi communities which had previously had limited engagement in agriculture aside from rainfed rice cultivation. The collective models in West Bengal are unique, whereby farmers have voluntary provided their land to the collective. This appears to have built trust and empathy between the farmers. The land-poor women members who have taken part in the groups have benefitted from enhanced knowledge and experience, although some challenges remain (see discussion in Sugden et al 2018, Report No 14).

Across sites, Marginalized communities are coming forward to establish their voice and actively participate in meetings and farming activities. Some cultural barriers remain, such as woman being reticent to sell their product to the local market. The empowered local institutions are establishing social capital and networks. Collectives are also spreading knowledge and raising political awareness beyond the immediate group. For example, in Uttar Chakoakheti, a predominantly Adivasi (tribal) village, the farmer group members were instrumental in encouraging other villagers to apply for Scheduled Tribe status, as well as make a collective application for government installed tubewells, and even land ownership certificates.

8.3.3 Environmental impacts

In a number of sites, particularly Kanakpatti, farming has commenced on land which had been fallow and neglected for a decade. Land fertility is being improved and better nutrient management and agronomic practices are being introduced, which will improve soil nutrition and weed control. These improved management practices are starting to be adopted by farmers adjacent to pilot sites. Farmers are learning that land will be more productive over a longer period when using correct application of especially organic fertilizers and judicious use of water. There is greater understanding of the role of pulses in increasing soil nutrition. Environment friendly technology has also been used to control pest and insects.

Better irrigation practices and systems that are more efficient have been introduced, limiting water waste and unnecessary extractions from groundwater. In many sites, where the cropping system has been dominated by monsoon rice production, sustainable rice intensification has been demonstrated in which alternate drying and wetting has resulted in a saving of water, and repeated tillage operations needed for puddling have been avoided. Less water demanding pulses and oil seeds have also been introduced.

The major environment impact has been crop diversification. In many parts, the traditional rice-wheat cropping system has been replaced with new crops such as moong bean, okra, lentil, cabbage, cauliflower, cucumber and brinjal. This assists in building of soil health and management of some pests and diseases, which were prevalent in the rice-wheat cropping systems.

Farmers are irrigating more effectively using improved irrigation practices. Solar pump systems have been introduced and efficient water management techniques are being practised. Efficient irrigation methods are being promoted reducing exploitation of ground water resources.

Improved agronomic practices are also resulting in more targeted chemical inputs of fertiliser and pest and disease control. In many sites environment friendly technologies to control insect pests such as lure traps are being used. Soil quality is being improved through reduced tillage and use of organic composts. Fertigation of vegetable crops is practiced at sites in Madhubani and Saptari which should reduce leaching of fertilizers to the groundwater and secondary salinization of the soils. Farmers are being informed about proper nutrient management. Organic fertilizers, especially vermicompost, cow dung, compost fertilizers etc are increasingly used in production.

Environmental benefits have included transition from diesel pumps to solar pumps. With the introduction of solar pumping systems, there has been reduction in the consumption of diesel at some sites resulting in reduction in the greenhouse gas emissions.

Resource conservation technologies are being promoted to ensure sustainable crop production with less environmental impact. Previously with limited access to groundwater many areas were mono-cropped. With the development of adequate irrigation infrastructure there has been a shift from traditional rice-based cropping system to multi-crop systems with greater crop diversity in the villages.

The establishment of the farmer collectives has resulted in some farmers moving away from illegal sand mining and forest harvesting practices.

8.4 Communication and dissemination activities

Continuous partner communication and dissemination activities have been fundamental to support, train and mobilise local farmers and has complemented ongoing engagement at the thirty-five demonstration sites located across 12 villages. Communication with district level agencies has primarily been through one on one stakeholder meetings.

Social media was successfully used to share information. The project website http://dsi4mtf.usq.edu.au/dsi4mtf/ is linked to Facebook and Twitter. Over 60 blogposts were written and twelve project videos are linked to the site. WhatsApp supported sharing progress across the team and Drobox supported data exchange.

Internal communication occurred through sixty-two local partners meetings, four annual review meetings and 10 regional coordinating meetings. Twenty-two draft reports have been prepared and published on the web site. Forty-seven case studies have been prepared of which seventeen are included in an integration document.

There have been over 20 conference presentations/papers. The Australian TV program Landline filmed activities on site in June 2017 and the program screened in August 2017. Five agronomic training pamphlets were launched at the annual meeting in December 2017. Project technical notes and training sheets supported training of farmers and advisors.

Links were maintained with ACIAR projects “Promoting socially inclusive and sustainable agricultural intensification in West Bengal and Bangladesh” (SIAGI, LWR/2014/072), and “Sustainable Resilient Farming System Intensification” (SRFSI) with two way learnings (e.g. introduction of SRFSI piloted zero tillage systems in West Bengal, and SIAGI adoption of DSI4MTF’s community engagement approach).

Links were developed with the IFPRI-led CGIAR research program on Policies, Institutions and Markets (PIM), and they funded additional associated research, focussed on identifying the barriers and opportunities for upscaling collectives at a policy level. Professor Bina Agarwal, a global leader in women farmer empowerment and authority on farmer collectives, has participated in a joint publication and participated in the farmer cross-learning event in Madhubani in 2017.

9 Conclusions and recommendations

9.1 Conclusions

Innovative social interventions, through the formation of flexible models of farmer collective, proved beneficial to marginal and tenant farmers as well as landlords. Importantly, the formation of collectives overcame many of the common barriers to technical innovation amongst marginalised groups. The collectives made possible the introduction of appropriate high value crops and cost effective irrigation systems, which improved yield and incomes for marginal and tenant farmers. This interdisciplinary approach has developed a potentially ground-breaking model to address the challenges of food security and poverty alleviation in the Eastern Gangetic Plains at a time of high agrarian stress. The key achievements from this approach are outlined below:

9.1.1 Irrigation and cropping systems

- Traditional cropping systems comprised kharif rice, with limited winter cropping of wheat, maize, mustard, potato or jute depending on region. There was little reliance on irrigation by marginal farmers and traditional irrigation systems were based on flood irrigation of paddy fields with low application efficiency, and high pumping costs.
- Cropping intensities increased from below 110% to above 200% in most sites following the interventions of the project. Intensification and diversification resulted in improved production, water use efficiency, profitability and nutrition.
- Profit margin from new cropping systems typically ranged between 20% and 60%. There was however large variability, between sites and seasons, driven by the complex mix of crops, seasonal productivity and market price. Seasonal cropping and input costs depend on the cropping system and varied depending on the need for labour, agri-inputs and machinery.
- Profitability is not the only benefit for these communities. Improved nutrition, and stable income and food sources are key benefits from diversified farming practices. Cropping decisions are often about labour, cultural preferences, risk aversion, market limitations, input costs and local consumption needs.
- Vegetable crops require careful management and are sensitive to untimely rainfall, inadequate irrigation during critical crop stages, pest and disease and volatile market prices. Vegetables are not part of traditional commercial farming systems and capacity development, training and agronomic support is required to improve skill in crop selection, planning, agronomy, pest and disease management and marketing.
- Groundwater is readily accessible using centrifugal pumps, with depth seldom exceeding 7m. Local irrigation had no significant impact on ground water levels, which recovered during monsoon rains. Impact of large expansion into irrigated crops on groundwater requires further research.
- Groundwater quality is generally good, however reports from surrounding areas suggest potential for iron, fluoride and arsenic contamination.
- Ponds are small, offer limited potential for irrigation, and are dry in summer due to evaporation and seepage losses. They are usually reserved for more profitable fish production and domestic purposes.
- Improved irrigation systems and management practices showed much potential for marginal and woman farmers. More technically advanced systems (drip, solar pumping) and processes (irrigation scheduling) proved more challenging. Low-tech solutions, such as improved surface irrigation and water conveyance through poly-pipe, had greatest impact.
- The cost of some technologies is prohibitive for small-scale farmers, even when they are part of a group, and better access to subsidies is needed. Technical support is crucial to sustain technologies such as solar pumps and drip irrigation and is not always available locally.

- While the payback on solar pumps is less than 3 years when compared with diesel pumping costs, the initial capital cost is too high for marginal farmers. Solar pumps need to be integrated with efficient irrigation systems producing high value crops, and need maximum utilisation to justify the capital outlay.

9.1.2 Bangladesh experiences

- Drivers for change in cropping systems have included availability of irrigation, and advances in research, extension and government support. Recent maize expansion is driven by market demand, availability of water, better profits and a shift from subsistence to commercial farming. Potato is the most profitable crop but initial investment and risk is very high. Maize has similar initial investment as rice but much higher profit.
- In some areas, irrigation of Boro rice has resulted in lower groundwater tables, resulting in greater water stress in the dry season. Adaptation to water shortages has been through deployment of electric deep tubewells, which have halved the cost of irrigating rice, and doubled profits. In some areas, drawdown of groundwater levels has limited access to groundwater by shallow tubewells and hand pumps resulting in inequality.
- Total cost, gross benefit and gross income significantly differ among locations based on types of pumps used for irrigation, and varieties of rice and transplanting dates. Cost of irrigation is high being typically 35% of the total production cost of rice, but is affected by different water pricing models.
- Farmers are generally efficient in applying water to the crops, especially shallow tubewell operators. Deep tubewell sites have greater oversupply since water price and pump costs are lower. Water saving measures, such as alternative wetting and drying and piped distribution, have improved irrigation efficiency and have been driven mainly by need to reduce pumping costs. Over-irrigation recharges groundwater and is not necessarily a loss to the resource.
- Water use efficiency by farmers is generally much better than believed and impacts on groundwater are not as severe as expected. Nevertheless there is need to better understand the impacts on groundwater of expanding dry season agriculture, and different crop selections, as well as multiple water sources, not fully dependent on groundwater.

9.1.3 Collective farming and institutional innovations for marginal farmers

- There are significant socio-economic, structural and institutional constraint to agricultural production by marginal farmers, whereby access to technology is constrained by unequal distribution of resources and landlord-tenant relations. An ageing farmer population, migration and feminization of agriculture has impacted labour availability. The availability, price and quality of various production inputs, particularly seeds and fertilizers, affect productivity and profitability, alongside external stresses such as climate change. Price fluctuations, lack of favourable marketing infrastructure, and inadequate and less organized marketing mechanism hinder the potential to reap benefits from agriculture intensification.
- While policies exist to support agriculture and water management, marginal farmers are not well equipped to follow procedures and access subsidies and support services and local facilitation is required to help them benefit from these services.
- The lack of a progressive large farmer class has meant limited exposure to new irrigation and farming systems. Improving access to irrigation is a priority, particularly given that groundwater is plentiful.
- Drought and untimely rain and flooding is the most severe shock encountered by farmers and responses included supplemental irrigation, changing cropping pattern, following improved crop production practices, and selling livestock to supplement

income. Key determinants of household vulnerability include farm size, household age, marital status, main occupation and access to credit.
- Gender relations and migration has a major impact on agriculture. Woman have limited capacity to influence decisions in the households, are powerless to change gendered norms for access to water, and can be exploited. Typically men purchase inputs, negotiate with traders, plough and arrange irrigation pumps while woman conduct time intensive but low value tasks like weeding, harvesting, and do this alongside domestic chores. After male out-migration, women's decision making power sometimes increases, yet they suffer a crippling work burden as they have to take on formerly 'male' tasks, facing numerous cultural barriers in the process. Women from better off households can hire in labour to offset these constraints. Gender training provides a platform for better understanding of gender norms roles and relations and helps promote enthusiasm, self-esteem and promote change.
- Different models of cooperation evolved, based on the land ownership structure, and local experience with running groups over time. There are clear gains from cooperation and collectives benefit most when labour is pooled to overcome peak labour shortages and irrigate fields more efficiently without competing for pump sets. Certain crops are more amenable to collective farming than others, due to cultural practices and intensity of labour use. Flexibility is required in developing appropriate collective models.
- The collectives have helped farmers increase their farm size, work on larger contiguous plots, and benefit from associated economies of scale in machine use and labour sharing. It has also increased farmers' bargaining power with landlords – enabling them to obtain better rental terms and undermine the landlord's ability to extract additional 'rents' through labour contributions. The collectives have also supported better organisation for claiming state subsidies and other resources.
- Ethical community engagement, which implies that knowledge production is inclusive, and respects the wisdom and perspective of communities, is a foundation for successful engagement, communication and capacity development, and a prerequisite to facilitate maximum adoption.
- Value chain mapping identified limited value addition and processing activities at farm level and poor access to credit and subsidies. Local institutions, such as collectives could play a key role in improving access to inputs, government support and strengthening marketing through linkages with traders and better market information.
- Increased scaling is required to maximize impact. Different typologies of scaling exist. While scaling out and up facilitate physical and spatial spread, scaling deep offers the cultural glue to keep the impacts intact and internalized.
- Institutional structures should be strengthened at a local level, through identifying ways for groups to team together as a community based organisation or federation to better access services and share high cost investments. The improved sustainability of collective farmer groups will also require stronger local institutions and better linkages with markets and service providers. This will require a greater scale of production, which again points to the need for larger scale institutional structures.
- The government has a key role in creating the conditions for long term sustainability and
- out-scaling, through incentivizing the adoption of a collective approach by increasing awareness of the benefits to collectives, allocation of budget to support local establishment and making it easier to access subsidies. Governments can also support access to land and tenure security and provide trainings on collectives' management and agro-economic skills and empower lead collective farmers to act as a knowledge hub to wider communities.
- There is a critical need for further training and support and strengthened linkages with service providers.
- The small scale of interventions makes commercial service support a challenge. There is limited ability to negotiate prices or discounts on inputs. Scaling farming operations,

strengthening supply chain linkages, better market prices and improved linkages with agencies and government support has been limited and should be a key focus in future work.

9.2 Recommendations

Further research is required to facilitate scaling, social inclusiveness and resilience of cooperatives to withstand future climatic, hydrological, social and economic stresses.

There is a need to address these risks by strengthening climate-smart agricultural and water management practices, improving understanding of the impact of scaling on regional water resources, and identifying opportunities to strengthen institutional structures and supply chains, more fully integrating cooperatives with market development opportunities in the Eastern Gangetic Plains.

Further research should consider three key aspects.

1. How climate-smart irrigation and water management practices for marginal farmers can be extended and scaled into government and agency implementation programs and initiatives to improve irrigation productivity.
2. What institutional structures, policy frameworks and value chain interventions are required to support the long-term sustainability of farmer collectives at a village level.
3. The regional hydrological impact of farm-scale water abstraction under different out-scaling and upscaling scenarios.

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10.2 List of publications produced by project

Project Working Reports see https://dsi4mtf.usq.edu.au/publications-resources/

Report No 1: Sugden, Fraser; Raut, Manita; Das, Dipika; Kumar, Anoj; Kanugoe, Prasun Deb (2016): Village characterization and agrarian relations. Working Paper for the ACIAR project "Improving dry season irrigation for marginal and tenant farmers in the Eastern Gangetic Plains". 80 p.

Report No 2: Bastakoti, Ram C (2017): Socio-economic context and institutional constraints to sustainable water use in Eastern Gangetic Plains. Working Paper for the ACIAR project "Improving dry season irrigation for marginal and tenant farmers in the Eastern Gangetic Plains". 49 p.

Report No 3: Leder, Stephanie (2015): Gendered Access to Water Resources within the Feminisation of Agriculture. Working Paper for the ACIAR project "Dry season agriculture by marginal and tenant farmers in the Eastern Gangetic Plains". 39 p.

Report No 4: "Participatory gender training" (2016): Participatory gender training for community groups. A Manual for Critical Discussions on Gender Norms, Roles and Relations. Training Manual for the ACIAR project "Dry season agriculture by marginal and tenant farmers in the Eastern Gangetic Plains". 39 p.

Report No 5: Shrestha, Bibek Bahadur; Roy, Prithwish (2016): Utilisation of residual soil moisture through relay Cropping. Working Paper for the ACIAR project "Improving dry season irrigation for marginal and tenant farmers in the Eastern Gangetic Plains". 51 p.

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Report No 7: Palanisami, K (2016): Economic Feasibility of Irrigation (technology) Interventions: Review of Concepts and Case Studies with typical irrigation interventions. Working Paper for the ACIAR project "Improving dry season irrigation for marginal and tenant farmers in the Eastern Gangetic Plains". 95 p.

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Report No 9: Palanisami, K (2016): Analysis of Climate Change Perception, Vulnerability of Households and Adaptation Strategies in the Eastern Gangetic Plains (Nepal, Bihar and West Bengal). Working Paper for the ACIAR project "Improving dry season irrigation for marginal and tenant farmers in the Eastern Gangetic Plains". 40 p.

Report No 10: Mishra, Rajeshwar; Sugden, Fraser; Schmidt, Erik (2017): The power of the Marginal: Local institutions and innovations are the key. Working Paper for the ACIAR project "Improving dry season irrigation for marginal and tenant farmers in the Eastern Gangetic Plains". 14 p.

Report No 11: Rajmohan, N; Okwany, R; Prathapar, S.A. (2017): Occurrence and extend of arsenic and fluoride contamination in groundwater in selected districts of the Eastern Ganges Basin. Working Paper for the ACIAR project "Improving dry season irrigation for marginal and tenant farmers in the Eastern Gangetic Plains". 21 p.

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Report No 13: Bastakoti, Ram C; Sugden, Fraser; Raut, Manita; Shrestha, Surendra: Key constraints and collective action challenges for groundwater governance in the Eastern Gangetic Plains. Working Paper for the ACIAR project "Improving dry season irrigation for marginal and tenant farmers in the Eastern Gangetic Plains". 17 p.

Report No 14: Sugden, Fraser; Leder, Stephanie; Agarwal, Bina; Saikia, Panchali; Raut, Manita; Kumar, Anoj; Ray, Dhananjay (2018): Farmer collectives to overcome agrarian stress and inequalities: learnings and opportunities from the Eastern Gangetic Plains. Working Paper for the ACIAR project "Improving dry season irrigation for marginal and tenant farmers in the Eastern Gangetic Plains". 45 p.

Report No 15: Bastakoti, Ram; Raut, Manita; Kumar, Anoj; Deb, Prasun (2017): Assessing value chain opportunities for smallholder vegetable growers in Eastern Gangetic Plains. Working Paper for the ACIAR project "Improving dry season irrigation for marginal and tenant farmers in the Eastern Gangetic Plains". 48 p.

Report No 16: Maitra, Soumen (2017): A Report on the bio-physical intervention in protected cultivation of crops at Dhalaguri and Uttar Chokowakheti Villages. Working Paper for the ACIAR project "Improving dry season irrigation for marginal and tenant farmers in the Eastern Gangetic Plains". 10 p.

Report No 17: de Silva, Sanjiv; Leder, Stephanie (2017): Agricultural innovations for water security in North West Bangladesh from institutional, gender, food and livelihood security perspectives. Working Paper for the ACIAR project "Improving dry season irrigation for marginal and tenant farmers in the Eastern Gangetic Plains". 83 p.

Report No 18: Mohammed Mainuddin, Md. Maniruzzaman, Md. Mahbubul Alam, Md. Towfiqul Islam, Md. Jahangir Kabir, Masud Hasan, Michael Scobie, Erik Schmidt (2019): Irrigated agriculture in the northwest region of Bangladesh. Working Paper for the ACIAR project "Improving dry season irrigation for marginal and tenant farmers in the Eastern Gangetic Plains". 77 p.

Report No 19: Shrestha, Surendra; Okwany, Romulus; Neupane, Madhu; Raj Thapa, Bhesh (2018): Report on Electric Resistivity Survey in Kanakpatti VDC of Saptari District. Working Paper for the ACIAR project "Improving dry season irrigation for marginal and tenant farmers in the Eastern Gangetic Plains". 19 p.

Report No 20: Renewable World (2018): Is solar pumping technology a viable solution for irrigation system in Terai Plain of Nepal? Working Paper for the ACIAR project "Improving dry season irrigation for marginal and tenant farmers in the Eastern Gangetic Plains". 60 p.

Report No 21: Okwany , R (2016): Pond and groundwater resources for irrigation intensification. Working Paper for the ACIAR project "Improving dry season irrigation for marginal and tenant farmers in the Eastern Gangetic Plains". 43 p.

Report No. 22: "Synthesized Case Studies" (2019): Improving Dry Season Irrigation for Marginal and Tenant Farmers on the Eastern Gangetic Plains: Synthesized Case Studies. A Compilation of Case Studies: 42pp.

Report No 23: Maniruzzaman M; Alam, MM; Mainuddin M; Islam MT; Kabir MJ; Scobie M, and Schmidt E (2019): Technological interventions for improving water use efficiency in the northwest region of Bangladesh. Working Paper for the ACIAR project "Improving dry season irrigation for marginal and tenant farmers in the Eastern Gangetic Plains". 44p.

Other Reports

Mid-term socio-economic and institutional monitoring for project: "Improving Dry Season Irrigation for Marginal and Tenant Farmers on the Eastern Gangetic Plains." A Compilation of Case Studies Volume 1. 128 p.

Mid-term socio-economic and institutional monitoring for project: "Improving Dry Season Irrigation for Marginal and Tenant Farmers on the Eastern Gangetic Plains". A Compilation of Case Studies: Volume 2. 61 p.

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Policy Brief

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Journal Papers

Fraser Sugden, Bina Agarwal, Stephanie Ledar, Panchali Saikia, Manita Raut, Dhananjay Ray, Anoj Kumar, Ritesh Kumar (2019). Farmer collectives to overcome agrarian stress and inequalities: learnings and opportunities from the Eastern Gangetic Plains: Journal of Agrarian Change. Submitted Jan 2019

Leder, Stephanie; Sugden, Fraser, Panchali Saikia, Manita Raut, Dhananjay Ray (2016). Ambivalences of Collective Farming: Feminist Political Ecologies from the Eastern Gangetic Plains. International Journal of the Commons. Accepted

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Schmidt, Erik; Mishra, Rajeshwar; Sugden, Fraser; Scobie, Michael; Bastakoti, Ram (2019): Socio-economic and biophysical assessment of agricultural intensification of marginal farmers in Eastern Gangetic Plains. Agricultural and Water Management. In preparation.

Conference Papers/Presentations

Forum / conference / publishing organisation	Date	Location	Paper title	Presenter
National Extension Education Conference	Nov-18	Ranipool, Sikkim	Crop diversification for improving livelihood of marginal and tenant farmers through improved dry season irrigation in Eastern Gangetic Plains	Tshering Bhutia
ASABE conference	Oct-18	Hyderabad	Transdisciplinary research to improve food production for MTF in the EGP	Erik Schmidt and Mike Scobie
National Conference on Doubling Farmers' Income for Sustainable & Harmonious Agriculture (DISHA-2018)	Aug-18	Ranchi	Solar irrigation systems for sustainable intensification of agriculture and doubling of farmers' income in Eastern Gangetic Plains of India	Santosh Mali
ICID Asian regional conference	May-18	Kathmandu	Development of smart apps for data collection and decision support in India and Nepal:	Michael Scobie, Ralph Shippam and Erik Schmidt
ICID Asian regional conference	May-18	Kathmandu	Improving water use for dry season agriculture by marginal and tenant farmers in the Eastern Gangetic Plain	E Schmidt , Fraser Sugden, Ram Bastakoti and Michael Scobie
ICID Asian regional conference	May-18	Kathmandu	Comparative Assessment Of Various Water Application Methods For Improving Water Productivity During Dry Season Agriculture	Bhesh Raj Thapa, Michael Scobie, Rabindra Karki, Manita Raut, Ram C. Bastakoti, Emma Karki and Erik Schmidt
RETURD-018, Kathmandu Nepal	29-31, October, 2018	Kathmandu	Is solar powered irrigation technology sustainable option for groundwater irrigation management in Nepal's Terai?	Bhesh Thapa
International Association of the Commons	20/06/2017	Utrecht, Netherlands	Farmer Collectives and Shifting Gender Relations in the Eastern Gangetic Plains	Stephanie Leder, Manita Raut, Panchali Saikia, Fraser Sugden
Sudasien	20/08/2017	Augsburg, Germany	Auswirkungen der Emigration auf die landwirtschaftlichen Strukturen in der östlichen Gangesebene	Stephanie Leder
CGIAR Gender Platform	6/12/2017	Amsterdam, Netherlands	"Feminisation of Agriculture? Exploring changing gender norms and power relations in the Eastern Gangetic Plains". Annual Conference of the CGIAR Gender Platform, KIT Amsterdam, 4.-8.12.2017	Stephanie Leder
POLLEN - Political Ecology Network	22/06/2017	Oslo, Norway	Evolving farmer collectives at the margins: Reflections on the making of life-in-common from the Eastern Gangetic Plains	Stephanie Leder
IAL National Conference, Sydney Australia	1/06/2018	Sydney	Water Productivity Improvement in North West Regions of Bangladesh,	Md Maniruzzaman and Md Mainuddin
Rural transformations		Uppsala, Sweden	On out-migration and changing gender relations: Feminisation of Agriculture	Stephanie Leder
CGIAR Gender and Agriculture Network Meeting, poster presentation	10/11/2016	Cali, Colombia	Participatory Gender Training for Community Groups	Stephanie Leder
Development Research Conference	22/08/2018	Göteborg, Sweden	Feminisation of Agriculture? Migration, changing gender norms and power relations in the Eastern Gangetic Plains" , Göteborg, 21.-23.08.2018	Stephanie Leder

Forum / conference / publishing organisation	Date	Location	Paper title	Presenter
International Silver Jubilee Conference of the Asian Development Research Institute "Bihar and Jharkhand: Shared History to Shared Vision	2/03/2017	Patna, India	Migration, gendered water institutions and farmer collectives in a changing agrarian structure in Mithilanchal	Stephanie Leder
CGIAR Gender Platform Webinar		Webinar online	Participatory Gender Training Webinar	Stephanie Leder, Gitta Shrestha, Andrew Reckers
Annual Research Meeting of the International Water Management Institute	17/11/2016	Colombo, Sri Lanka	Participatory gender training for farmer groups	Stephanie Leder
German Congress for Geography	6/10/2015	Berlin, Germany	Gender relations in agricultural development processes in the Eastern Gangetic Plains	Stephanie Leder
International Tropical Agriculture Conference (TropAg2017)	Nov-17	Brisbane, Australia	Strengthening agriculture for marginal and Tenant farmers in eastern Gangetic Plains: Agrarian relations with Gender perspective in agricultural value chain	Dipika Das
SEEDS of CHANGE CONFERENCE, 2019	Apr-19	Canberra, Australia	Gendered challenges of bargaining in agricultural value chains in the Eastern Gangetic Plains	Dipika Das

Other

Blog articles and project updates

https://dsi4mtf.usq.edu.au/category/project-updates/

Training and Information Sheets

Agronomy training manuals (local language)

Videos

Project Videos

https://dsi4mtf.usq.edu.au/videos/

"Participatory Gender Training for Community Groups. Experiences from Nepal. IWMI-media, 12 minute documentation.

https://www.youtube.com/watch?v=ir0snUnE4mc&t=1s

11 Appendixes

Appendices are available in separate documents

11.1 Appendix 1: General Considerations Regarding Intervention and Site Selection in Nepal and India

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11.3 Appendix 3: Engagement, Communication and Capacity Building Strategy and Plan

11.4 Appendix 4: Participatory Impact Pathway Analysis and Monitoring and Evaluation Plan

11.5 Appendix 5: Project Monitoring and Evaluation Reporting

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