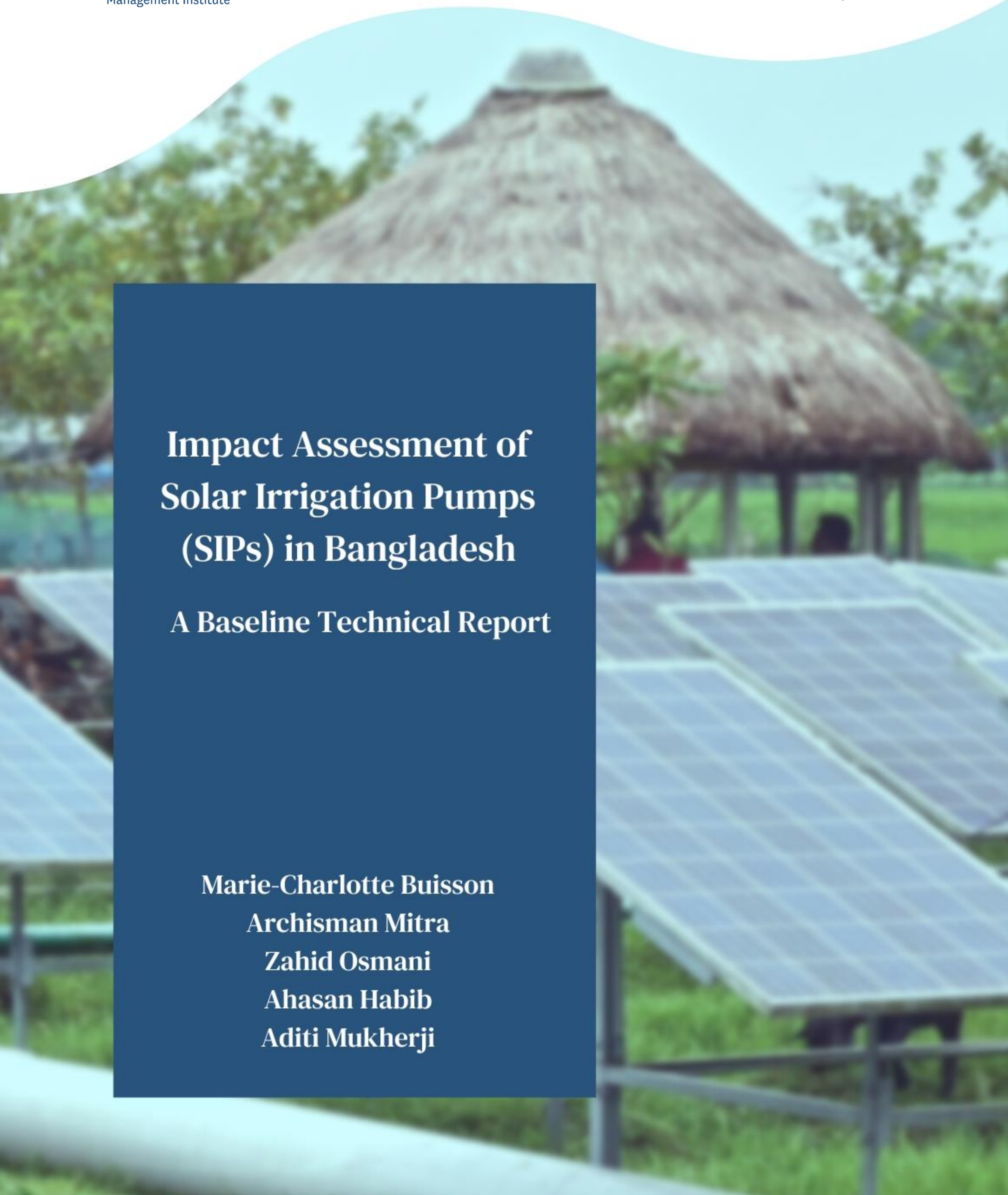
IWMI International Water Management Institute

SoLAR Solar Irrigation for Agricultural Resilience

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Agency for Development and Cooperation SDC



Impact Assessment of Solar Irrigation Pumps (SIPs) in Bangladesh

A Baseline Technical Report

Marie-Charlotte Buisson
Archisman Mitra
Zahid Osmani
Ahasan Habib
Aditi Mukherji

About IWMI: The International Water Management Institute (IWMI) is an international, research-for-development organization that works with governments, civil society, and the private sector to solve water problems in developing countries and scale up solutions. Through the partnership, IWMI combines research on the sustainable use of water and land resources, knowledge services, and products with capacity strengthening, dialogue, and policy analysis to support the implementation of water management solutions for agriculture, ecosystems, climate change, and inclusive economic growth. Headquartered in Colombo, Sri Lanka, IWMI is a CGIAR Research Center with offices in 14 countries and a global network of scientists operating in more than 30 countries.

About CGIAR: CGIAR is a global research partnership for a food-secure future. CGIAR science is dedicated to transforming food, land and water systems in a climate crisis. Its research is carried out by 13 CGIAR Centers/Alliances in close collaboration with hundreds of partners, including national and regional research institutes, civil society organizations, academia, development organizations and the private sector. www.cgiar.org

About SoLAR: Solar Irrigation for Agricultural Resilience (SoLAR) in South Asia aims to sustainably manage the water-energy and climate interlinkages in South Asia through the promotion of solar irrigation pumps (SIPs). The project's main goal is to contribute to climate-resilient, gender-equitable, and socially inclusive agrarian livelihoods in Bangladesh, India, Nepal, and Pakistan by supporting government efforts to promote solar irrigation. This project responds to government commitments to transition to clean energy pathways in agriculture. All countries in this project have NDC commitments to reduce greenhouse gas (GHG) emissions, and SIPs can play a significant role in reducing emissions in agriculture.

About SDC: The Swiss Agency for Development and Cooperation (SDC) is the agency for international cooperation of the Federal Department of Foreign Affairs (FDFA). Swiss International Cooperation, an integral part of the Federal Council's foreign policy, aims to contribute to a world without poverty and in peace for sustainable development. SDC, through its Global Program Climate Change and Environment (GPCCE), helps find solutions to global challenges linked to climate change. It engages in global political dialogue and manages specific projects in the fields of energy, climate change adaptation, sustainable development of mountainous regions, and prevention of natural hazards that are likely to influence regional and international policy.

Authors: Marie-Charlotte Buisson is a Senior Researcher and the Research Group Leader, Economics and Impact Assessment at IWMI, Sri Lanka; Archisman Mitra is a National Researcher - Water Resource Economics at IWMI, India; Zahid Osmani is Research Officer at NGO Forum for Public Health, Bangladesh; Ahsan Habib is the Head of Research, Monitoring, and Evaluation at NGO Forum for Public Health, Bangladesh and Aditi Mukherji is a Principal Researcher at IWMI, India.

Buisson, M.-C.; Mitra, A.; Osmani, Z.; Habib, A.; Mukherji, A. 2023. *Impact assessment of Solar Irrigation Pumps (SIPs) in Bangladesh: a baseline technical report.* New Delhi, India: International Water Management Institute (IWMI). 75p. doi: https://doi.org/10.5337/2022.230

/solar powered irrigation systems / pumps / impact assessment / solar energy / energy generation / gender equity / social inclusion / cropping patterns / irrigation practices / water extraction / tube wells / climate-smart agriculture / business models / tariffs / costs / tenant farmers / training / seasonal cropping / cultivated land / plot size / food security / public-private partnerships / villages / household surveys / socioeconomic environment / greenhouse gas emissions / diesel oil / Bangladesh /

ISBN 978-92-9090-949-1

Please send inquiries and comments to iwmi-solar@cgiar.org

A free copy of this publication can be downloaded at https://solar.iwmi.org/reports/

Acknowledgments

This report is a part of the Solar Irrigation for Agricultural Resilience (SoLAR) project supported by the Swiss Agency for Development and Cooperation (SDC). The Infrastructure Development Company Limited (IDCOL) is the main project partner for the SoLAR-SA project in Bangladesh.

We express our gratitude to Infrastructure Development Company Limited (IDCOL) for sharing data and providing valuable insights. We also extend our thanks to members of the Sustainable and Renewable Energy Development Authority (SREDA) of Bangladesh. The report is enriched by discussions among the SREDA members during the country project management committee (CPMC) meetings. We also thank Ms. Sunipa Das Gupta, IWMI for her editorial support and Mr. Aariz Raza, IWMI for his support in designing the report.

Donor

Swiss Agency for Development and Cooperation (SDC)

Partner

Infrastructure Development Company Limited (IDCOL)

Executive summary

The Infrastructure Development Company Limited (IDCOL), a government-owned non-banking financial institution (NBFI), is the primary agency financing and implementing solar irrigation projects in Bangladesh. The IDCOL solar irrigation pumps (SIPs) follow a 'fee-for-service' model consistent with public-private partnership principles.

Solar Irrigation for Agricultural Resilience (SoLAR) in South Asia is a research project implemented by the International Water Management Institute (IWMI)with financial support from the Swiss Development Cooperation (SDC). The project aims to sustainably manage South Asia's water-energy-climate interlinkages by promoting SIPs. As part of this project, IWMI partnered with IDCOL in Bangladesh and designed an impact assessment of their SIP program. The present report describes the result from the baseline surveys conducted for this impact assessment in 2020 and 2021.

The analysis is organized around six research questions related to diesel use, co-benefits from SIP use, inclusion and equity, cropping patterns, irrigation practice and water abstraction, and operation of the SIPs. It uses data from two primary surveys: first, a survey of a representative sample of 83 SIPs over three cropping seasons, and second, a household survey across 900 households comprising 20 villages with an IDCOL SIP installed and operating, 20 villages identified as future sites for IDCOL SIPs, and 20 control villages without any SIP.

The results show that farmers using SIPs reduce their diesel consumption even if the diesel pump use is not eliminated. Beyond the primary objective of reducing greenhouse gas (GHG) emissions, SIPs present significant co-benefits for the users. The SIP using farmers can reduce labor time and costs spent on irrigation, and access cheaper and more reliable irrigation services. While the number of irrigations and the duration of irrigations are significantly lower for SIP users, once weighted by the estimated average flow rate of solar and diesel pumps, water application on SIPs is 7% more than all diesel irrigated plots but the difference is not significant and not consistent across different types of diesel irrigated plots. Nevertheless, access to SIP favors supplementary irrigation in the monsoon season, especially in the event of delayed or uncertain rainfall. In terms of equity in access to irrigation, our results establish that SIPs serve marginal farmers and tenant farmers through IDCOL's fee-for-service model, wherein farmers have to pay only a fee for using the irrigation services of the SIPs, while the costs of installation, operation, and maintenance of these capital-intensive irrigation systems are borne by the sponsors.

However, IDCOL's business model relies heavily on *boro* cultivation, and the unused surplus energy beyond the *boro* season can strain the financial viability of the model in the longer run. Grid integration or additional energy services can open up the potential for additional revenue earning from the surplus power generated. The SIP operators who play a vital role in the operation and maintenance of the SIPs may further expand their role toward agricultural extension services with the SIPs becoming agricultural multi-service hubs. SIP farmers themselves would benefit from additional and better-targeted training on irrigation efficiency and climate-smart agricultural practices.

Contents

1. Introduction

Agriculture significantly contributes to greenhouse gas (GHG) emissions in South Asia. Measures for mitigation in the agriculture sector are being increasingly promoted by national governments and donors and are frequently included in the *Nationally Determined Contributions (NDCs)* pledges. GHG emissions from the agricultural sector in Bangladesh for 2014–15 were estimated at 76.79 million tons (Mt) of carbon dioxide equivalent (CO_2e) (Sapkota et al., 2021). Their estimate did not include emissions from groundwater irrigation, but diesel pumps supporting the access to groundwater for irrigation of water-intensive *boro* rice cultivated during the dry season contribute substantially to emissions. The government and donors promote solar irrigation pumps (SIPs) to tackle emissions from irrigation. SIPs eliminate emissions while maintaining strategic access to groundwater for food security.

The Infrastructure Development Company Limited (IDCOL), a government-owned financial company, is the primary agency financing and implementing solar irrigation projects in Bangladesh. Until May 2022, IDCOL approved 1,619 Solar Irrigation Pumps (SIP) corresponding to a 45 Mega Watt peak (MWp) capacity. Despite the regular increase in the number of pumps installed and the entry of new stakeholders, this is still a long way to reach the target of 10,000 pumps installed by 2030. IDCOL SIPs irrigate approximately 15,000 hectares, i.e., less than 1% of the country's total net cropped area, while 1.26 million diesel pumps irrigate about 3.0 million hectares (38% of the net cropped area), and another 0.34 million electric pumps cover 2.3 million hectares (29% of the net cropped area) (Islam and Hossain, 2022; BADC, 2020).

The IDCOL SIPs follow a 'fee-for-service' model consistent with the public-private partnership principles. Partner organizations, referred to as sponsors, buy solar pumps and related equipment by taking grants and loans from IDCOL. A sponsor receives approximately 50% of the SIP's cost as a grant and another 35% as a loan from IDCOL. The remaining amount, referred to as equity, has to be paid directly by the sponsor. The sponsor then operates the SIP and sells water to farmers for a fee. This fee is used to cover the operational costs (operator fees and maintenance costs), recover the investment, and pay back the loan to IDCOL.

Solar Irrigation for Agricultural Resilience (SoLAR) in South Asia is a research project implemented by the International Water Management Institute with financial support from the Swiss Development Cooperation. The project aims to sustainably manage South Asia's water-energy and climate interlinkages by promoting solar irrigation pumps (SIPs). The project aims to (i) generate improved empirical evidence to support the development of climate-resilient, gender-equitable, socially inclusive, and groundwater-responsive solar irrigation policies; (ii) validate innovative actions and approaches for promoting gender-equitable, socially-inclusive, and groundwater-responsive solar irrigation; and (iii) increase national and global knowledge and capacity for developing gender-equitable, socially inclusive, and groundwater-responsive solar irrigation policies and practices. To respond to these objectives, IWMI partnered with IDCOL in Bangladesh and designed an impact assessment of IDCOL's SIP program. The present report describes the result from the baseline surveys conducted for this impact assessment in 2020 and 2021.

The report is organized as follows. The next section presents the research questions and the impact assessment framework. The third section describes the methods and the design used to answer the research questions. In the fourth section, we describe our samples in terms of demographics, socioeconomic characteristics, and agricultural practices. The fifth section highlights the key results of the baseline survey, organized around six areas: diesel use; co-benefits; inclusion and equity; cropping patterns; irrigation practices, and water use; and finally, SIP operation. Finally, the last section summarizes the lessons from the household and the SIP surveys by revisiting our research questions.

2. Research questions

As part of the Solar Irrigation for Agricultural Resilience in South Asia (SoLAR-SA) in Bangladesh, we aim to conduct an impact assessment of the IDCOL SIPs to understand their impact on diesel consumption and mitigation of climate change and their potential co-benefits and development outcomes. More specifically, the impact assessment focuses on the research questions detailed in Table 1 and is organized around six main areas:

- **Diesel use**: We assess the climate change mitigation role of solar irrigation through the conversion from diesel-operated pumps to solar-operated pumps.
- **Co-benefits**: We consider as potential co-benefits from the SIP at the farmer level the reduction in the cost of irrigation and the reduction in time spent on irrigation tasks. Those are measured as well as the level of satisfaction by the farmers from their different irrigation services.
- **Inclusion and equity**: Our objective here is to understand who the beneficiaries of the SIP services are and how representative they are of the farmers in those locations. We will also assess how equity in access to irrigation is impacted by the presence of SIP in a community.
- **Cropping patterns**: When the source of irrigation and the source of energy evolves, inducing a lower cost of irrigation, more water-intensive crops or higher cropping intensity are usually observed. We test this hypothesis in the context of conversion to SIP with a fee-for-service model.
- **Irrigation practices and water abstraction**: With or without a change in cropping patterns, the irrigation practices in terms of frequency and duration may evolve with access to SIP service. We assess these changes in irrigation practices and estimate the consequences on groundwater abstraction.
- **Operation:** This topic aims to assess in a descriptive manner the SIP's functioning, including the operators' role and the model's financial sustainability.

These questions are answered by analyzing two primary sources of data: household survey and SIP scheme level survey. The SIP scheme survey aims to collect SIP level data for each cropping season from *aman* 2020 to *boro* 2023. This will produce a panel of 83 IDCOL SIPs observed for three years and nine cropping seasons.

The microeconomic study at the household level will use quasi-experimental methods to understand the impact of access to SIP on household and plot level outcomes. Two rounds of data will be used: the baseline data collected in 2021 and the follow-up to be collected in 2023. The sample comprises a group of treated households located in villages with an IDCOL SIP installed and operating, a group of future IDCOL SIP sites where SIPs will be implemented in the near future, and a group of control households located in villages without any SIP. In the present report, only the baseline data is used, and the analysis is therefore based on descriptive statistics.

The impact of SIPs is considered at the plot level, the farm and household level, and the command area level. We follow a nested approach in which each research question is answered at different levels. This allows considering the potential spillovers and reallocation of resources within a farm or within the command area, for example.

Topic	Questions	Data	Methods	Level Of Analysis		
				Plot	Farm/ Household	Command Area
Diesel	What is the effect of SIP on **diesel** consumption?	Household survey data SIP survey data	Descriptive statistic (baseline) and quasi-experimental quantitative impact evaluation (baseline and follow-up survey)	✓	✓	✓
Co-benefits	What is the impact of SIP **on the cost of irrigation and time use** for the farmers? What is the level of satisfaction by the users?	Household survey data			✓	
Inclusion and equity	Who are the **beneficiaries** of the SIP? What is the impact of SIP on **equity** in water access?	Household survey data SIP survey data			✓	✓
Cropping patterns	What is the effect of SIP on **cropping patterns** and crop choices?	Household survey data SIP survey data		✓	✓	✓
Irrigation and water	What is the impact of SIP on **farmers' irrigation practices and water abstraction**?	Household survey data SIP survey data		✓	✓	
Operation	How are the SIP operated and respond to shocks? Is the SIP fee for service model financially sustainable?	SIP survey data	Descriptive statistic			✓

Table 1 – Research questions and methods

The present baseline report considers descriptive statistics from three first rounds of the SIP survey (*kharif* 2/*aman* 2020, *rabi* 2020-21 and *kharif* 1/*boro* 2022[1]) and from the baseline survey conducted in August -

[1] *Kharif 2* season is the monsoon season and runs from end-June to mid-October where the main crop is *aman* paddy, *rabi* season runs from November to January where the main crops are potato, wheat, mustard, and vegetables and the *kharif 1* season is the dry season requiring most

September 2021, covering the previous cropping year. Since only descriptive statistics from the baseline data are used, the results and correlations highlighted here cannot be considered causal. Further econometric analysis, matching methods at the plot and farm level, and follow-up surveys will be needed to establish the impact of the IDCOL SIPs rigorously.

3. Methods and samples design

3.1. Household survey: Design and methods

3.1.1. Sample design and methods

The microeconomic study at the household level will use quasi-experimental methods to understand the impact of access to SIP on household and plot level outcomes. Two rounds of data will be used: the baseline collected in August-September 2021 and the follow-up to be collected in 2023. In this report, the baseline data collected in August-September 2021 is used for analysis.
The sample comprises a group of treated households located in villages with a SIP installed and operating, a group of future SIP sites (that is where SIPs will be installed within a year or two), and a group of control households located in villages without SIP. Control and treated villages were selected with similar observable characteristics and using IDCOL and sponsor information on future sites (see below villages selection methods).

Through a targeted selection of villages, we expect future sites surveyed in 2021 to become treated as the SIP program will expand toward new locations within the two years gap. This will allow us to use a difference-in-differences method to estimate the impact of the SIP using the two survey rounds. In addition, propensity score matching at the household level and instrumental variables methods (or endogenous switching regressions) will be used to estimate the direct or indirect impacts of SIP using both the data collected in 2021 and the data collected in 2023.

Finally, the sampling design will allow us to analyze the heterogeneity in the impacts, especially in terms of the pump ownership status of the farmers. We expect the effect of accessing irrigation from SIP to be different for former water buyers and former water sellers (diesel pump owners).

The household sample exclusively focuses on the North West of Bangladesh (Dinajpur and Thakurgaon districts). As the largest share of the IDCOL SIPs is in North-West, this choice allowed to maximize the power of the sample while minimizing the cost of the survey.

In the present baseline report, we describe the household data collected through descriptive statistics and analyze the outcomes of the three groups of villages (treated, pipeline, control) or depending on the

of the irrigation and running from January to May where the main crops are *boro* paddy and maize. These months are indicative as the dates of planting and harvesting differ depending on the agro-ecological zones and the climatic conditions. The definition of the season used here may also partly differ from the official dates of seasons defined by IDCOL for monitoring purpose. In our definition in this report, *aus* falls under *kharif* 2 season while *boro* and *boro* equivalent crops correspond to *kharif* 1.

status of the household (water buyer from SIP, water buyer from diesel, water buyer from individual or Barind Multipurpose Development Authority (BMDA) electric pumps, diesel pump owner).

3.1.2. Sample size and power analysis

The power analysis was done using the data collected among 1400 households in West Bengal, India, in 2013. The questionnaire collected detailed information on irrigation practices for water buyers and pump owners and on crop economics. In the absence of such detailed information in Bangladesh, we consider that the West Bengal data can reasonably approximate the mean, standard deviation, and intra-class correlation for indicators of interest; this is especially true for the North-Western districts of Bangladesh. The means, standard deviation (σ_Y) and intra-cluster correlations (ρ) used for the sample size analysis come from this database. Then conventional rates have been used for the power of detection ($R^2 = 0.8$) and confidence (0.95). The minimum detectable effect size (*MDI*) is calculated for several sample designs. We use the below formula, which considers two levels of selection, in our case, clusters (villages) and households. We consequently do sensitivity analysis with different options for the number of control and treatment clusters (respectively a_c and a_t) and for the number of households per cluster (b_c and b_t).

The power analysis is done with four outcome variables available in this database and which are of interest to the present impact evaluation. At the household level, we consider the cropping intensity, the proportion of households cultivating *boro* paddy, and the yields of *boro* paddy (in kg per acre). At the plot level, we consider the number of irrigations for the entire *boro* season. Plot level calculations assume an average number of 6 plots per household.

The sensitivity analysis (Annex A) was conducted to identify the minimum detectable effect size, given several sample designs (sample size, number of clusters, and number of units per cluster). Given the results of the sensitivity analysis, we considered a sample of 900 households from 60 villages (20 SIP villages, 20 pipeline villages, and 20 control villages in 2020). In each village, 15 households were surveyed.

The data collected through this sample design will be able to detect an impact of the SIP intervention equivalent to 32.1% of the standard deviation of the cropping intensity or equivalent to 28.7% of the standard deviation of the *boro* yields using the baseline data.

$$MDI = a2.487\ \sigma_y \sqrt{(1-R^2)\left[(1-\rho)\left(\frac{1}{a_t b_t}+\frac{1}{a_c b_c}\right)+\rho\left(\frac{1}{a_t}+\frac{1}{a_c}\right)\right]}$$

3.1.3. Sample selection

Selection of villages

- **Group B – Pipeline villages**

We started by selecting the 20 villages in the pipeline, i.e., which will receive a SIP between the survey in 2021 and the follow-up in 2023. IDCOL shared in April 2021 an updated list of the SIP, which was approved and will be operational by the end of 2021. This list identifies 39 sites. Among those, 22 sites were planned to become operational in June 2021. The questionnaire aimed to collect recall data regarding the k*harif*1 season of the agricultural year 2020. To minimize the risk of the future SIPs already serving some farmers at the end of *kharif*1 season in 2020, we selected only three sites that were expected to be operational in August 2021. These 20 pipeline villages are located in six Upazillas (Baliadangi, Biral, Bogura, Birganj, Bochaganj, Gabitali), which were used to narrow the selection of the villages in the other groups.

- **Group A – Treated villages**

Several constraints applied to the selection of the villages from **group A**. These are villages with at least one SIP already operational located in the six Upazilla previously targeted. In addition, we purposively selected the SIPs which will be connected to the grid for the analysis at the grid level. Four future grid-connected sites are in the six Upazillas. We also selected those villages among the ones already followed through the seasonal SIP survey and, when possible (two cases), within the chosen locations for the groundwater study. Finally, we ensured a balanced number of SIP from the six Upazilla and different sponsors. This purposive selection of villages from group A yielded a list of 20 villages.

- **Group C – Control villages**

Control villages are expected to present characteristics similar to those observed in the pipeline villages (Group B), especially regarding cropping patterns, irrigation equipment or practices, and groundwater. Control villages (group C) were selected by matching with the pipeline villages (group B) through a two-steps approach:

- **Step 1** – A village-level database was collected based on publicly available census data (BBS, 2013), including all the villages from the six Upazilla with the following indicators:
    - Number of households
    - Population (Total, Male, Female)
    - Literacy rate
    - Population engaged in agriculture (Male, Female)
    - Percentage of households with a domestic electric connection

Using this dataset, the 20 villages in group B were matched with a propensity score matching 40 villages without SIP.

- **Step 2** – For the 40 villages selected in step 1, further village-level information was collected through on-site visits and key informant interviews on the following indicators:
    - Total cultivable land in 2020
    - Net cropped area in 2020

- Number of DTW (Diesel/Electric)
- Number of STW (Diesel/Electric)
- Number of cultivating households (farmers)
- Number of diesel pump-owning farmers
- Number of farmers buying water from diesel pump owners
- Cropping patterns with the percentage of land allocated to each crop
- Presence of arsenic/iron/salinity in the groundwater
- Soil texture with percentage (Sandy/Clay/Clayey/Loamy/Mixed)
- Total number of irrigations required for *boro* in 2020
- Natural disasters in the last ten years Floods/Rock rain/Storm/Drought
- Price of seasonal contract for irrigation of *boro* from diesel pump (BDT/*bigha*)

Combined with the data already collected by IDCOL for the 20 pipeline villages, this data was used for the second round of matching. Some indicators were used as exclusion criteria (presence of arsenic or salinity of groundwater), while others were used for matching (cropping intensity, share of net cropped area allocated to *boro*, number of irrigations for *boro*, number of electric and diesel pumps operating). At the end of this second step, we obtained the list of the 20 control villages (Group C).

A list of selected villages is presented in Annex B, and the map below shows the sampled villages' location (Figure 1).

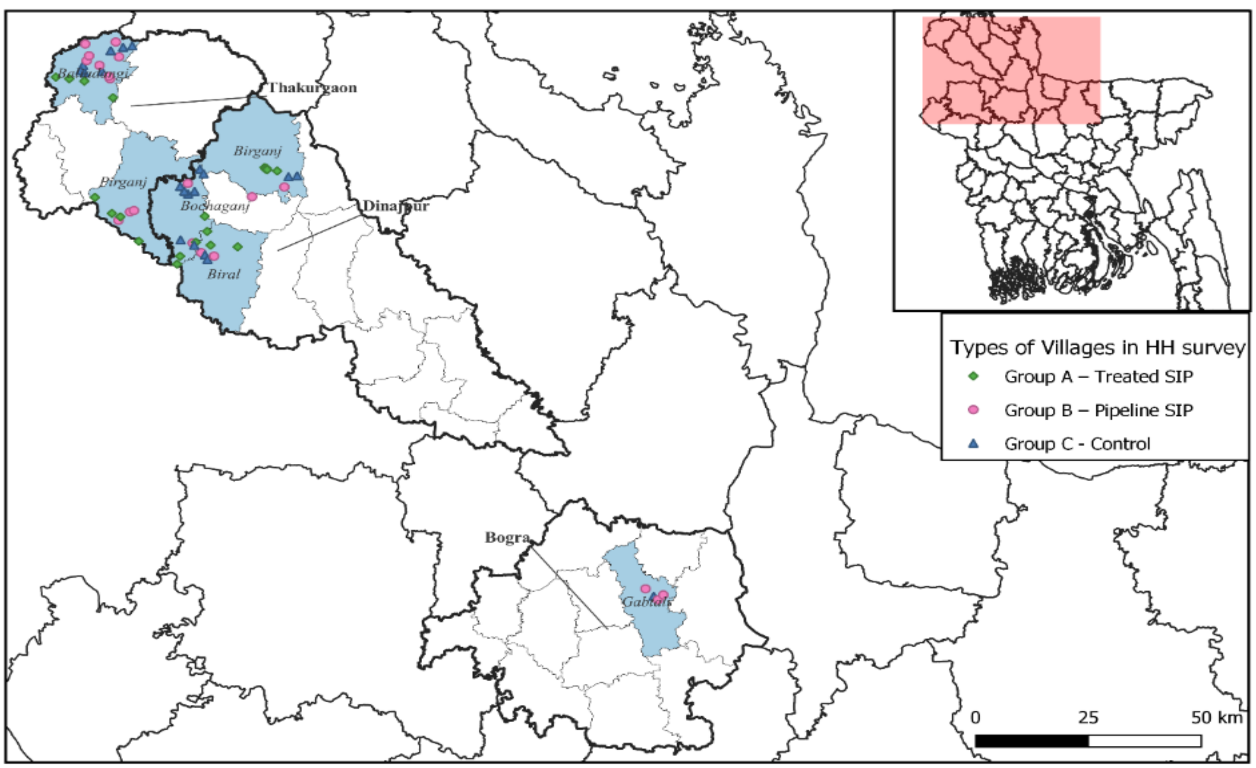


Figure 1 – Map of sampled villages for the household survey

Selection of households

In SIP villages (Group A), a stratified random sample of 15 households to be surveyed was selected using the list of SIP clients, developed by each SIP on a seasonal basis. The sample of 15 farmers is stratified based on pump owners and water buyers in the same proportion as in the farmer list for each SIP location. We consider that farmers on these lists cultivate at least one plot within the SIP command area for this particular season. The SoLAR household survey was conducted in August 2021, and we used the lists developed for the 2021 *boro* season. The status of each farmer regarding ownership of a diesel pump or water buying before the SIP started its operation was added to the list to allow a proportional sampling.

In the pipeline villages (Group B), as community mobilization had started and sponsors had already identified the exact location of the SIP, we collected the lists and the status of the future SIP clients. Those were used to draw a proportional random sample of 15 households per village.

In the other control village (Group C), as mentioned before, we collected the lists of households from U*nion Parishad.* Since we do not have information on the status of diesel pump ownership or water buying, we selected a random sample of 15 households from the farmers' list.

In all the three cases mentioned above and, in all villages, we drew a list of replacement households (10 per village) to be used in cases where the household from the principal list cannot be located during the survey, doesn't give his consent for the data collection, or doesn't cultivate. Table 2 presents an overview of the household sample.

Zilla	Number of Upazilla	Number of Unions	Number of villages				Number of households			
			Group A	Group B	Group C	Total	Group A	Group B	Group C	Total
Bogura	1	1		3	1	4	0	45	15	60
Dinajpur	3	8	12	6	12	30	180	90	180	450
Thakurgaon	3	9	8	11	7	26	120	165	105	390
Total	7	18	20	20	20	60	300	300	300	900

Table 2 – Household survey sample

3.1.4. Household questionnaire

Selected respondents were administered a detailed household questionnaire in August 2021 and referred to the last agricultural year i.e., from *rabi* 2020 to *kharif* 2021. The head of the household answered the questionnaire and could be accompanied by any other household member as we considered the

information collected not to be private within the household. Each respondent was asked to give formal consent before starting the survey, per the rule of ethics in research involving human subjects[2].
The questionnaire includes the sections described in Table 3 and is appended in Annexure D.

Section	Description
Demographics	Composition of the household Age, gender, education
Farm and cropping patterns [by plot]	Area owned, cultivated, sharecropped Number and areas of the plots Type of crop cultivated Seasonality
Water access and irrigation [by crop]	Water sources – SIP, diesel, electric pumps Irrigation practices (frequency, duration) Energy consumption (fuel, electricity) Type of contractual arrangement Cost of irrigation and fee payment Time allocation Perception on water delivery service
Crop economics [1 plot[3]]	Cost of production
Food consumption and food security	Consumption from 16 food groups in the last 24 hours and frequency in the last seven days
Shocks and adaptation	Experience of shocks Adaptation practices
Social network, extension, and training	Participation in groups Access to information Training
Housing and assets, decision making	House characteristics Household assets ownership Livestock ownership

Table 3 – Household questionnaire modules

3.2. SIP survey: Design and methods

3.2.1. Sample design

The SIP scheme level survey aims to collect SIP level data for each cropping season from *aman* 2020 to *boro* 2023. This will produce a panel of 82 SIPs observed for three years and nine cropping seasons.
Table 4 indicates for which cropping seasons the data has been and will be collected. The actual data collection is organized just after each cropping season when the harvesting is done, i.e., in April for *rabi*,

[2] This research was reviewed by the IWMI Institutional Review Board (IRB) and received an exempt certification (# #2020_25a) in November 2020.
[3] The plot selected for the crop economic section was randomly drawn by the CAPI software among the high land plots irrigated by the (future) SIP in Group A and B villages and among all high land plots irrigated in Group C.

July for *kharif* 1, and November for *kharif 2*. The actual dates partly differ for the Northern and Southern divisions to match agricultural practices and the availability of operators and sponsors. In this present baseline report, we consider three rounds of SIP survey: *kharif* 2 2020, *rabi* 2020-21 and *kharif* 1 2021[4]. This allows observing one entire year of operation for the selected SIPs.

	2020	2021	2022	2023
Kharif 1		✓✓	X	x
Kharif 2	✓✓	✓	X	
Rabi	✓✓	✓	x	

Note: ✓✓ means completed and used in this report, ✓ completed, X not completed.

Table 4 – Cropping seasons for collection of SIP scheme level data

The data is collected for a sample of 83 SIPs. The sample has been selected to be representative of the IDCOL SIPs in terms of divisions (Rangpur, Rajshahi, Khulna), type of sponsor (private company, NGO), and year of approval. However, due to a delay in the implementation of the program, SIPs approved after 2019 were not necessarily operational in *kharif*-2 2020 and *rabi* 2020-2021. To avoid losing some of the observations, these SIPs initially selected have been replaced by SIPs from the same location and same type of sponsor but approved earlier. The list of sites included in the SIP survey sample is available in Annex C.

3.2.2. SIP questionnaire

The questionnaire for the SIP scheme study is concise and includes no more than three pages. The questionnaire includes six sections which are repeated for each round of data collection, and one section on a topic defined for each round. This design allows the collection of the panel data needed for the analysis as well as to cover other subjects independent from the agricultural seasons.

Table 5 summarizes the different sections of the SIP questionnaire, and the questionnaire is provided in Annex E. The survey instrument initially developed in English is translated and administered in Bangla. The SIP survey is administered by phone and answered by the operator of each SIP. The operator is a farmer appointed by the sponsor to operate the pump, collect fees from the clients and do minor maintenance[5]. However, to simplify the call, the SIP questionnaires are circulated to the operators and to the sponsor supervisor in advance, and they pre-fill the questionnaire before the call. The schedule is fixed in coordination with the SIP sponsors so that both the operator and the sponsor supervisor are present at the time of the call. After three rounds of data collection, this organization has been validated both by the enumerator and the respondents. It avoids multiple calls, as the sponsor supervisor can back up with the missing information from the operator when needed during the call.

[4] At the time of publishing this baseline report, two more rounds of survey have been conducted and will be added to upcoming analysis.

[5] The detailed responsibilities of the operators are described in Section 5.6.

	Title	Content	Round 1 – *Kharif* 2 2020	Round 2 – *Rabi* 2020-21	Round 3 – *Kharif* 1 2021
Section 1	Introduction and consent		✓	✓	✓
Section 2	Identification		✓	✓	✓
Section 3	SIP characteristics	Technical specification, command area, other agricultural services in the SIP sites, damages	✓	✓	✓
Section 4	Coverage	Plot, farmers, and crops served	✓	✓	✓
Section 5	Fees	Fees collected from the previous season and arrear of payment	✓	✓	✓
Section 6	Operations	Time of operation (days, hours), meter reading if available, complaints	✓	✓	✓
Section 7	COVID-19	Disruption by the measures linked to the covid-19 pandemic and potential consequences on SIP operation and SIP farmers	✓		
	Operators	Socio-economic characteristics, benefits, and tasks		✓	
	Training	Training received by the operator and advisory role			✓

Table 5 – SIP questionnaire module

4. Description of the samples

4.1. Demography and socio-economic characteristics of the household sample

4.1.1. Composition of the households

The average household size for the sample of farmers in our baseline survey is 4.6, and it is the lowest for farmers in group C villages, with 4.4 being the average household size (significantly lower than group A farmers). Out of the average of 4.6 members, 1.3 members are under the age of 15. The average number of members under the age of 15 is 1.1 for group B farmers, which is significantly lower than for group A (1.4) and group C (1.4) farmers (Table 6).

In terms of gender composition, there are, on average, 1.8 male members and 1.5 female members who are 15 or above (adult) in each household. The number of adults (>=15 years) male members is highest in group B households at 1.9 members, significantly higher than group A household with 1.7 adult male members and group C households with 1.6 adult male members. In group C households, the number of female adult members at 1.4 is significantly lower than in group A (1.5 adult female members) and group B (1.6 adult female members) households (Table 6).

Group	Group A farmers (IDCOL SIP villages)	Group B farmers (Future SIP villages)	Group C farmers (Control villages)	Level of sig.	Full Sample
Number of members	4.7[a]	4.6[ab]	4.4[b]	*[1]	4.6
Number of members under the age of 15	1.4[a]	1.1[b]	1.4[a]	***[1]	1.3
Number of male members who are 15 or above	1.7[a]	1.9[b]	1.6[c]	*[1]	1.8
Number of female members who are 15 or above	1.5[a]	1.6[a]	1.4[b]	*[1]	1.5
Total	300	300	300		900

[1] Based on multiple Mann-Whitney tests accounting for family-wise error. If there is a common superscript letter between any two groups, then their group difference is not significant ($p>=0.1$), but if there is no common superscript letter, it indicates statistical significance at least at the indicated level.

Table 6 - Composition of households across three groups of villages

4.1.2. Age, gender, education of respondents, and household head

As mentioned in Section 1.4, our target in the household survey was to interview the head of the household. If the household head was not available, any other household member aware of the details concerning the household's agricultural practices was interviewed instead. Overall, in 76% of cases, the respondent was the household head. In another 12% of cases, the interview was done with the spouse, and in 8% of the cases, it was with the son of the household head.

The profile of our survey respondents is described in Table 7. The average age of the respondents in our sample is 43.5 years, and there is no significant difference across the three groups of villages (IDCOL SIP villages, Future IDCOL SIP villages, and Control villages). In 14% of the cases, the respondent was female[6]. In group B villages, the percentage of female respondents (10%) was significantly lower than in group A (17%) and group C (16%) villages.

31% of respondents in the sample did not complete any schooling (there is no significant difference across the three groups of farmers). 62% have completed schooling till class 5 or above, while 25% have completed till class 10 or above. In group B villages, the educational level of the respondents is slightly but significantly higher (67% have completed schooling till class 5 or above, while 35% have completed till class 10 or above) (Table 7).

[6] In most of these cases, the household head was male. Only 1% of the sample had female household heads.

Group	Group A farmers (IDCOL SIP villages)	Group B farmers (Future SIP villages)	Group C farmers (Control villages)	Level of sig.	Full Sample
Age (years)	43.1	44.2	43.2	n.s[1]	43.5
Female (%)	17%	10%	16%	**2	14%
No Schooling (%)	33%	27%	34%	n.s[2]	31%
Schooling completed till class 5 or above (%)	60%	67%	58%	**2	62%
Schooling completed till class 10 or above (%)	21%	35%	19%	****2	25%
Total	300	300	300		900

[1] Based on multiple Mann-Whitney tests accounting for family-wise error. If there is a common superscript letter between any two groups, then their group difference is not significant (p>=0.1), but if there is no common superscript letter, it indicates statistical significance at least at the indicated level.
[2]Based on chi-square test; **** p<0.001, *** p<0.01, ** p<0.05, * p<0.1

Table 7 - Demographic characteristics of respondents across three groups of villages

The average age of household heads is slightly higher than that of the respondents at 46.5 years, and in group B villages, the average age is even higher at 48.1 years (it is significantly higher than the age of household heads in group A and group C villages). In only 1% of cases, the household head is female, and in 98% of cases, the household head is married.

Group	Group A farmers (IDCOL SIP villages)	Group B farmers (Future SIP villages)	Group C farmers (Control villages)	Level of sig.	Full Sample
Age	45.3[a]	48.1[b]	45.9[a]	**1	46.5
Female (%)	1%	1%	2%	n.s[2].	1%
No Schooling (%)	35%	35%	37%	n.s[2].	36%
Schooling completed till class 5 or above (%)	59%	61%	54%	n.s.[2]	58%
Schooling completed till class 10 or above (%)	20%	30%	17%	****2	22%
Married	98%	98%	97%	n.s.[2]	98%
Total	300	300	300		900

[1] Based on multiple Mann-Whitney tests accounting for family-wise error. If there is a common superscript letter between any two groups, then their group difference is not significant (p>=0.1), but if there is no common superscript letter, it indicates statistical significance at least at the indicated level.
[2]Based on chi-square test; **** p<0.001, *** p<0.01, ** p<0.05, * p<0.1

Table 8 - Demographic characteristics of household heads across three groups of villages

36% of household heads did not complete any schooling, and 58% only completed schooling till class 5 or above (there is no significant difference across the three groups of farmers). Regarding higher education, 22% have completed class 10 or above. Again, in group B villages, the educational level of the household head is slightly but significantly higher (30% have completed class 10 or above)(Table 8)

SoLAR Team visits farmers in Bangladesh (*photo* : Waresul Haque)

4.1.3. Religion and tribal group

Only 1.2% of households in our sample belong to a tribal group, and there was no significant difference across the groups. In terms of religion, 66.2% of households belong to Islam, but it is significantly higher for Group B villages (77%), as compared to group A (63%) or group C (58.7%) villages (Table 9).

	HHs belonging to a tribal group (%)	Religion of HH head is Islam (%)	N
Group A farmers (IDCOL SIP villages)	1.3%	63.0%	300
Group B farmers (Future SIP villages)	1.3%	77.0%	300
Group C farmers (Control villages)	1.0%	58.7%	300
Level of significance[1]	n.s.	****	
Total	1.2%	66.2%	900

[1] Based on Chi-square test; **** p<0.001, *** p<0.01, ** p<0.05, * p<0.1

Table 9 - Characterization of sampled households according to religion and tribal group

4.1.4. Main occupation and agricultural activities by members and for the head of household

Crop cultivation is the main source of income for 71.6% of households in our sample. Although this proportion is slightly higher in group B villages (75.3%), we do not find any significant difference across these three groups (Figure 2).

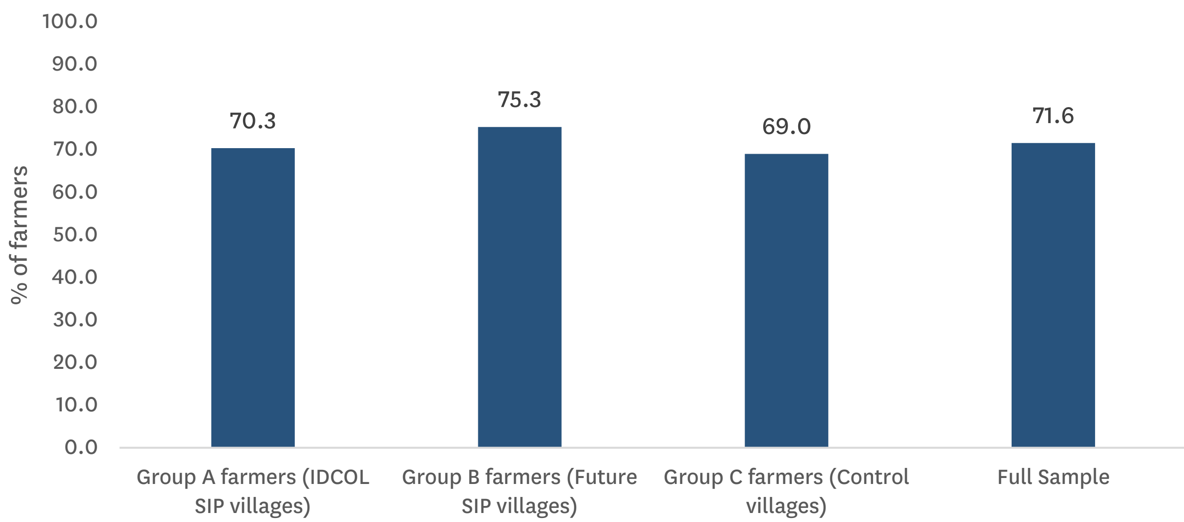


Figure 2 - Percentage of households with crop cultivation as their main source of income

In 70% of households, there is at least one adult (15 years and above) male member whose main occupation is "Self-employed farmer/ family farm worker" (Figure 3).

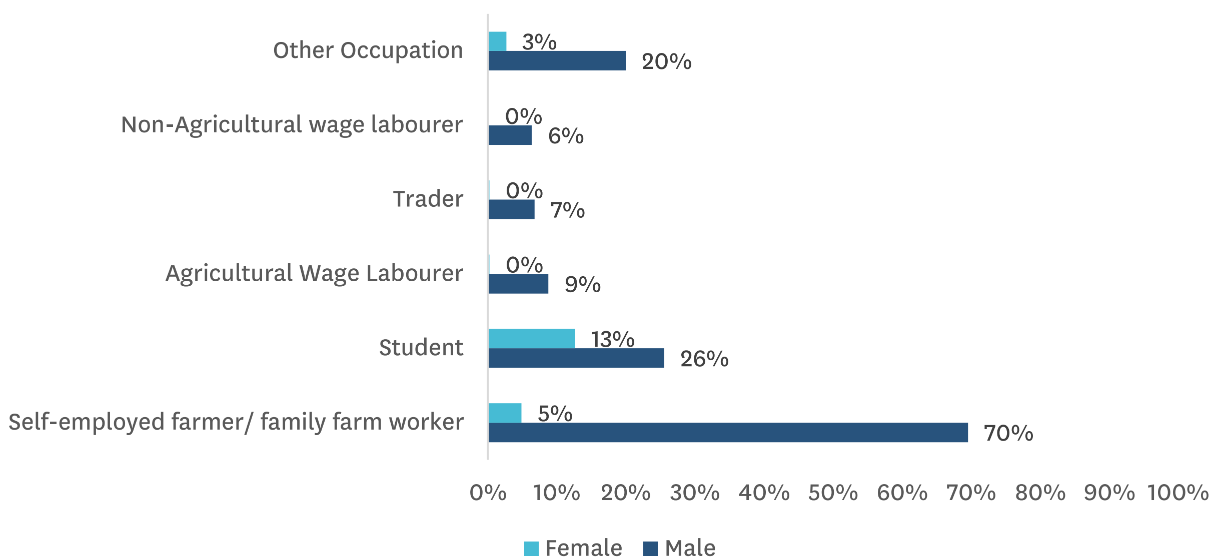


Figure 3 - Percentage of farmer households with at least one adult (male and female separately) member's main occupation across various occupation types

In comparison, only 5% of households had at least one female member with the main occupation as "Self-employed farmer/ family farm worker." 26% of households had at least one adult male member as a student, while for adult female members, it is only in 13% of the households. In terms of other major types of occupations in our sample – the percentage of households with at least one adult member's main occupation as "Agricultural wage labor" is 9%; "Trader" is 7%, and "Non-agricultural wage labor" is 6% respectively. 20% of households had at least one adult male member with various other occupation types as their primary employment (Figure 3).

We can tell that very few households have adult female members whose main occupation is agriculture. In each household, on average, 1.05 adult members have agriculture as their main occupation (i.e., self-employed farmer/ family farm worker or agricultural wage laborer); but it is 1.00 male adult members compared to only 0.05 female adult members with agriculture as the main their occupation. However, in terms of adult members participating in agriculture but not their main occupation, we find much higher involvement of female household members. Every household has, on average, 1.5 adult members participating in agriculture (without it being their main occupation), and on average, it is 1.00 female adult members and only 0.5 male adult members involved in agriculture as a secondary activity (Table 10).

	% of households with at least 1 (male/female/combined) member spending 3 months away from the house			Number of adults (male/female/combined) members with agriculture as main occupation			Number of adults (male/female/combined) members participating in agriculture (but not main occupation)			N
	Male	Female	Combined	Male	Female	Combined	Male	Female	Combined	
Group A farmers (IDCOL SIP villages)	10%	3%	11%	0.97	0.07[a]	1.04	0.53	0.95[a]	1.48	300
Group B farmers (Future SIP villages)	12%	2%	13%	1.05	0.04[b]	1.08	0.51	0.96[a]	1.47	300
Group C farmers (Control villages)	8%	2%	10%	0.97	0.05[ba]	1.02	0.46	1.09[b]	1.55	300
Level of sig.	n.s.[2]	n.s.[2]	n.s.[2]	n.s.[1]	*[1]	n.s.[1]	n.s.[1]	**[1]	n.s.[1]	
Full Sample	10%	2%	11%	1.00	0.05	1.05	0.50	1.00	1.50	900

[1] Based on multiple Mann-Whitney tests accounting for family-wise error. If there is a common superscript letter between any two groups, then their group difference is not significant (p>=0.1), but if there is no common superscript letter, it indicates statistical significance at least at the indicated level. **** p<0.001, *** p<0.01, ** p<0.05, * p<0.1

[2] Based on Chi-square test.

Table 10 - Gender disaggregated participation in agricultural activities and short-term migration

Table 10 also shows that there is no significant difference across the groups of farmers in terms of short-term migration. In terms of short-term migration, 11% of households had at least one member spending three months away from the house, and such short-term migration is mostly among male members (10% of households) (only 2% of households had female members migrating). Among the migrant households, in 30% of households with at least one migrant, the main occupation of the migrant was for studying for 30% of households, and a substantial portion of the migrants worked as salaried employees in the government or private sector respectively (Figure 4).

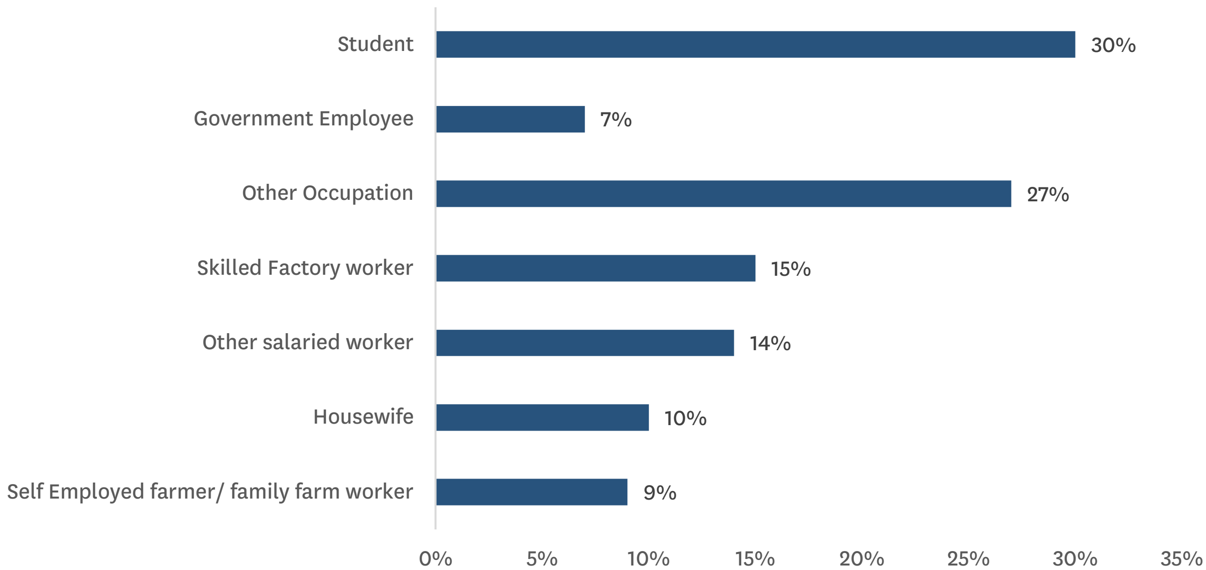


Figure 4 - Main occupation of migrants (spending 3 months away from the house) as percentage of households with at least one adult migrant member

4.1.5. Wealth indexes: domestic and agricultural assets

Two wealth indices were constructed for our household sample using principal component analysis. The first one is based on household asset ownership and characteristics of the main house, access to cooking fuel, drinking water, latrine, and bank account. The second index is constructed based on agricultural asset ownership and livestock ownership. Higher index values indicate wealthier households in the sample.

Comparing the distribution of these two wealth indices across our three groups of farmers in Figure 5, we find that for both indices, group B farmers have a fatter right tail indicating a larger share of them have a high wealth index as compared to Group A and Group C farmers. This holds true for both the agricultural asset and livestock ownership (right panel) and household asset ownership (left panel).

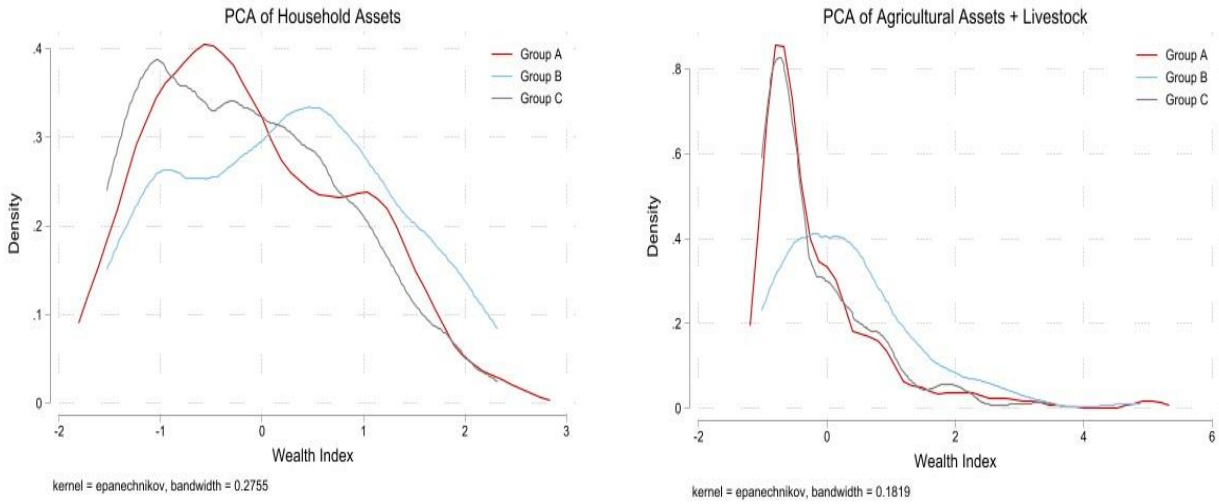


Figure 5 - Kernel density distribution of wealth indexes across three groups of farmers

This becomes even clearer if we look at the distribution of farmers in different groups across terciles[7] of wealth index in Table 11 (terciles are calculated separately for both indexes - i.e., based on household asset ownership and agricultural asset plus livestock ownership, respectively). The proportion of farmers in the highest tercile (i.e., top 33% of the sample in terms of wealth index constructed based on ownership of household or agricultural assets) is most frequent among Group B farmers. This implies sample farmers in Group B are significantly wealthier as compared to those in the other two groups.

	Wealth Index constructed from Household Asset				Wealth Index constructed from Agricultural Asset			
	Group A farmers (IDCOL SIP villages)	Group B farmers (Future SIP villages)	Group C farmers (Control villages)	Full Sample	Group A farmers (IDCOL SIP villages)	Group B farmers (Future SIP villages)	Group C farmers (Control villages)	Full Sample
Lowest tercile	34%	26%	39%	33%	48%	23%	52%	41%
Middle tercile	36%	31%	33%	33%	27%	27%	22%	25%
Highest tercile	30%	43%	27%	33%	24%	50%	25%	33%
Total	300	300	300	900	300	300	300	900

Table 11 - Distribution of farmers in different groups across terciles of wealth indexes

4.1.6. Food consumption and food security

A sizeable proportion of farmers in our sample reported at least one form of food insecurity in the last 12 months - 14% reported that they "worried about not having enough food"; 20% were "unable to eat healthy and nutritious food" and 16% "ate less than they thought they should" (Figure 6). However, in

[7] A set of data arranged in order with values that partition the data into three groups, each containing one-third of the total data.

terms of skipping a meal or not eating for a whole day, there were not many instances. The extent of food insecurity is greatest in Group C villages as compared to either group B or group A villages (for Group C farmers - 20% were "worried about not having enough food"; 28% were "unable to eat healthy and nutritious food" and 23% "ate less than they thought they should") (Figure 6).

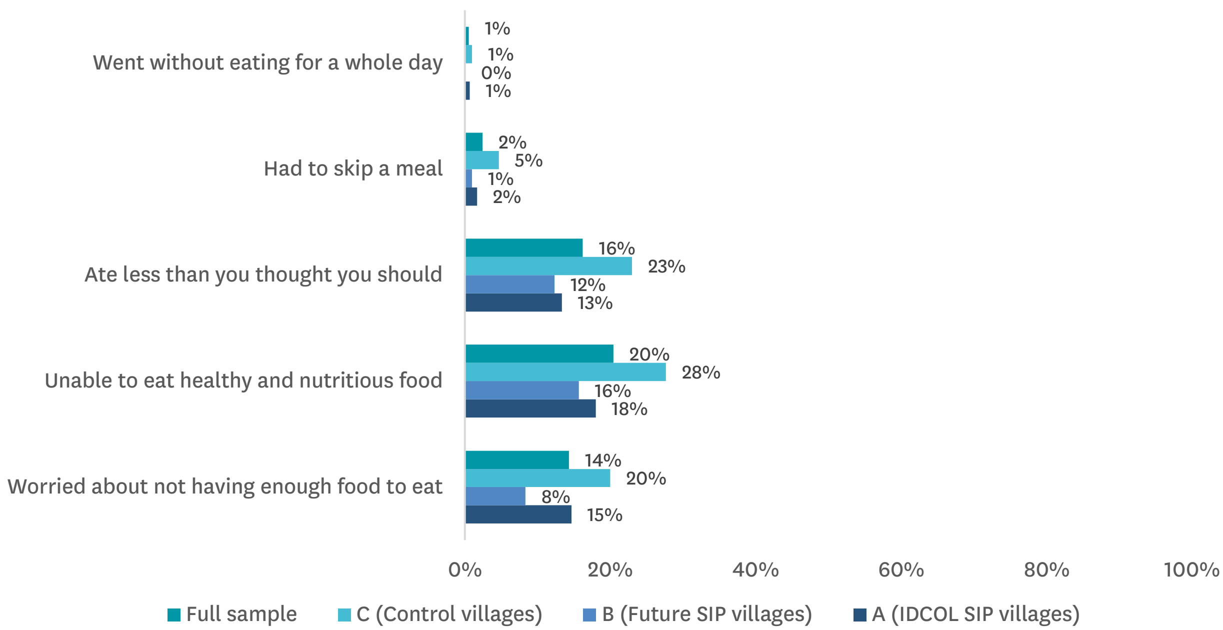


Figure 6 - Percentage of farmers across three groups of villages reporting food insecurity in the last 12 months

A farmer working in a vegetable field (*photo* : Waresul Haque, NGO-Forum)

This is also clear from Figure 7, where we can see that farmers buying water from diesel pumps or hiring diesel pump machines have significantly higher food insecurity as compared to diesel pump owners or those buying from electric or solar pumps.

Table 12 summarizes food consumption of our sample farmers in the last 24 hours across 16 major food groups. Almost 95% of households had cereals/grains, 85% had green leafy vegetables, and 84% had roots and tubers in the last 24 hours. Regarding meat consumption in the last 24 hours, only 37% of households reported having it, while 55% reported having fish or seafood in the last 24 hours.

	Group A farmers (IDCOL SIP villages) (%)	Group B farmers (Future SIP villages) (%)	Group C farmers (Control villages) (%)	Sig.[1]	Full Sample (%)
Cereals and grains	97%	92%	97%	***	95%
Roots and tubers	87%	83%	81%	n.s.	84%
Pulses, Legumes, nuts, and seeds	53%	48%	52%	n.s.	51%
Orange vegetables and tubers	26%	26%	22%	n.s.	25%
Green leafy vegetables	86%	85%	83%	n.s.	85%
Other vegetables	48%	39%	36%	***	41%
Orange fruits	30%	28%	16%	***	24%
Other fruits	31%	32%	22%	**	29%
Meat	40%	40%	31%	**	37%
Fish/seafood	52%	60%	53%	*	55%
Liver, kidney, heart, and/or other organ meats	5%	6%	1%	***	4%
Eggs	57%	46%	61%	***	55%
Milk and other dairy products	59%	58%	53%	n.s.	57%
Oil/fat/butter	80%	78%	65%	****	74%
Sugar and sweetener	51%	42%	33%	****	42%
Misc. - Condiments, spices, coffee, tea, etc.	75%	83%	67%	****	75%
Total	300	300	300		900

[1]1 Based on Chi-square test; **** p<0.001, *** p<0.01, ** p<0.05, * p<0.1

Table 12 - Consumption of various food groups in the last 24 hours

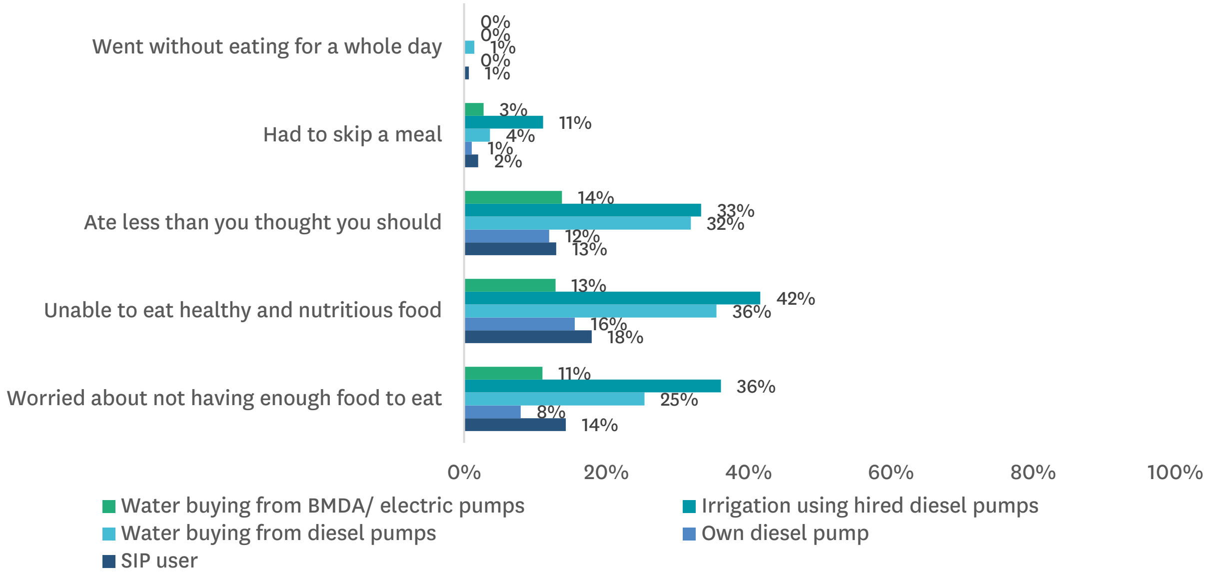


Figure 7 - Percentage of farmers across different types of water buyers reporting food insecurity in the last 12 months

Based on these 16 major food groups, we created a dietary index as the proportion of food groups consumed by the household in the last 24 hours (if all 16 food groups were consumed, the index is 1; while if only one type of food group was consumed then the index is 1/16, i.e., 0.0625). Table 13 indicates that

	Dietary Index (0-1)	N
Group A (IDCOL SIP villages)	0.55	300
Group B (Future SIP villages)	0.53	300
Group C (Control villages)	0.48	300
Full sample	0.52	900
	Dietary Index (0-1)	
SIP user	0.54	301
Own diesel pump	0.56	276
Water buying from diesel pumps	0.44	138
Irrigation using hired diesel pumps	0.46	36
Water buying from BMDA/ electric pumps	0.52	109
Total	0.52	860

Table 13 – Dietary diversity index

the overall dietary index is 0.52 (i.e., around eight major food groups consumed in the last 24 hours on average) in our sample. More interestingly, we find that the dietary index is lowest in Group C villages (0.48) which is significantly lower (based on multiple Mann-Whitney tests) than in Group A villages (0.55) and group B villages (0.53) (Table 13). Again, this could be driven by the fact that group C farmers include more water buyers from diesel pumps (or hiring diesel machines) who are relatively poorer farmers.

4.1.7. Shocks and adaptation

Almost 56% of farmers in our sample reported having experienced at least one shock/hazard in the last 12 months. It is not significantly different between group A (47%) and group B (48.3%) villages. But in group C villages, a significantly higher percentage of farmers (72%) experienced some sort of shock/hazard in the last 12 months (Table 14).

		Group A farmers (IDCOL SIP villages) (%)	Group B farmers (Future SIP villages) (%)	Level of Sig.	Group B farmers (Future SIP villages) (%)	Group C farmers (Control villages) (%)	Level of Sig.	Full Sample (%)
	Experienced any shock/ hazard in the last 12 months	47.0	48.3	n.s.	**48.3**	**72.0**	****	55.8
	N	300	300		**300**	**300**		900
Type of shock	Drought	3.5%	3.4%	n.s.	3.4%	1.9%	n.s.	2.8%
	Flood	44.7%	40.7%	n.s.	**40.7%**	**60.2%**	****	50.2%
	Cyclone/storm	1.4%	2.8%	n.s.	2.8%	4.6%	n.s.	3.2%
	Erosion	0.7%	0.0%	n.s.	0.0%	3.2%	**	1.6%
	Decline in groundwater table	5.7%	11.0%	n.s.	11.0%	1.4%	****	5.4%
	Heatwave	1.4%	0.7%	n.s.	0.7%	1.4%	n.s.	1.2%
	Pests	**28.4%**	**49.0%**	****	49.0%	36.1%	**	37.6%
	Crop diseases	**39.7%**	**57.9%**	***	57.9%	36.6%	****	43.6%
	Animal diseases	27.0%	32.4%	n.s.	**32.4%**	**18.5%**	***	24.9%
	High input prices	**9.9%**	**20.0%**	**	20.0%	3.7%	****	10.2%
	Low output prices	10.6%	16.6%	n.s.	**16.6%**	**6.5%**	***	10.6%
	Employment loss, business failure	5.0%	4.8%	n.s.	4.8%	3.2%	n.s.	4.2%
	Serious illness/death of HH members	5.0%	4.1%	n.s.	4.1%	6.0%	n.s.	5.2%
	Covid-19 disease for HH members	0.0%	0.0%	n.s.	0.0%	0.0%	n.s.	0.0%
N		141	145		145	216		502

[1] For rows 2-15; % of farmers imply those experiencing at least one shock in the last 12 months

[2] Based on chi-square test; **** p<0.001, *** p<0.01, ** p<0.05, * p<0.1

Table 14 - Percentage of farmers[1] across three groups of villages experiencing shock/hazard in the last 12 months

Among those who experienced some shock/hazard, the most important ones were flooding (50.2%), crop disease (43.6%), pests (37.6%), and animal disease (24.9%). In group C villages, mostly floods affected those who experienced shocks (at 60.2%); while in Group B villages, other kinds of shocks like pest attacks, crop, and animal diseases, along with high input price and low output prices were experienced by a significantly higher proportion of farmers (Table 14).

4.1.8. Group membership

In terms of membership in various groups or associations, Table 15 shows that 14.8% of households had at least someone as a member of a group in the last three years. There is no significant difference across farmers in these three types of villages (15.3% households in Group A, 13.0% in Group B and 16.0% in Group C villages). Regarding the type of group where farming households have a membership, "Farmer group/ cooperative/association" is the most common (69.9%), followed by "Savings/microfinance group" (30.1%). There is no significant difference between Group A and Group B in terms of group membership. However, between Group B and Group C farmers, membership in "Farmer group/ cooperative/association" is significantly higher for Group C. In comparison, membership in "Savings/microfinance group" is significantly higher among Group B farmers (Table 15).

		Group A farmers (IDCOL SIP villages) (%)	Group B farmers (Future SIP villages) (%)	Level of Sig.[2]	Group B farmers (Future SIP villages) (%)	Group C farmers (Control villages) (%)	Level of Sig.[2]	Full Sample (%)
	Anyone from HH has been a member of a group in last 3 years	15.3	13.0	n.s.	13.0	16.0	n.s.	14.8
	N	300	300		300	300		900
Type of group membership	Farmer group/ cooperative/assoc.	60.9%	61.5%	n.s.	61.5%	85.4%	**	69.9%
	Savings/micro finance group	37.0%	35.9%	n.s.	35.9%	18.8%	*	30.1%
	Other Group	4.3%	10.3%	n.s.	10.3%	14.6%	n.s.	9.8%
N		46	39		39	48		133

[1] For rows 2-4; % of farmers imply those with at least one household member in any group in last 3 years [2] Based on chi-square test; **** p<0.001, *** p<0.01, ** p<0.05, * p<0.1

Table 15 - Percentage of farmers[1] across three groups of villages with someone from the household as a member of a social group in last three years

In Figure 8, we compare the percentage of households with any household member, friend, or relative in institutional positions (currently or in the last three years). Overall, 6.8% of households report having someone in the Union Parishad (local administration at the Union level), while 5.9% have someone in any local NGO (non-government organization). Only 2.4% had someone in Government administration at a level higher than Union Parishad. There is no significant difference across Group A, B, and C farmers in terms of having someone in institutional government administration positions at the Union Parishad level or higher. The likelihood of holding an institutional position in a local NGO is slightly (but significantly) lower among Group B households (1.3%) when compared to Group A (6.0%) or Group C (10.3%) households. Additionally, in Group A villages, 3.3% of households had someone in an institutional position within an IDCOL sponsor organization, while it is 2.3% in Group B villages (no significant difference).

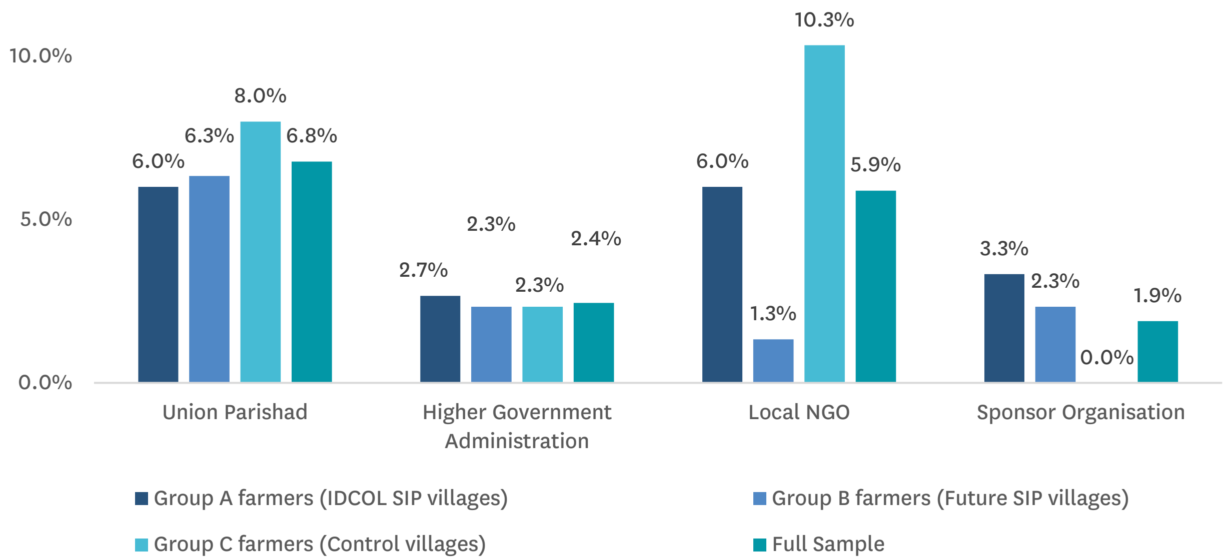


Figure 8 - Percentage of farmers across three groups of villages with someone from household holding institutional position in the last three years

More than three-quarters (77%) of our respondents in Group A villages indicated that they had close acquaintance with the SIP operator: for 64% of respondents, the SIP operator is a friend/neighbor. But there is also a meaningful number of the respondents who were directly related to the SIP operator (i.e., household member/self - 3% or relative – 8%) (Figure 9).

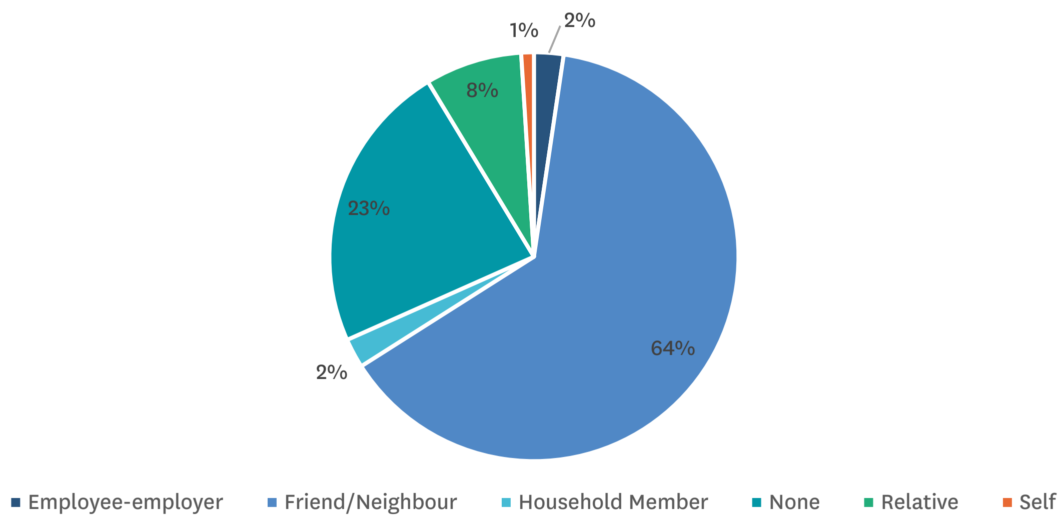


Figure 9 - Relationship with SIP operator in Group A villages (IDCOL SIP villages)

4.1.9. Source of information

Most farmers (81%) had at least one source to receive advice or information on agricultural-related questions (Table 16). There is a bit of variation in the source to access agricultural information among the three groups of farmers – access is highest in Group A villages, with 84% reporting to have at least one source of information on agriculture, followed by Group C villages with 81.3% and the lowest in Group B villages at 77.7% (Table 16).

		Group A farmers (IDCOL SIP villages) (%)	Group B farmers (Future SIP villages) (%)	Level of Sig.[2]	Group B farmers (Future SIP villages) (%)	Group C farmers (Control villages) (%)	Level of Sig.[2]	Full Sample (%)
	Has at least one source of information on agriculture	84.0%	77.7%	**	77.7%	81.3%	n.s.	81.0%
	N	300	300		300	300		900
Source of Information for those with at least 1 source	DAE / Govt. Agricultural Extension Agent	39.3%	51.1%	***	51.1%	27.5%	****	39.1%
	SIP operator	11.9%	5.6%	**	5.6%	0.0%	****	5.9%
	Officials from the Sponsor/ IDCOL	5.6%	2.6%	*	2.6%	0.4%	**	2.9%
	TV/ Radio/ Newspaper/Internet	5.2%	6.4%	n.s.	6.4%	3.3%	n.s.	4.9%
	Farmer group/cooperative/ MFI/ SHG	10.3%	5.2%	**	5.2%	14.8%	****	10.2%
	Local input dealers/ traders	35.3%	42.5%	n.s.	42.5%	52.9%	**	43.5%
	Other farmers in the village	56.3%	54.5%	n.s.	54.5%	69.7%	****	60.2%
N		252	233		233	244		729

[1] For rows 2-7; % of farmers imply those with at least one source of information

[2] Based on chi-square test; **** p<0.001, *** p<0.01, ** p<0.05, * p<0.1

Table 16 - Percentage of farmers[1] across three groups of villages using different sources to receive advice or information on the agricultural-related questions

"Other farmers in the village" is the primary source of information on agriculture-related questions for most farmers (60.2% in the total sample) across all three groups of farmers (in group C villages, it is reported by 69.7% of farmers, significantly higher). Other significant sources of information are "Local input dealers/ traders" (43.5%) and "DAE / Government Agricultural Extension Agents" (39.1%). For group C farmers, "Local input dealers/ traders" are the second most important source of information (52.9%); while "DAE / Government Agricultural Extension Agents" are the second most important source among group B (51.1%) and Group A (39.3%) farmers.

Interestingly SIP operators and officials from the sponsor organizations/IDCOL have become an important source to receive advice or information on agricultural-related questions for farmers in IDCOL SIP villages (i.e., Group A). For group A farmers, 11.9% reported SIP operator as a source of information, and 5.6% reported Sponsor/IDCOL officials. Moreover, in Group B villages, 5.6% of farmers use SIP operators as sources of information, and 2.6% use Sponsor/IDCOL officials. Since SIP operation has not yet started fully in Group B villages, this is expected to increase in the future.

A SoLAR installation with rainwater harvesting facility (*photo* : Waresul Haque, NGO-Forum)

4.1.10. Training

In Table 17 we describe the training received by sample farmers on different agricultural topics in the last five years. Around 14.9% of farmers in our sample reported having received at least one training on an agricultural topic in the last five years. There is no significant difference across the three groups of villages. Among those farmers who received at least one training, 59% received training on "Seed selection (classification, selection criteria, production technique),"; followed by 20.1% receiving on "Insect and Pest management," 15.7% on "Paddy nursery bed preparation," 14.9% on "Crop choice"; 10.4% on fertilizer management and 9.7% on "agricultural credit" (Table 17). NGOs were the provider for 53% of households that received some training in the last five years, followed by DAE providing training to 48% of the households. IDCOL, BADC, and Agricultural Universities accounted for less than 5% of the households receiving training.

We did not find any significant difference in the topic of training amongst Group A or Group B farmers (except "Insect and Pest Management" training being significantly higher among Group B farmers). Similarly, Group B and Group C farmers are not significantly different except that training on "agricultural credit" and "cropping calendar" is significantly higher for group C farmers, while training on "Paddy nursery bed preparation" is significantly lower for Group C farmers (Table 17).

		Group A farmers (IDCOL SIP villages) (%)	Group B farmers (Future SIP villages) (%)	Level of Sig.[2]	Group B farmers (Future SIP villages) (%)	Group C farmers (Control villages) (%)	Level of Sig.[2]	Full Sample (%)
Any household member has received at least one training in the last 5 years		14.0	14.7	n.s.	14.7	16.0	n.s.	14.9
N		300	300		300	300		900
Topic of training for those with at least one training in the last 5 years	Seed selection (classification, selection criteria, production technique)	54.8%	63.6%	n.s.	63.6%	58.3%	n.s.	59.0%
	Paddy nursery bed preparation	19.0%	20.5%	n.s.	20.5%	8.3%	*	15.7%
	Maintenance of underground pipes and cleaning of pipes and riser	2.4%	2.3%	n.s.	2.3%	0.0%	n.s.	1.5%
	Use of hose pipe for irrigation	0.0%	2.3%	n.s.	2.3%	0.0%	n.s.	0.7%
	Development and maintenance of improved earthen channels	0.0%	0.0%	n.s.	0.0%	0.0%	n.s.	0.0%
	Irrigation scheduling	0.0%	4.5%	n.s.	4.5%	10.4%	n.s.	5.2%
	Optimum Irrigation methods for different crops	2.4%	9.1%	n.s.	9.1%	8.3%	n.s.	6.7%
	Water saving technologies (AWD, direct seeded rice, drip or sprinkler irrigation)	7.1%	4.5%	n.s.	4.5%	0.0%	n.s.	3.7%
	Choice of crops	14.3%	11.4%	n.s.	11.4%	18.8%	n.s.	14.9%
	Insect and pest management	11.9%	27.3%	*	27.3%	20.8%	n.s.	20.1%
	Fertilizer management	7.1%	13.6%	n.s.	13.6%	10.4%	n.s.	10.4%
	Harvesting procedures	0.0%	4.5%	n.s.	4.5%	2.1%	n.s.	2.2%
	Agricultural credit	4.8%	0.0%	n.s.	0.0%	22.9%	***	9.7%
	Cropping calendar (date of transplanting, irrigation, harvesting)	2.4%	2.3%	n.s.	2.3%	14.6%	**	6.7%
	Marketing the harvest	2.4%	0.0%	n.s.	0.0%	2.1%	n.s.	1.5%
	Post-harvest transformation	4.8%	0.0%	n.s.	0.0%	4.2%	n.s.	3.0%
	N	42	44		44	48		134

[1] For rows 2-17; % of farmers imply those with at least one training in the last five years

[2] Based on chi-square test; **** p<0.001, *** p<0.01, ** p<0.05, * p<0.1

Table 17 - Percentage of farmers[1] across three groups of villages receiving training on different agricultural topics in the last five years

Training on agricultural topics (and especially irrigation-related ones) is low in general, and this is the case even in IDCOL SIP villages. Although in IDCOL SIP villages, training on improved agricultural and irrigation practices is provided to farmers, this has not led to a significant rise in the number of farmers reporting to have received any training. This indicates the scope for more widespread training to be provided in IDCOL SIP villages, which can be beneficial not just for the farmers but also for the sponsors providing solar irrigation services business.

4.2. Characteristics of the SIP sample

The representative sample of SIPs for this seasonal survey includes SIPs located in three districts of Bangladesh: Khulna, Rangpur, and Rajshahi. The North-West Region, including both Rangpur and Rajshahi, accounts for 67.8% of the SIPs installed by IDCOL and is therefore overrepresented in the sample with 68% of the selected sites.

The below map (Figure 10) presents the location of the selected SIPs and that of all IDCOL-installed SIPs.

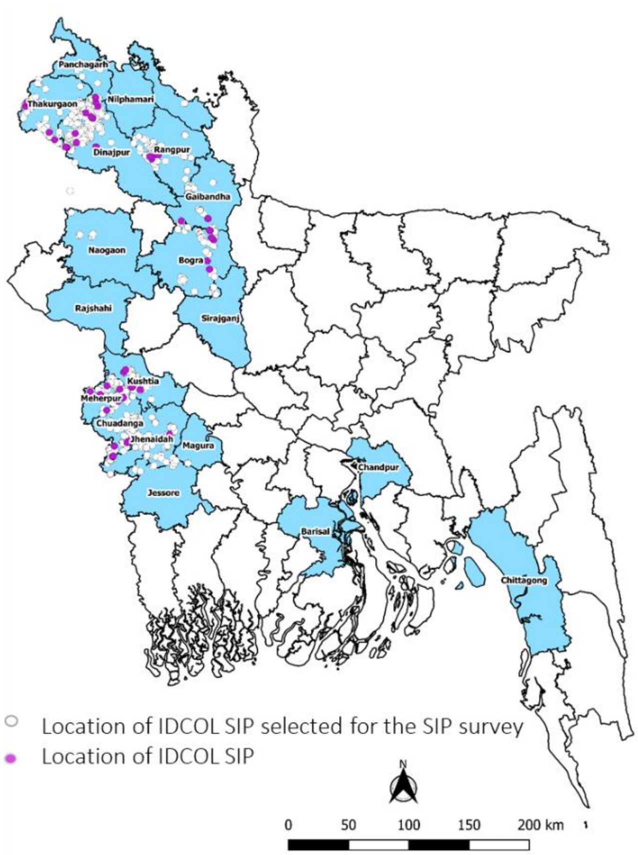


Figure 10 – Location of IDCOL SIPs and sampled sites

As mentioned above, the year of approval was also considered a criterion for the representative sampling. In 2020 when the sample was selected, the largest share of SIPs was approved in 2017 (24%) and 2018

(30%), which matches the growth in project implementation during this period. From the SIP survey, we also collected the date of the beginning of operation for the SIP (Figure 11). As expected, there is a 12 to 18 months delay between the approval and the start of operation. This gap has tended to have increased during the COVID-19 pandemic due to constraints in movement, transport, and fieldwork but it is said to be back to normal for newly installed SIPs. The third criterion for selecting SIP was the type of sponsor: NGO or private company. In the sample and the total number of IDCOL SIPs approved by 2020, 30% of the SIP are operated by NGO sponsors, while the rest of the SIPs are operated by private companies. All the IDCOL SIPs led by NGOs are located in the South-West (Khulna), and there is, therefore, 80% of the SIPs in the South-West which are run by NGO sponsors, while private companies run all the SIPs in the North-West. In total in the SIP sample, there are SIPs from 16 sponsors, which are also called partner organizations.

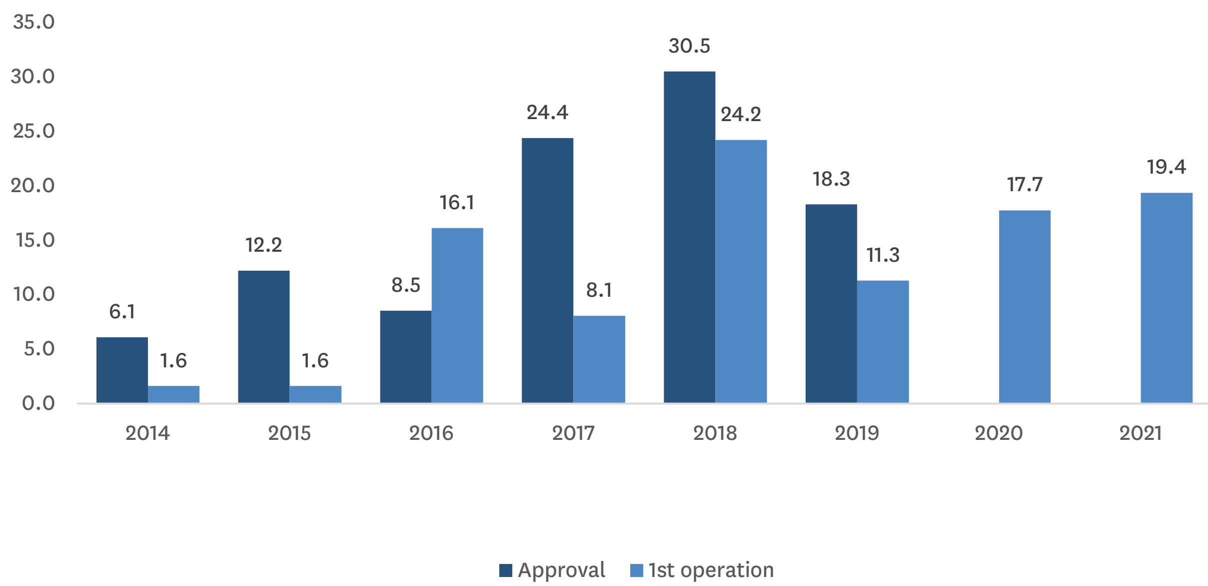


Figure 11 – Share of sampled SIPs by date of approval and start of operation

This sampling allows having a large range of technical characteristics within the selected sample. For example, the panel capacity ranges per second, it ranges from a minimum of 20 to a maximum of 97, as declared by the operators. Another proxy for measuring the flow rate of the SIP used the time required to irrigate one unit of land. On average, it takes 2 hours to irrigate 1 acre in the head tail of the SIP command area, 3 hours to irrigate 1 acre in the middle of the command area, and 4.5 hours to irrigate 1 acre that would be located in the tail end of the SIP command area. Beyond these averages, there is a high heterogeneity, as confirmed by the density graphic (Figure 12).from 10 to 43 KW. Similarly, while the average flow rate is 66 liters[8]

[8] This flow rate is the technical flow rate of the pump and differ from the flow rate at one riser point delivering water to one plot.

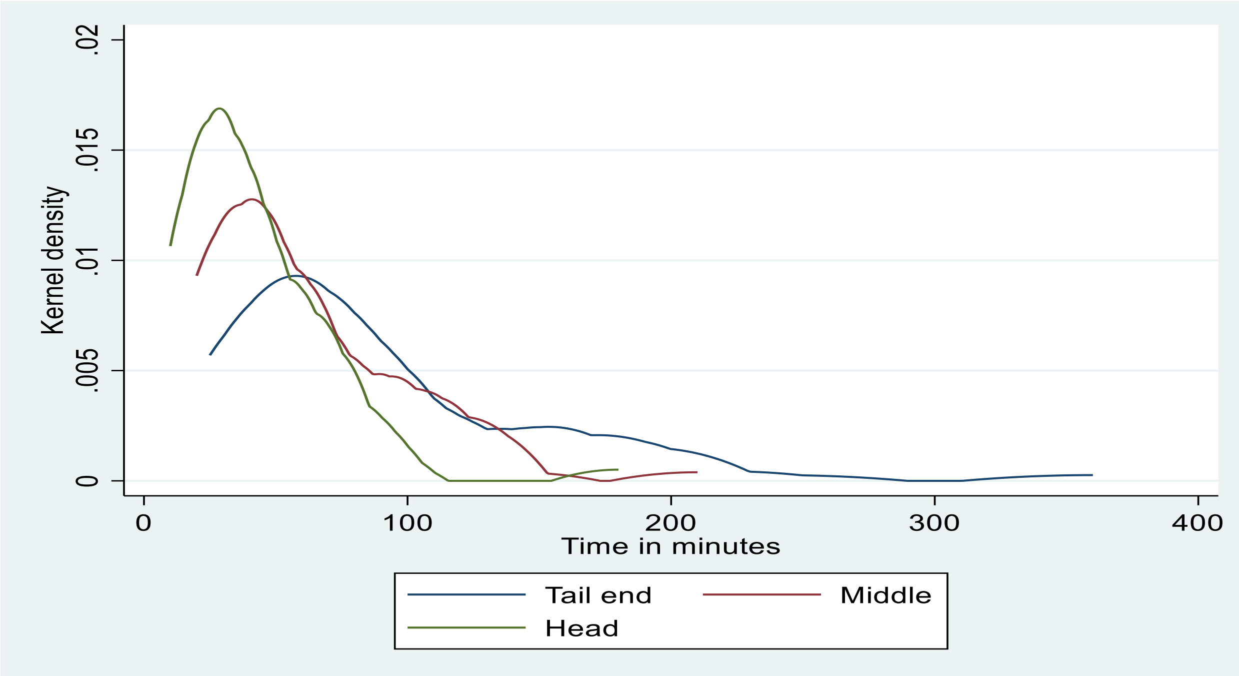


Figure 12 – Kernel density estimates of the time to irrigate one bigha of land by selected SIPs

5. Key results from the baseline data

5.1. Conversion from diesel to solar irrigation and diesel consumption

5.1.1. Pump and tube well ownership

In our sample, 60.2% of farmers have their own pump, and 57.8% of farmers have their own tube well (Table 18). There is, however, a substantial difference across our three groups of villages in Bangladesh in terms of tube wells and pump ownership. We find that ownership of own tube well and own pump is lowest in IDCOL SIP villages (45.3% and 51%, respectively), while it is highest in group B villages, i.e., villages which are selected for future SIP installation by IDCOL sponsors (69.7% own their own tube well and 71% own their own pump). In control villages, approximately 58% of farmers own their own tube well and own pumps (Table 18). The IDCOL SIPs are targeted in off-grid areas with diesel-based irrigation, and the lowest pump ownership among IDCOL SIP water buyers indicates that at least some of the erstwhile pump-owners in this group must have sold off their diesel pumps after the installation of the SIP. Irrigating using own electric pump ownership is very low in our sample (only 0.7%), and this is slightly higher in group B villages (future IDCOL SIPs). However, there is no significant difference across the groups in terms of irrigating using own electric pump (Table 18).

Village Group	% farmers owning tube well/borewell	% farmers owning (diesel + electric) pump	% farmers irrigating using own electric pump	N
A (IDCOL SIP villages)	45.3%[a]	51.0%[a]	0.0%	300
B (Future SIP villages)	69.7%[b]	71.0%[b]	1.7%	300
C (Control villages)	58.3%[c]	58.7%[a]	0.3%	300
Sig.[1]	***	***	n.s.	
Total	57.8%	60.2%	0.7%	900

[1]Based on multiple Chi-square tests accounting for family-wise error (Bonferroni adjustments). If there is a common superscript letter between any two groups, then their group difference is not significant (p>=0.1), but if there is no common superscript letter, it indicates statistical significance at least at the indicated level.

Source: Authors' calculation based on household survey data

Table 18 - Percentage of farmers across three groups of villages (IDCOL SIP villages, Future IDCOL SIP villages and Control villages) owning tube wells and pumps

A women farmer holding Taro (Colocasia esculenta) (*photo* : Waresul Haque, NGO-Forum)

5.1.2. Irrigation sources at the farm level

Table 19 summarizes the sources of irrigation across our three groups of farmers, where we find that in group A farmers (i.e., for buyers from IDCOL SIPs), 24% are still irrigating using their own diesel pump, 8% are buying water from diesel pump owners and 6% hiring diesel pumps from others. Since SIP farmers have an area outside the command area of the solar pump, those are still irrigated using diesel pumps. Only 2% of farmers in group A villages are buying from electric pump owners.

In group B villages where future SIPs are planned, the penetration of electric pumps is also quite low. Most of the farmers (68%) are using their own diesel pump, and 33% are buying water from diesel pump owners. Interestingly in Group C villages, the penetration of electric pumps is higher, with 13% buying water from electric pump owners and 23% buying water from BMDA pumps which are electrically powered. There is also a substantially high number of farmers in group C villages who are using diesel pumps (35% irrigating using their own pumps, 24% from buying from diesel pump owners, and 12% are hiring diesel pump machines to irrigate their plots) (Table 19).

	% of farmers irrigating by								
Village Group	Own diesel pump	Water buying from diesel pump owner	Hiring diesel machine	Own electric pump	Water buying from electric pump owner	Hiring electric machine	Buying from BMDA pump	Buying from SIP	N
A (IDCOL SIP villages)	24%[a]	8%[a]	6%[a]	0%	2%[a]	0%	1%[a]	96%[a]	300
B (Future SIP villages)	68%[b]	33%[b]	3%[a]	1%	1%[a]	0%	2%[a]	4%[b]	300
C (Control villages)	35%[c]	24%[c]	12%[b]	0%	13%[b]	0%	23%[b]	0%[c]	300
Sig.[1]	**	**	**	n.s.	****	n.s.	****	***	
Total	43%	22%	7%	1%	5%	0%	9%	33%	

[1]Based on multiple Chi-square tests accounting for family-wise error (Bonferroni adjustments). If there is a common superscript letter between any two groups, then their group difference is not significant (p>=0.1), but if there is no common superscript letter, it indicates statistical significance at least at the indicated level.

Table 19 - Percentage of farmers irrigating using different sources across three groups of villages

So, the use of diesel pumps is significantly lower in IDCOL SIP villages, as expected. Overall, the proportion of farmers irrigating using their own diesel pump is substantially higher as compared to buying water from diesel pump owners or hiring diesel machines to irrigate, and this is more so among group B farmers.

5.1.3. Diesel use within the SIP command area

The primary motivation for introducing solar pumps in Bangladesh has been to reduce diesel use in irrigation because of its negative environmental externalities and high cost. From the SIP survey, we find evidence of very limited diesel use within the SIP command area as shown in Figure 13. Within the SIP command area, the use of diesel is just 8% during *kharif* 1 (i.e., the *boro* season), 3% during *kharif* 2 (i.e., the *aman* season), and 22% during *Rabi* season. This reduction of diesel use within the SIP command area points to the success of solar pumps in replacing diesel-based irrigation, especially if we consider the total

Source: Authors' calculation based on SIP survey data cultivated area of SIP farmers. They were previously irrigating from 100% diesel (from their own pump or buying) and now have 70% of their total irrigated area from the solar pump in *kharif* 1, 95% in *kharif* 2, and 51% in *rabi*.

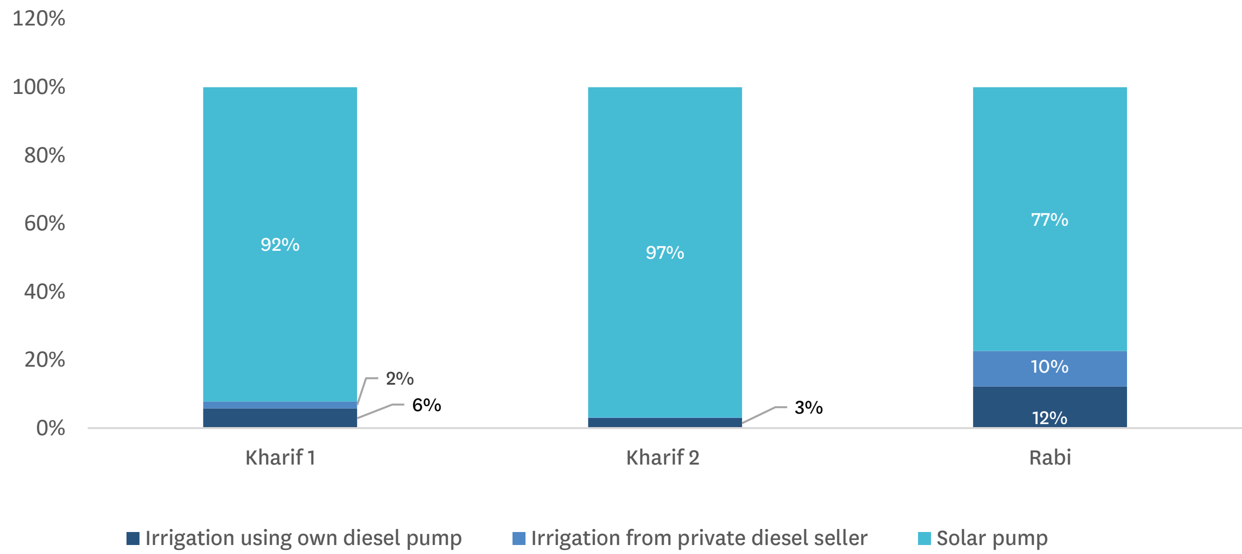


Figure 13 – Percentage of the SIP command area irrigated by different sources
Source: Authors' calculation based on SIP survey data

The slightly higher use of diesel during *rabi* season is related to the fact that for vegetable cultivation (generally grown during *Rabi*), controlled application of water is required. With a very high flow rate from solar pumps, this is not always possible, and the use of smaller diesel pumps becomes necessary. SIPs are installed in areas that were predominantly irrigated from diesel pumps, and they are designed to be able to deliver the irrigation needs for a determined command area even in the peak season of the *boro* crops. While we note above that the share of the SIP command area not irrigated by the SIP is limited, we check the proportion of SIP with at least some irrigation from non-solar sources in Figure 14. We note that during the 2020 *kharif* 2 season, 53% of the SIPs had diesel pumps operating within their command area.

This figure matches with only 50% of the SIP being operated during the 2020 wet season. Facing erratic or delayed rainfall, farmers need supplementary irrigation for their *aman* crop. When the SIP cannot deliver this service, they have to rely on diesel pumps. On average, for the SIP where such supplementary irrigation from diesel pumps is used, the percentage of SIP command area receiving at least some irrigation from the diesel pumps is still quite low during the *kharif* 2 season.

During the *kharif* 1 season as well, some farmers with plots within the SIP command area use diesel pumps. On average, 12% of the SIPs used some supplementary irrigation from diesel pumps and 2% from electric pumps during the 2021 *kharif* 1 season (Figure 14). Contrary to the situation observed during the *kharif* 2 season, all the SIP are operated in *kharif* 1. We, therefore, assume that diesel pumps are used in case of high demand when the irrigation needs for the *boro* crop cannot be satisfied with minimal delay. Yet, this is be supplemented.

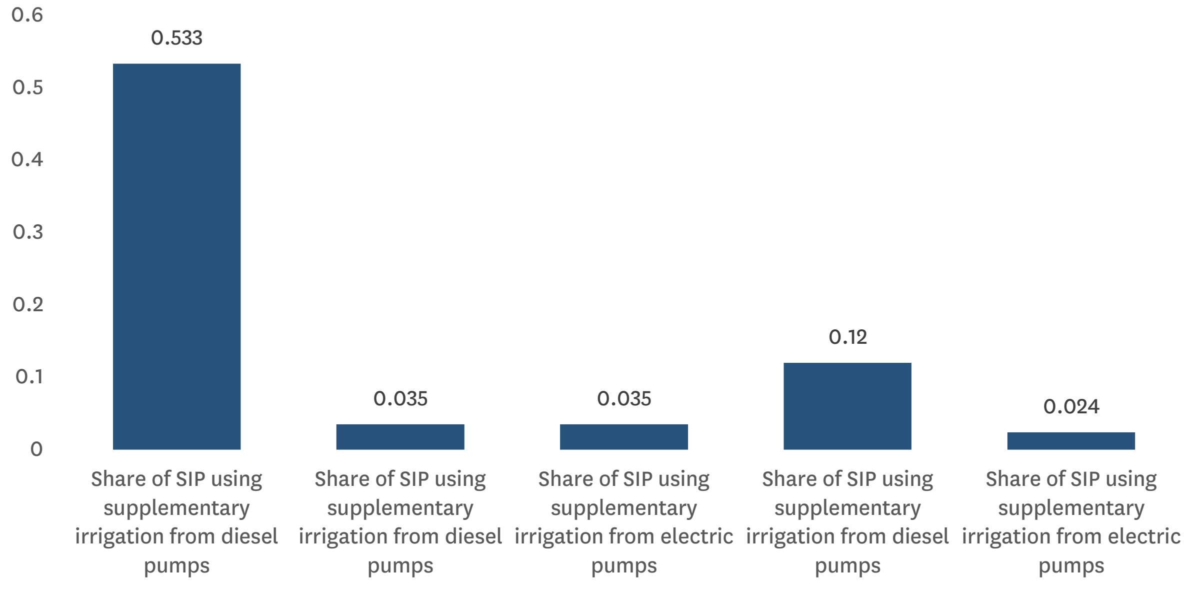


Figure 14 – Supplementary irrigation within the SIP command area

5.2. Co-benefits: cost, time, and satisfaction

5.2.1. Tariffs of irrigation from SIP

The tariffs for the irrigation service are set up by each SIP with guidance from the sponsor and from IDCOL at an initial stage. From Figure 15 we can see that for the paddy crops (*aus*, *aman* and *boro*) most of the SIPs operate with seasonal contractual arrangements with the farmers. In those cases, the agreement is for serving the irrigation needs of the crop for the entire season. Even for *aman,* for which we would expect the irrigation to be provided only as complementary to rainfall, still, 90% of the arrangements were on a

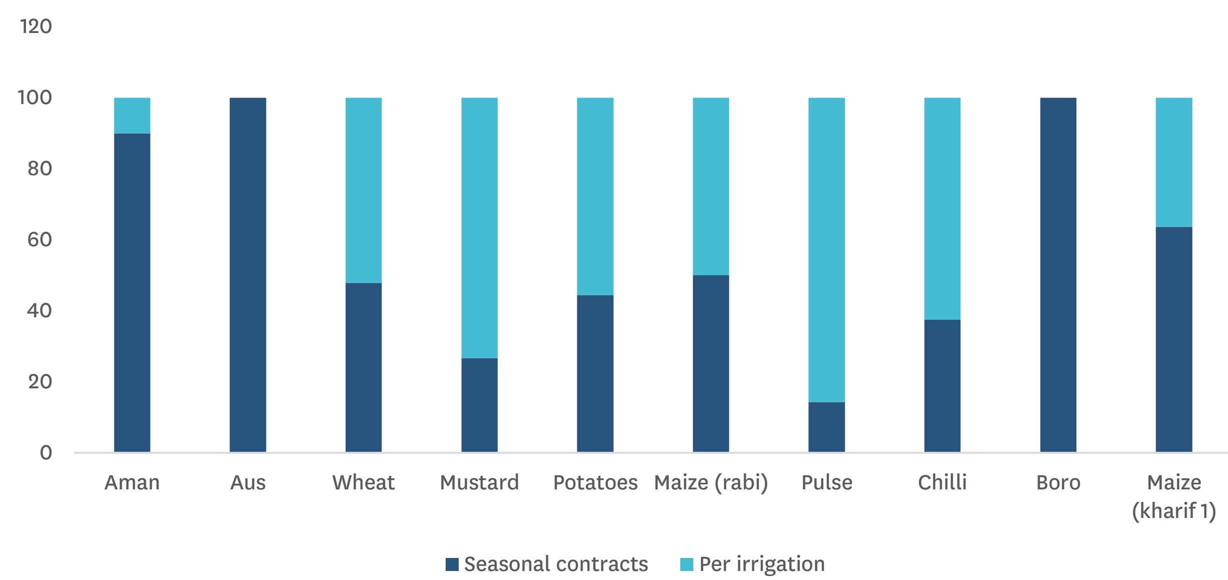


Figure 15 – Contractual arrangement for irrigation services

seasonal basis (Figure 15). For other crops requiring a lower number of irrigations, the arrangements vary between SIPs with both irrigation-based arrangements and seasonal contracts.

The average tariffs are calculated for each crop's main type of contract. For *boro*, on average, the tariff per acre for the entire season was 5950 BDT. There seems to be a significant difference between the tariff in North-West and in South-West with a higher tariff in the former. Yet when the seasonal tariff is divided by the actual number of irrigations provided, this difference becomes significantly positive, with the South-West tariff being slightly lower instead. The difference in seasonal tariff is, therefore mostly led by the difference in the number of irrigations reflecting the characteristics of the plots. The same holds true for other crops and especially *aman*. (Table 20)

		North West	South West	Difference	Combined
Aman	Tariff of irrigation per acre per season	2467.1	3558.5	-1091.3**	3316.0
	Tariff of irrigation per irrigation for one acre	713.8	529.9	183.8	572.8
Aus	Tariff of irrigation per acre per season		2813.8		2813.8
	Tariff of irrigation per irrigation for one acre		408.1		408.1
Wheat	Tariff of irrigation per irrigation for one acre	465.6	717.1	-251.5**	654.2
Mustard	Tariff of irrigation per irrigation for one acre	531.3	696.9	-165.6*	614.1
Potatoes	Tariff of irrigation per irrigation for one acre	452.2			465.1
Maize (*rabi*)	Tariff of irrigation per acre per season		3181.8		3181.8
Boro	Tariff of irrigation per acre per season	5319.9	7335.7	-2015.8***	5949.8
	Tariff of irrigation per irrigation for one acre	249.5	201.1	48.3*	234.4
Maize (*kharif*1)	Tariff of irrigation per acre per season	1993.2	3080.5	-1087.2**	2614.5
	Tariff of irrigation per irrigation for one acre	457.6	533.0	-75.3	484.2

Note: ***, ** and * indicate significance at 1%, 5% and 10% level, respectively, for the T-test of difference between NorthWest and SouthWest

Table 20 – Tariffs of irrigation by crop and location

5.2.2. Cost of irrigation for farmers

Based on the household data, Table 21 shows that the cost of irrigation (i.e., the out-of-pocket expense on irrigation by water buyers) at the plot level from solar pumps is 20-30% cheaper than buying water from diesel pumps in the case of *boro*, and it is slightly cheaper in case of Maize but not significantly cheaper[9] (the two most important summer crops in North-West Bangladesh). The savings are much more in cases where irrigation requirement is higher (i.e., savings is higher in highland plots or for *boro* cultivation).

	Cost of Boro irrigation (BDT/acre)			Cost of Maize irrigation (BDT/acre)		
	Plot not in lowland	Plot in lowland	Combined	Plot not in lowland	Plot in lowland	Combined
Diesel private seller (N=117/164/281) paddy; (N=70/26/96) maize;	8053[a]	6958[a]	7414[a]	3429	2940	3296
Electric private (N=26/13/39) paddy; (N=3/0/3) maize;	5927[b]	4861[b]	5571[b]	2546		2546
BMDA (N=34/46/80) paddy; (N=2/0/2) maize;	5331[b]	5707[ab]	5547[b]	1438		1438
Solar pump IDCOL (N=119/143/343) paddy; (N=24/23/47) maize;	5561[b]	5490[b]	5518[b]	3007	2610	2813
Sig.[1]	**	**	**	n.s.	n.s.	n.s.
All plots	5747	5486	5595	2328	2175	2278

[1] Based on multiple Mann-Whitney tests accounting for family-wise error. If there is a common superscript letter between any two groups, then their group difference is not significant (p>=0.1), but if there is no common superscript letter, it indicates statistical significance at least at the indicated level.

Table 21 - Cost of irrigation across different irrigation sources for *Boro* and Maize

[9] although number of maize plots are much lower, implying a lower power of our tests

5.2.3. Perception of irrigation service among water buyers

IDCOL solar pumps are run by sponsor organizations (private or NGO) to provide an irrigation service business to the farmers. To understand the quality of service provided by IDCOL SIPs vis-à-vis diesel pump owners and electric pump owners, we look at the perception of water buyers on different aspects of the irrigation service delivery in Figure 16.

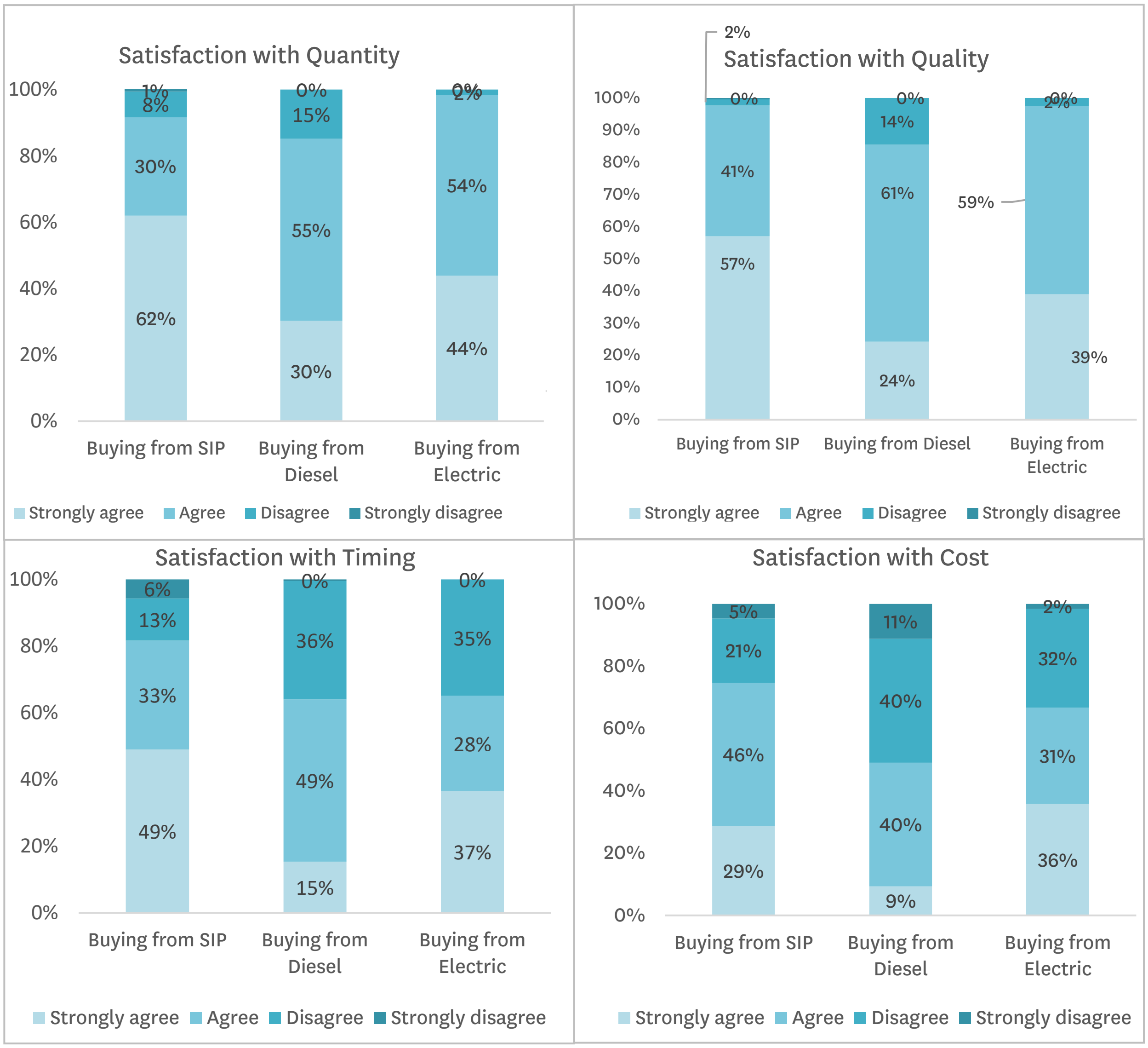


Figure 16 - Satisfaction about irrigation service amongst water buyers from solar, diesel, and electric pumps, respectively

In terms of the quantity and quality of water received from the seller, the percentage of water-buyers who did not agree that they were satisfied is very low when buying from solar pumps (9% for quantity and 2% for quality) or electric pumps (2% for both quantity and quality). The percentage of water-buyers who strongly agree that they were satisfied with the quantity (62%) and quality (57%) of service is highest among buyers from solar pumps, vis-à-vis diesel, or electric pumps. In terms of whether irrigation was received at adequate timing, we find that dissatisfaction is substantially higher amongst water buyers from electric (35%) or diesel pump (36%), as compared to solar pumps (only 19%). Again, the proportion of buyers who strongly agree that they were satisfied with the timing of irrigation service is highest among solar pump buyers (49%) in comparison to electric pump buyers (37%) or diesel pump buyers (15%). Finally, given the very high cost of diesel, we find that 51% of respondents among diesel pump buyers were not satisfied with the cost of irrigation, much higher than the dissatisfaction amongst electric pump buyers (34%) and solar pump buyers (26%).

So based on the reported satisfaction level, we find that SIPs have clearly higher satisfaction levels amongst the water buyers in terms of timing and cost of irrigation. While in terms of quantity and quality of irrigation, the satisfaction level is similar between electric and solar pump buyers, and they are better than diesel pump water buyers. The slightly higher dissatisfaction about the quantity of water amongst water buyers from SIPs (9%) over electric pumps (2%) could be related to the fact that in some locations, due to fog during early *boro* season, the water supply from solar pumps gets affected, which is not the case for electric pump sellers who can sell throughout the day and night.

5.2.4. Irrigation time allocation

One of the key contrasts of buying irrigation from a solar pump under IDCOL's fee-for-service model compared to irrigating using a diesel pump is the associated time spent on irrigation. If a farmer is using his own diesel pump or hiring it from another farmer to irrigate his plots, it involves a lot of associated activities – to carry the pump from home to the field, install it at the borewell, start the engine and then control irrigation delivery on the plot, with close monitoring to switch off the pump when irrigation is completed, so as not to waste expensive diesel. The pump also then needs to be carried back from the field to the home. All of this requires either paying a laborer for irrigation purposes or the farmer himself needs to spend time in the field to oversee irrigation (which can be valued in terms of the opportunity cost of lost wages). While in the case of fee-for-service solar irrigation, a lot of the work is done by the operator – like operating the pump, controlling the irrigation delivery, and monitoring the plots till irrigation demand is met. The farmer still needs to contact the operator or maybe spend some time in the field to monitor when irrigation is being provided, but the time requirement should be substantially lower as compared to diesel pump irrigation. In our sample, 99% of SIP water buyers agree that they saved time due to their access to SIP.

In terms of how the saved time in irrigation is used by farmers, the most frequent response was income-oriented activities (59.5%), followed by personal time like resting, eating etc. (55.3%), on household care-work like taking care of children or the elderly (30.2%), engagement in the community (6.9%) and capacity building (5.8%). This again highlights the fact that time saved from managing irrigation is used for earning income from other activities. Figure 17 and Figure 18 describe the time saved in irrigation when buying from solar irrigation pumps as compared to other sources by calculating the total time spent on irrigation-related activities (normalized per acre in Figure 18) on a typical day during the *boro* season by our sample farmers.

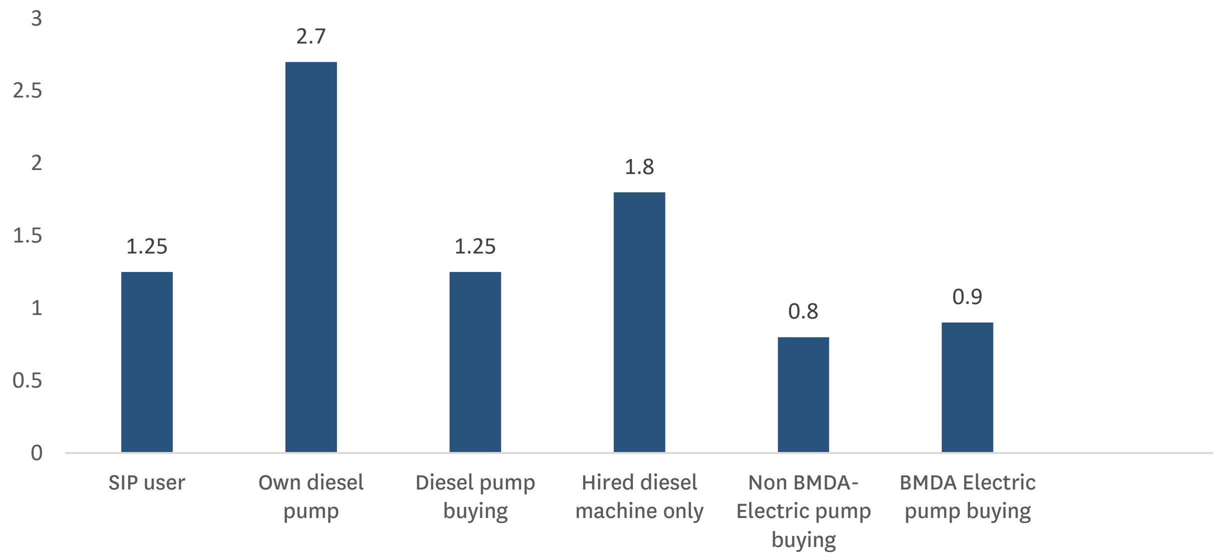


Figure 17 - Average hours spent on irrigation on a typical day during the *Boro* season

We find that the time spent for irrigation is significantly lower if irrigation is bought from a fee-for-service IDCOL solar pump (1.3 hours/day) as compared to irrigating using own diesel pump (2.6 hours/day) or hired diesel machines (1.8 hours/day) (Figure 17). Interestingly, the savings in time comes from the fact that the solar pumps in our sample are part of an irrigation service business. The time spent is not significantly different if the irrigation service provider is a diesel pump owner (1.3 hours/day) or even lower if the service provider is an electric pump owner (0.8 hours/day) (Figure 17).

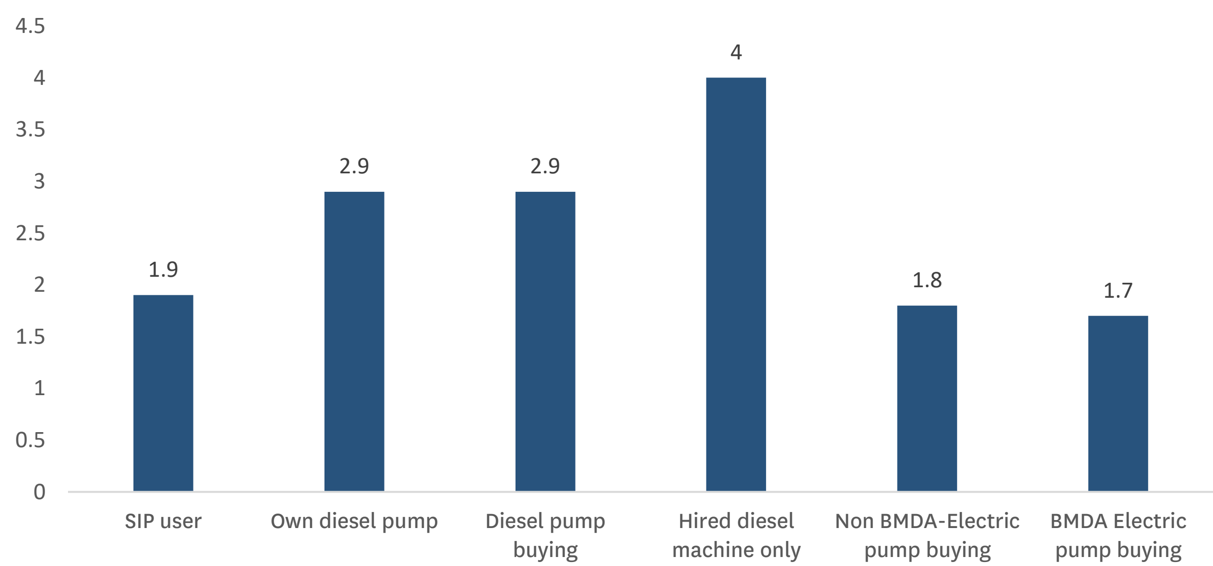


Figure 18 - Average hours per acre spent on irrigation on a typical day during the *Boro* season

To quantify this time-saving in monetary terms for a *boro* cultivator in North West region, we assume 18 irrigations are required in total (mean number of irrigations for *boro* in our household sample in the North West region). It implies water buyers from an IDCOL SIPs, save 23.4 hours/ season as compared to own diesel pump users and 9 hours/season as compared to hired diesel machine users. The median daily wage rate for men in our sample villages varied between 400 BDT/day (normal time) – 500 BDT/day (peak time). Assuming a working day of 8 hours and a normal time wage rate, water buyer from an IDCOL SIP, saves in terms of lost wages around 1170 BDT/ season as compared to own diesel pump user and 450 BDT/season as compared to hired diesel machine user.

5.3. Farmers' characteristics and SIP users

5.3.1. Area and type of land cultivated

Table 22 summarizes the farmer's characteristics across three groups of villages in our sample. We find that the net cropped area per farmer is 1.25 acres, and the total owned area for agriculture is 1.26 acres in our sample on average, and there is significant variation across the three groups of farmers. Group B farmers have the largest net cropped area on average (1.53 acres), which is significantly higher than the net cropped area for group A farmers with 1.27 acres, which in turn is significantly higher than group C farmers at 0.93 acres. Similarly, total owned land is significantly higher for Group B (1.78 acres) farmers compared to group A (1.1 acres) and group C (0.91 acres) farmers. So, on average, group B farmers own more land than they themselves cultivate, which is the opposite of group A or Group C farmers who own less land than they cultivate (Table 22).

	Net Cropped Area (in acre)	Cropping Intensity (%)	Total owned area for agriculture (in acres)	Number of plots	Average plot size (in acres)	Proportion of cultivated area within SIP command area	N
Group A farmers (IDCOL SIP villages)	1.27[a]	204[a]	1.10[a]	2.5[a]	0.52[a]	78%[a]	299
Group B farmers (Future SIP villages)	1.53[b]	217[b]	1.78[b]	3.1[b]	0.51[ab]	2%[b]	300
Group C farmers (Control villages)	0.93[c]	201[a]	0.91[c]	2.0[c]	0.53[b]	0%[b]	298
Sig.[1]	***	****	**	****	*	****	
Full Sample	1.25	207	1.26	2.5	0.52	26%	897

[1] Based on multiple Mann-Whitney tests accounting for family-wise error. If there is a common superscript letter between any two groups, then their group difference is not significant (p>=0.1), but if there is no common superscript letter, it indicates statistical significance *at least* at the indicated level.

Table 22 – Farmer's characteristics across three groups of villages

This result may be related to the sampling design: while in group A and B villages, surveyed households were selected within the (future or actual) command area of IDCOL SIPs, in group C villages, a random sample of the farming households was selected among all the villagers.

Cropping intensity is 207% on average for our sample farmers, and it is slightly but significantly higher for group B farmers (217%) compared to either group A (204%) or group C (201%) farmers (Table 22). On average, each household has 2.5 plots, with an average plot size of 0.52 acres. The average plot size is slightly (but significantly) higher in group C villages, while the number of plots is significantly higher in group B villages (3.1 plots). In IDCOL SIP villages (group A), 78% of the total cultivated area is within the SIP command area, with the remaining 22% still irrigated by mostly diesel pumps outside of the SIP command area. There is also 2% of the cultivated area for group B farmers within the SIP command area already (Table 22). This is because, in one of the future SIP villages, the operation of SIP has already started during the time of the survey.

Overall, 26% sample farmers are marginal farmers (i.e., total cultivated area <=0.5 acres), 46% are small farmers (i.e., total cultivated area >0.5 acres & <=1.5 acres) and the rest 28% are medium and large farmers cultivating more than 1.5 acres[10]. We find there is substantial variation across the three groups of villages – in group A proportion of marginal farmers is 25%, which is higher than that in group B villages with 16% marginal farmers but substantially lower than group C villages with 38% marginal farmers (Figure 19). The proportion of medium and large farmers (i.e., >1.5 acres) is lowest in group C villages (15%) compared to group A (30%) and group B (39%) villages (Figure 19). This may be related to how these locations for IDCOL SIPs are chosen, by targeting diesel-operated and *boro* cultivating areas, probably with more diesel pump owners and larger farmers.

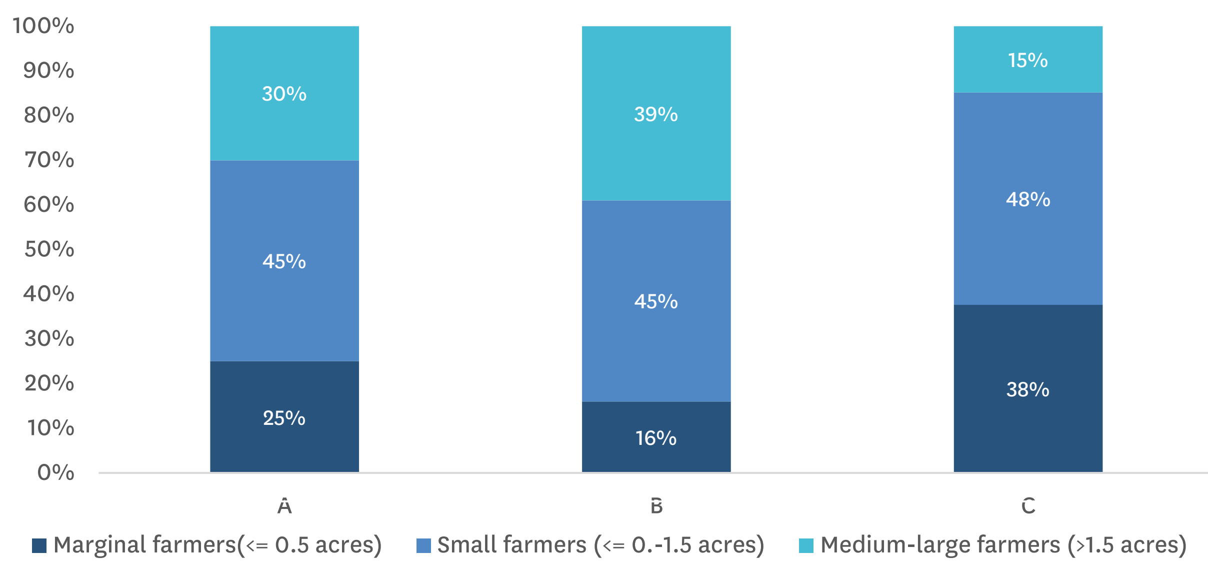


Figure 19 - Farmer composition in terms of land holdings across three groups

[10] In the Household Income and Expenditure Survey (HIES) 2010 report by Bangladesh Bureau of Statistics, rural households are classified based on land size into landless, 0.01-0.04; 0.05- 0.49; 0.50 - 1.49; 1.50 - 2.49; 2.50 -7.49; 7.50+. In IFPRI's "Agricultural Technology Adoption in the FEED THE FUTURE Zone of Influence in Bangladesh", the above classification is simplified into four groups - (<0.5 acres) marginal; (0.5 - 1.49 acres) small; (1.5 - 2.49 acres) medium; and (> 2.5 acres) large farmers. We have further clubbed the largest 2 groups as medium + large farmers.

The SIP survey allows us to focus on the SIP users. We compare the area of land cultivated by the beneficiaries across the season in Figure 20. While in 2020 *kharif* 2 season, there were 62% of the clients who were marginal farmers cultivating less than 0.5 acres of land; those were 47% during the 2021 *kharif* 1 season. Upcoming rounds of the SIP survey will be used to determine if this responds to an evolving sample of farmers served in different seasons, if there is a seasonal trend or if, over time, smaller farmers drop out from the SIP command area.

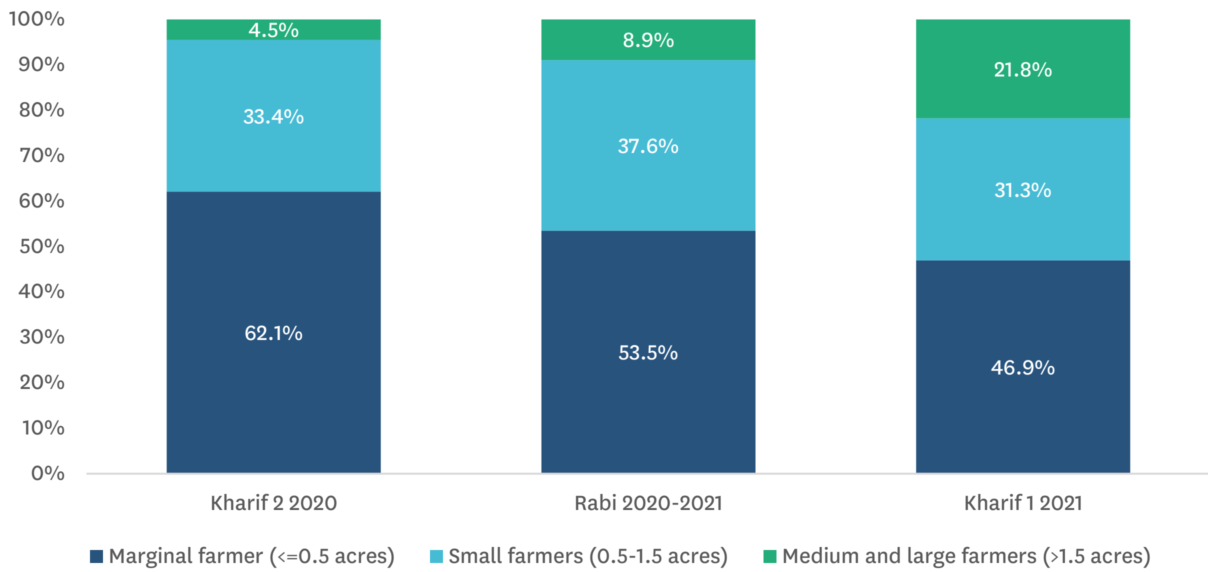


Figure 20 – Area cultivated by SIP farmers

5.3.2. Tenancy status

The plots receiving irrigation from the SIP can belong to farmers who own that plot or to sharecroppers who have taken the land on share or leased in the land. From the SIP survey, on average, during the 2020 *kharif* 2 season, 36% of the plots benefiting from SIP irrigation services were not cultivated by their owner and were instead cultivated by a sharecropper (10%) or a leaser (26%) (Figure 21).

Compared with secondary data indicating 11% of tenant-only farmers in Khulna and 17% in Rajshahi, this may indicate relatively more active land markets in the SIP command area.

Since the pool of clients' farmers and the area served evolve from one season to the other, we also note seasonal differences. In the *kharif* 1 season, i.e., when all the plots of the command area require irrigation, it is only 58% of the plots which are cultivated by their owner.

This result is in line with the household survey. Table 23 below describes the tenancy status for farmers in our sample and we find that among group A farmers, only 65% of the total cultivated area is owned and cultivated by households themselves, and the rest is either leased in, share-cropped in or mortgaged in. This is significantly different as compared to group B farmers, with 79% of the total cultivated land being owned and cultivated by household themselves (only 21% under tenancy contracts or mortgaged in); while among group C farmers, 73% of the total cultivated area is owned and cultivated by the households (Table

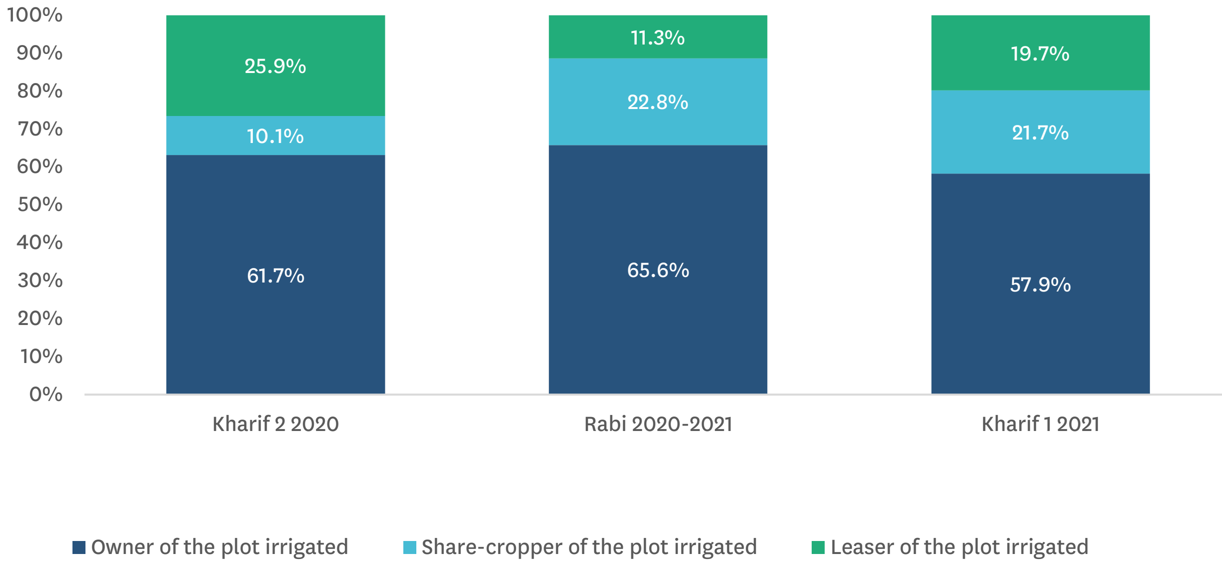


Figure 21 – Land tenure of the SIP irrigated plots

23). This indicates that current IDCOL SIPs are serving a considerable higher number of tenants and sharecroppers in its command area. In terms of leased-out or shared-out land out of the total owned area of the sample farmers, we find that overall, only 5% of the owned land is shared-out, and 3% is leased-out among the total land owned by our sample farmers. Across groups, the main difference is that group B sample farmers have a slightly higher portion (5%) of their own land that is leased out, which is significantly higher than that for group A (2%) or group C (1%) farmers (Table 23).

	Share of total cultivated area					Share of total owned land			
	Own & cultivated by HH	Leased in	Shared-in	Mortgaged in	N	Own & cultivated by HH	Leased out	Shared-out	N
Group A farmers (IDCOL SIP villages)	65%[a]	12%[a]	10%[a]	13%[a]	297	92%[ab]	2%[a]	6%	245
Group B farmers (Future SIP villages)	79%[b]	7%[b]	5%[b]	9%[ba]	300	89%[b]	5%[b]	5%	268
Group C farmers (Control villages)	73%[b]	11%[ab]	3%[b]	12%[a]	299	95%[a]	1%[a]	4%	246
Sig.[1]	***	***	***	**		***	*	n.s.	
Full Sample	72%	10%	6%	12%	896	92%	3%	5%	759

[1] Based on multiple Mann-Whitney tests accounting for family-wise error. If there is a common superscript letter between any two groups, then their group difference is not significant (p>=0.1), but if there is no common superscript letter, it indicates statistical significance *at least* at the indicated level.

Table 23 - Tenancy Status of total cultivated area and total owned land for farmers in various farmers' group

Comparing the tenancy status of plots based on their irrigation sources in Figure 22, we find that solar irrigated plots are more likely to be leased-in, share-cropped in or mortgaged-in compared to plots irrigated by electric pumps or those irrigated using own diesel pump. The plots irrigated by buying water from diesel pump owners are even more likely to be leased-in, share-cropped in or mortgaged in.

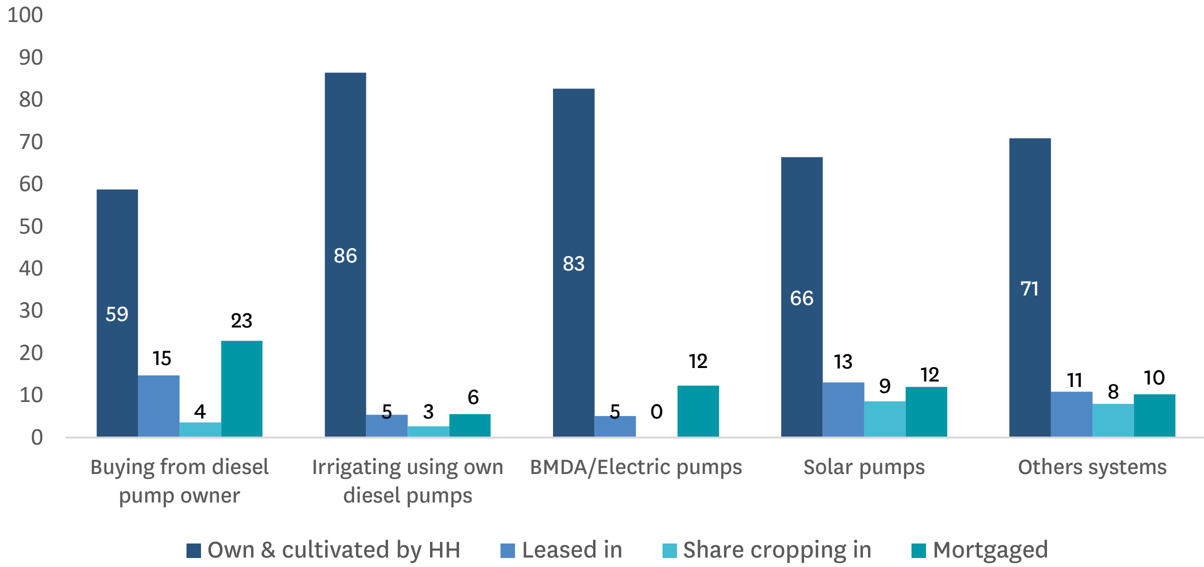


Figure 22 - Tenancy status of plots irrigated by various irrigation sources

A group of farmers in a rice field (***photo*** **: Waresul Haque, NGO-Forum)**

5.4. Cultivated area and crop choices

5.4.1. Cultivated area

In the five-year period between 2017-18 to 2020-21, the total cultivated area increased significantly from 1.2 acres to 1.34 acres for group A farmers, while for group B and group C farmers, there were no significant changes[11] (Table 24).

	Total cultivated area (in acres)				Percentage of farmers cultivating *Boro*			
	2017-18	2020-21	Sig.[1]	N	2017-18	2020-21	Sig.[1]	N
Group A farmers (IDCOL SIP villages)	1.20	1.34	****	299	86%	94%	****	300
Group B farmers (Future SIP villages)	1.67	1.55	n.s.	297	78%	82%	****	300
Group C farmers (Control villages)	0.96	0.97	n.s.	297	77%	85%	****	300
Level of sig.[2,3]	**	**			**	****		
Full Sample	1.28	1.29	****	895	80%	87%	****	900

[1] Wilcoxon Sign Rank test; [2] For continuous variables, we use Mann-Whitney rank sum test; [3] For categorical variables, we use chi square test

Table 24 - Changes in cropping pattern in the current year vis-à-vis five years back across three groups of farmers

The proportion of farmers who are cultivating *boro* increased from 80% to 87% during this five-year period, and the largest increase in *boro* farmers was among group A farmers (eight percentage point increase) (Table 24).

If we categorize our sample based on the source of irrigation, we find that between 2017-18 to 2020-21, the total cultivated area has increased slightly (but significantly) from 1.25 acres to 1.27 acres (p-value<0.001 for Wilcoxon signed rank test). The increase in net total cultivated area was highest for SIP users, from 1.22 acres to 1.38 acres (p-value<0.001) (Figure 23). For water buyers from diesel pump owners, it increased very slightly from 0.66 acres to 0.72 acres (p-value<0.05) & for water buyers from electric/BMDA pumps, it increased from 0.89 acres to 0.99 acres (p-value<0.1) (Figure 23). On the other hand, for farmers irrigating using their own diesel pump, there was a decline in the total cultivated area from 1.82 acres to 1.63 acres (p-value<0.1) (Figure 23).

[11] The cropping pattern five year back is reported by farmers in our survey in 2021 and hence is likely to have some recall bias, but it is unlikely that the recall bias to be systematically different across the three groups.

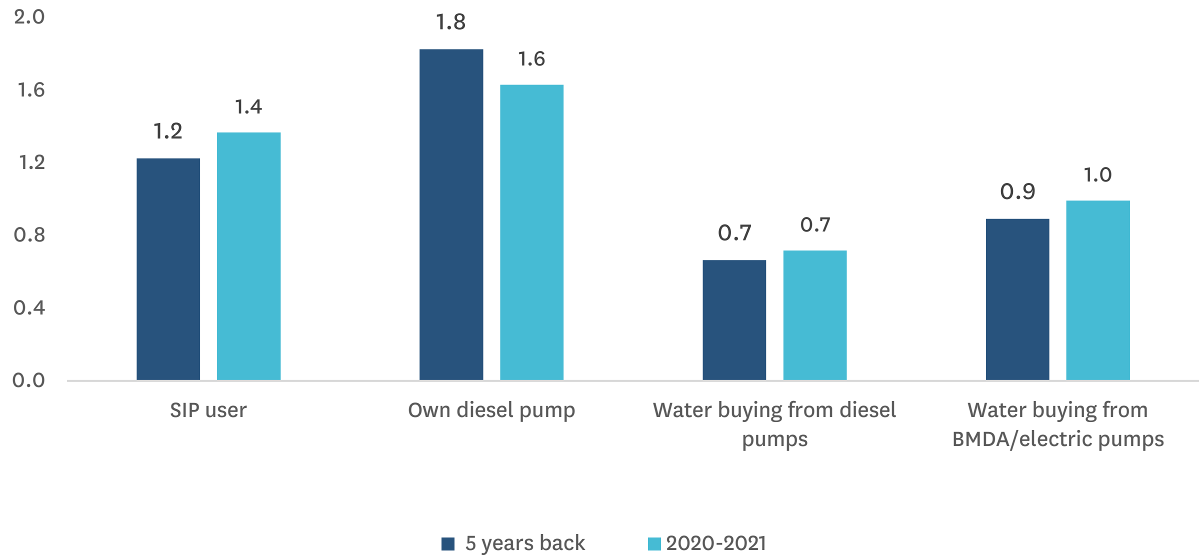


Figure 23 - Total cultivated area (in acres) of main types of irrigation users in the current year vis-à-vis five years back

5.4.2. Cropping patterns

From the SIP survey, we note a difference between North-West and South-West in terms of operation and coverage, which can be explained by regional cropping patterns (Figure 24). *Boro* occupied the largest share of the SIP irrigated area for both regions in the *kharif*1 season, as does *aman* in the *kharif*2 season. In *kharif*2, we still note that 13% of the SIP command area in South West is cultivated with *aus.* During the *rabi* season, when cultivated and irrigated by the SIP, the command area is mostly used to grow potatoes in North West (55%) while more diverse crops are found in the South-West including tobacco (27%), wheat (17%), maize (20%) and diverse vegetables (22%) (Figure 24).

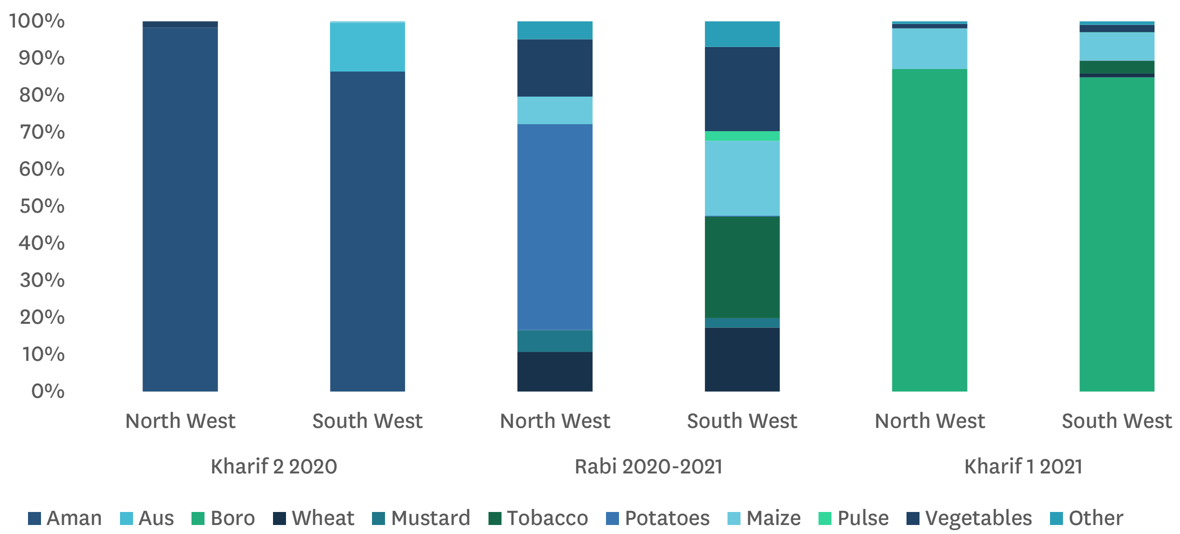


Figure 24 – Cropping pattern by season and location

At the farmer level and over this five-year period, there is also an increase in the percentage of farmers cultivating *boro* from 80% to 87% overall; but the increase is highest among SIP users from 85% in 2017-18 to 94% in 2020-21 (Figure 25). The smallest increase in percentage points was for those irrigating using their own diesel pumps, from 80% to 84% in the five-year period (Figure 25). Thus, in terms of total cultivated area and percentage of farmers cultivating *boro*, we find the largest increase for SIP users in the last five years.

The prevalence of *boro* cultivation among SIP irrigated plots is also clear if we look at cropping patterns across major irrigation sources. A significantly larger number of plots are cultivating *boro* when irrigated using solar pumps (84%) or electric pumps (89%) as compared to diesel irrigated plots (either own pump (61%) or bought irrigation (58%) (Figure 26).

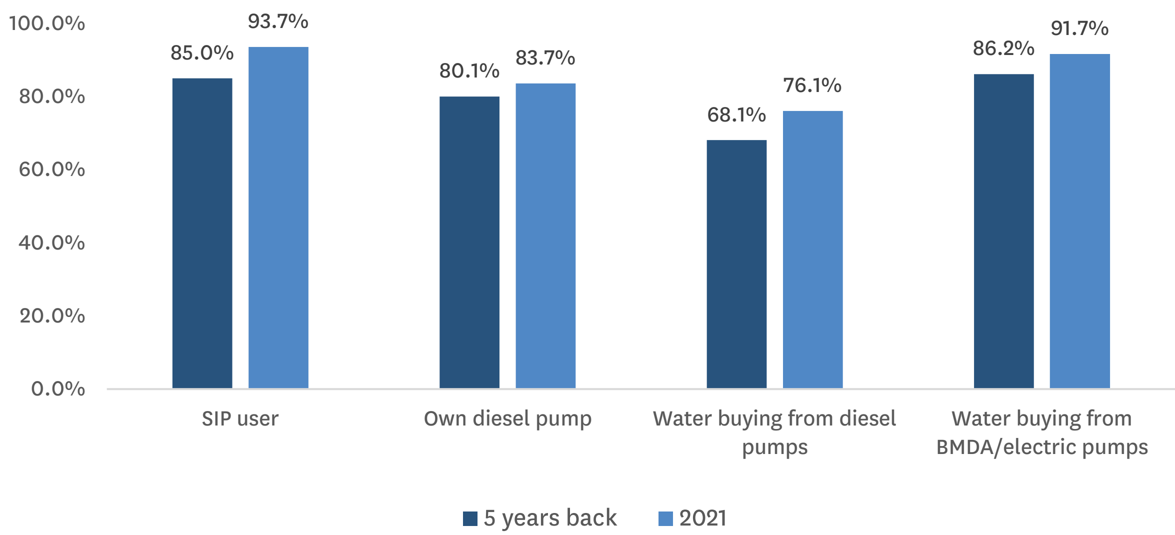


Figure 25 - Percentage of farmers cultivating *boro* across the main type of irrigation users in the current year vis-à-vis five years back

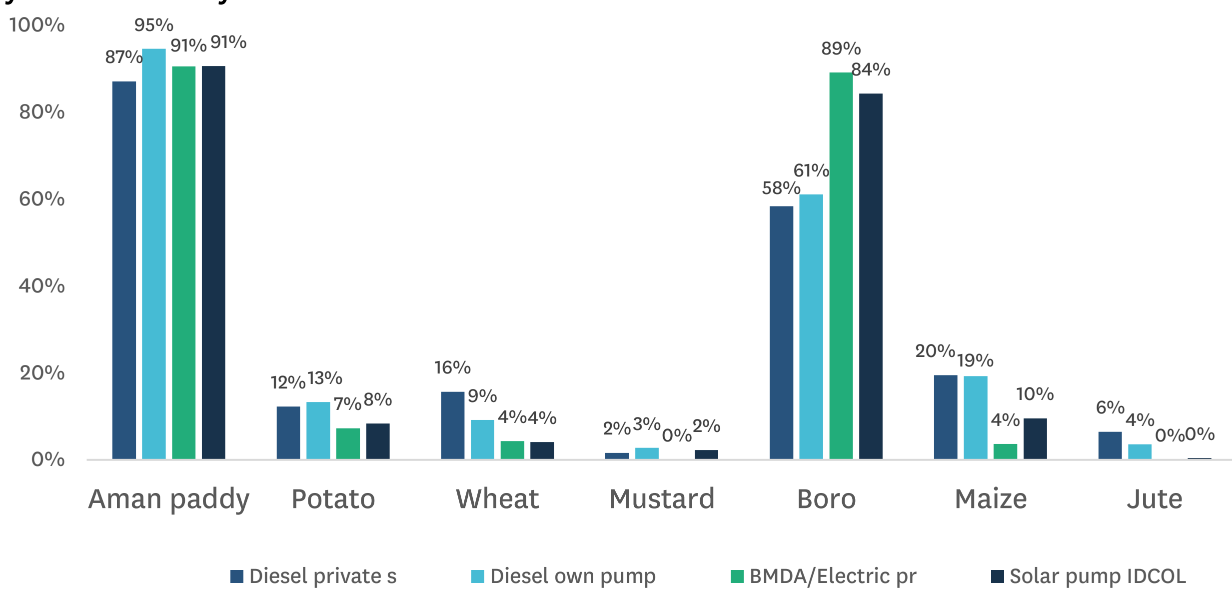


Figure 26 - Percentage of farmers growing different crops across irrigation sources

There is not much difference in *Aman* rice cultivation (in ~90% plots) across different irrigation sources (Figure 26). But since *boro* cultivation is less in diesel irrigated plots, farmers tend to grow a greater number of short-duration crops like maize, jute, wheat, potato, and other vegetables in those plots after *Aman* rice in monsoon. Hence, there is more crop diversity (non-paddy) in diesel irrigated plots in our sample. This is also reflected in the fact that diesel irrigated plots have higher cropping intensity, and a larger percentage of plots (close to 25% plots) have three crops or more when compared to plots under solar (16%) or electric (7%) irrigation (Figure 27). The specialization in *boro* in SIP or electric irrigated plots leads to less crop diversity and lower cropping intensity as compared to diesel-based irrigation.

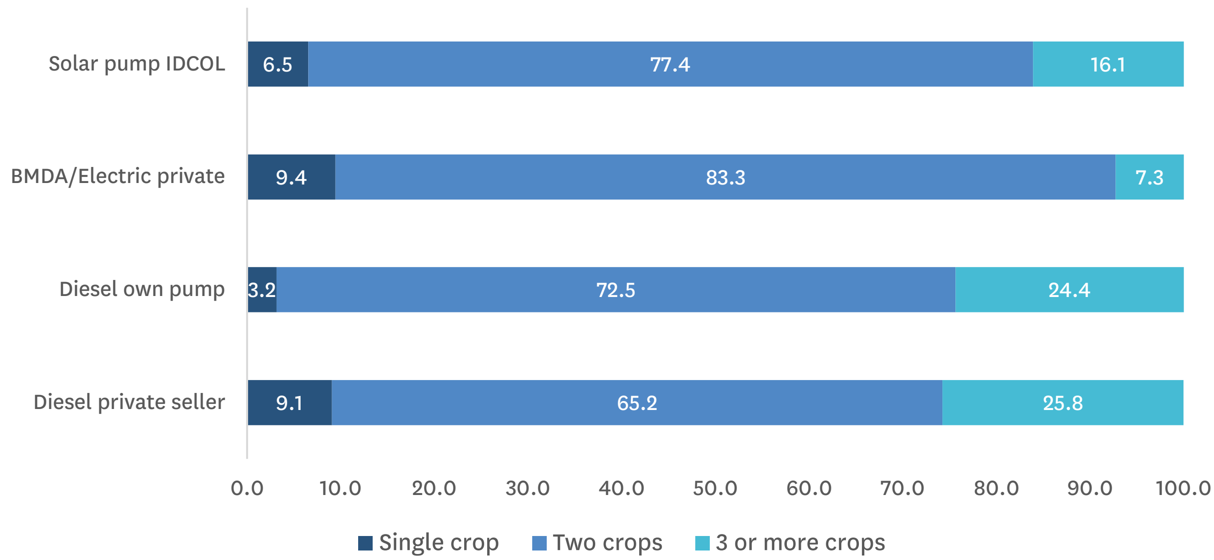


Figure 27 - Percentage of plots growing single, double or multiple crops across irrigation source

An array of SoLAR Panels (*photo* : Waresul Haque, NGO-Forum)

5.5. Irrigation practices and water abstraction

5.5.1. Hours of irrigation and estimated water abstraction

Based on the SIP survey, Table 25 summarizes the number of irrigations provided across different crop types and location. We note that the water requirement of different crops varies, but the need also depends on the type of land irrigated (elevation, slope, type of soil). In this regard, the number of irrigations provided by the SIP operator to each crop by the geographical location confirms that SIP located in the Khulna region are more often serving plots on high land. As a consequence, for the same crop, a significantly higher number of irrigations is provided in South-West SIP as compared to North-West SIP. This holds true irrespective of the season for *aman*, wheat, mustard, maize, and *boro*.

		North West	South West	Difference	Combined
Kharif 2 2020	*Aman*	6.142	11.652	-5.509	10.366
	Aus	-	9.000		9.000
Rabi 2020-2021	Wheat	1.285	2.437	-1.151**	2.086
	Mustard	1.444	2.000	-0.555*	1.666
	Potato	2.192	-		2.192
	Maize	3.000	4.750	-1.750***	4.166
	Pulses	-	1.285		1.285
	Chilli	3.333	2.000	2	1.333
Kharif 1 2021	*Boro*	25.145	38.84	-13.694***	29.425
	Maize	2.863	6.000	-3.136***	3.97

Table 25 – Number of irrigations provided by crop and location

Note: ***, ** and * indicate significance at 1%, 5% and 10% level, respectively for the T-test of difference between North-West and South-West

Both the SIP survey and the household survey confirm that the highest irrigation demand (hours of irrigation/acre) is during the *kharif* 1 season when *boro* is cultivated, which is almost 3-4 times the irrigation demand during *rabi* season (for those cultivating during *Rabi*) and 9-11 times more than what is required during *kharif*-2, i.e., the monsoon season. This is true for all types of irrigation sources.

The household survey data allows comparing the hours of irrigation across different irrigation sources as described in Figure 28. In *kharif* 1, water buyers from diesel pumps irrigate in total 52.2 hours/acre, while own diesel pump users irrigate for 45.5 hours/acre; significantly higher than irrigation by buyers of electric pumps at only 34.7 hours/acre and SIP users at 43.8 hours/acre. These irrigation hours, however, are not directly comparable because diesel pumps are relatively smaller and have a much lower flow rate than IDCOL solar pumps or electric pumps. In fact, given the fact that solar pumps have almost twice the flow rate as diesel pumps on average in the region of our study, it likely indicates slightly higher water use for SIP users across all three seasons. For a more direct comparison of irrigation water use, we look into the rate of irrigation for *boro* (the most important crop in terms of irrigation requirement) at the plot level from the household data in Table 26.

	Number of irrigations			Hours of irrigation per acre			Estimated water abstraction per acre (cubic meter)		
	Plot not in lowland	Plot in lowland	Combined	Plot not in lowland	Plot in lowland	Combined	Plot not in lowland	Plot in lowland	Combined
Diesel private seller (N=118/143/261)	20.8[a]	18.2	19.4[a]	83.1[a]	66.5[a]	74.0[a]	2626[a]	2101[a]	2338[a]
Diesel own pump (N=219/273/492)	19.1[b]	18.0	18.5[b]	69.8[be]	58.7[b]	63.6[b]	2207[b]	1855[b]	2012[b]
Electric private (N=26/12/38)	16.2[ba]	15.0	15.8[ba]	49.0[cde]	47.3[abcd]	48.5[bc]			
BMDA (N=29/40/69)	16.9[ba]	16.3	16.6[b]	34.5[d]	33.2[c]	33.7[d]			
Solar pump IDCOL (N=139/183/322)	18.3[ba]	18.7	18.5[ca]	56.4[c]	51.0[d]	53.3[c]	2412[ab]	2180[ab]	2280[c]
Sig.[1]	*	n.s.	*	**	***	***	***	***	*
All plots (N=559/687/1246)	19.1	18	18.5	66	57.1	61.1	-	-	-

[1] Based on multiple Mann-Whitney tests accounting for family-wise error. If there is a common superscript letter between any two groups, then their group difference is not significant (p>=0.1), but if there is no common superscript letter, it indicates statistical significance at least at the indicated level.

Table 26 - Irrigation hours and estimated water abstraction for *Boro* paddy across various irrigation sources

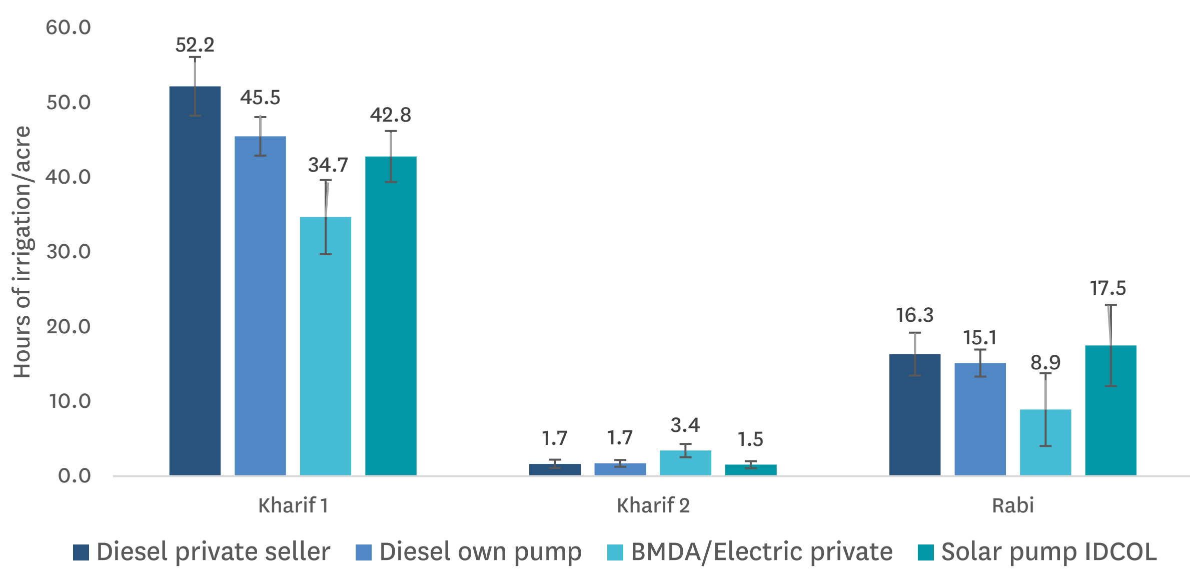


Figure 28 - Hours of irrigation per acre across different irrigation sources over 3 seasons

The number of irrigations for SIP plots is around 18.7 in lowland plots and 18.3 in highland plots; and in comparison, the number of irrigations if buying from diesel pump owners is 20.8 in highland plots and 18.2 in lowland plots[12]. In terms of the total hours of irrigation, SIP irrigated plots are significantly lower than those buying water from diesel pump owners or using their own diesel pump. The difference is even higher if the plot is not in the lowland. But as mentioned above, these values are not directly comparable due to differences in flow rates.

We have conducted direct field measurements of flow rates at the plot level in six SIP locations in North-west Bangladesh. Also corresponding to these six SIPs we identified six nearby villages to select another 56 diesel farmers for whom the flowrate and irrigation usage data have been collected. Another round of data for *boro* season will be collected in 2023 to understand the impact of SIP on groundwater usage. But using the flow-rate measurements from 2022, we have calculated the average flowrate as 8.78 liters/sec for diesel pumps and 11.88 liters/sec for SIPs to convert the irrigation hours per acre into water application per acre (in cubic meters). We find that water application in highland plots irrigated by SIPs is 2412 m^3/acre, which is 9% more than that of diesel pump owners (2207 m^3/acre) and 8% lower than that applied by diesel water buyers (2626 m^3/acre). Similarly, in lowland plots irrigated by SIPs, water application is 2180 m^3/acre, which is 18% more than what is applied by diesel pump owners (1855 m^3/acre) and 4% higher than that applied by diesel water buyers (2101 m^3/acre). However, when disaggregated between highland and lowland plots, we do not find any significant difference between diesel and SIP users. Combining lowland and highland plots, we find that SIP plots (2280 m^3/acre) using 13% more water than diesel pump owners and 2.5% lower than diesel water buyers. Compared to all diesel irrigated plots, SIP plots (2280 m^3/acre) use 7% more water, but this difference is not significant at 10% level. Thus, we do not find any robust evidence of higher rate of water application in the case of SIPs in comparison to diesel pumps, but it requires more careful analysis with another year of groundwater monitoring data and careful econometric analysis to control for plot level and farmer level selection issues.

[12] The number of irrigations collected from the SIP survey is higher than that of indicated by the farmers and collected with the household survey. Since most of the operators don't keep a logbook and the number of irrigations indicated is much higher than the requirements for a particular plot, we assume that there is a tendency to over-estimate the number of irrigations for a particular plot by the operators.

5.5.2. Supplementary irrigation in the monsoon season

Another important point to consider is the fact that access to SIP also means farmers are able to give supplementary irrigations during the *kharif*-2 (monsoon season) and consequently protect their crops in case of long gaps between two irrigation seasons, which are becoming more common due to climate change. In SIP irrigated plots, 22% of the farmers gave irrigation during *kharif* 2 season, which is significantly higher than 18% plots irrigated for those buying water from diesel pumps (chi-square test p-value<0.1) and 17% plots irrigated from their own diesel pump (chi-square test p-value<0.05) (Figure 29). But interestingly, supplementary irrigation is significantly higher in electric pump irrigated plots (82% use supplementary irrigation buying from private electric pumps, and 51% use supplementary irrigation from BMDA pumps) (Figure 29).

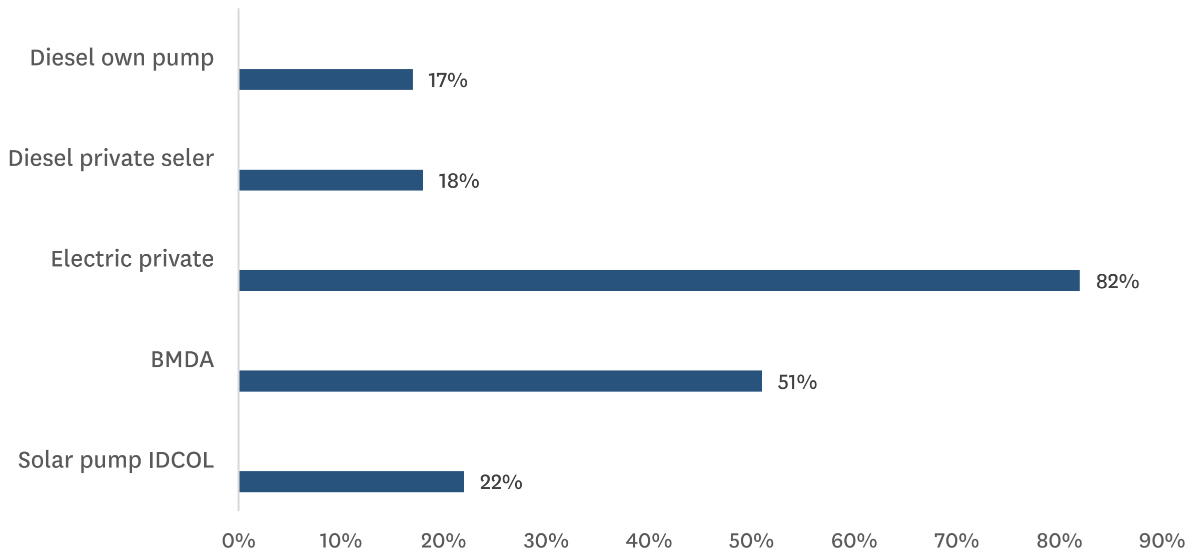


Figure 29 - Percentage of plots taking supplementary irrigation during the monsoon *Kharif* 2 season across different irrigation sources

5.6. SIP's operation

5.6.1. Operation and coverage

SIPs are not operational all the year-long, and that operation[13] depends on the agricultural season. While all the SIPs are operational during the irrigation season, i.e., in the *kharif* 1 (*boro*) season, only half of the SIP are operational in the *kharif* 2 season and 67% in the *rabi* season. Beyond averages, there is a clear difference in operational patterns between North-West and South-West. Only 20% of the SIP located in the North-West were operated during the 2020 *kharif* 2 season, while 88% were operated in the South-west in Khulna region (Table 27). The *kharif 2* -2020 season coincided with early and heavy monsoon rainfall

[13] Operation is here define by the provision of irrigation to SIP farmers for at least one day during the season.

resulting in massive floods[14]; this may explain the relatively low operation of the SIP during this season, especially in North-West, which was severely affected.

		North West	South West	Difference	Combined
Share of SIP operated	*Kharif* 2 2020	0.200	0.884	-0.684***	0.491
	Rabi 2020-2021	0.578	0.880	-0.301***	0.670
	Kharif 1 2021	1.000	0.925	0.074**	0.975
Area irrigated, in acres (if operational)	*Kharif* 2 2020	6.996	8.623	-1.627	8.243
	Rabi 2020-2021	4.320	10.885	-6.564***	6.946
	Kharif 1 2021	18.392	17.009	1.380	17.965
Number of farmers served (if operational)	*Kharif* 2 2020	33.285	32.695	0.590	32.833
	Rabi 2020-2021	13.757	36.590	-22.83***	22.890
	Kharif 1 2021	50.857	51.320	-0.462	51.000

Note: ***, ** and * indicate significance at 1%, 5% and 10% level, respectively for the T-test of difference between North-West and South-West

Table 27 – Operation and coverage by season and location

The same differences in terms of season and location of the SIP are reflected in the area irrigated by the SIP and in the number of farmers served. Not surprisingly, the area served by SIPs and the number of client farmers is higher in the *kharif* 1 (*boro*) season. On average, each SIP serves almost 18 acres of land in the *kharif* 1 season, benefitting 51 farmers. This is much lower during the *kharif* 1 and *rabi* seasons, with respectively 8.2 and 6.9 acres served and 32.8 and 22.9 farmers receiving irrigation services from the SIP (Table 27). In addition to the differences in operation mentioned earlier between North-West and South-West, we also note that the SIPs operated during the *rabi* season served a significantly larger number of clients and larger areas in South-West as compared to North-West.

Combining the area served by the SIP in the three agricultural seasons, we calculate the gross irrigated area of each SIP (Figure 30). With a larger number of SIPs operated for three seasons and larger areas irrigated in the *rabi* season, the SIPs from the South-West have significantly higher gross irrigated areas than those located in North-West.

[14] https://www.unocha.org/our-work/humanitarian-financing/anticipatory-action/summary-bangladesh-pilot

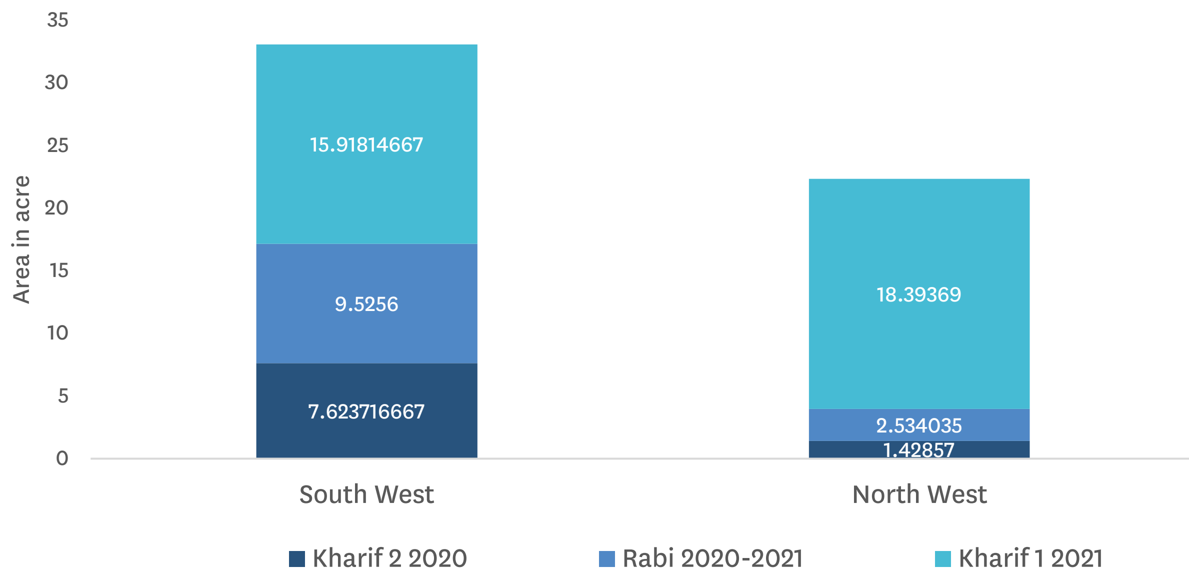


Figure 30 – Average gross irrigated area

5.6.2. Fee's collection

At each round of the SIP survey, data were collected on the collection of fees from the previous season. Table 28 shows that on average, the share of due fees collected exceeds 90% for all three seasons. We note that the share is slightly lower for the *kharif* 1 season, which with its *boro* crop is the most important season from the SIP finance, but we will need more round of data to confirm this observation.

For the three seasons, the share of due fees collected is higher in the South-West than in North-West, and the difference is significant in two out of the three cases (Table 28).

		North West	South West	Difference	Combined
Kharif 1 2020	Share of due fees collected	0.877	0.988	-0.111**	0.92
	Share of fees collected at the due date without delay or default	0.794	0.904	-0.11	0.839
Kharif 2 2020	Share of due fees collected	0.803	1	0.197***	0.96
	Share of fees collected at the due date without delay or default	0.591	0.984	-0.392***	0.89
Rabi 2020-21	Share of due fees collected	0.935	0.995	-0.059	0.958
	Share of fees collected at the due date without delay or default	0.46	0.759	-0.299***	0.557

Note: ***, ** and * indicate significance at 1%, 5% and 10% level, respectively for the T-test of the difference between North-West and South-West

Table 28 – Fee collection by season and location

As noted earlier, a difference in the cost of irrigation cannot explain that difference. One explanation might be the difference in the governance of the SIP between South-West and North-West as all the NGO-operated SIPs are in South-West, but this would need to be confirmed qualitatively. We also note that all except one SIP have no penalty system for late or default payments. The share of fees collected at the due date without delay or default was lower for the 2020-21 *rabi* season as compared to the other seasons and especially in the North-West, where only 46% of the fees were collected on time. Again, more rounds of the SIP survey will help understand if this was sporadic and possibly due to variability in the economic returns of the crop or if it reflects a continuous trend in some SIP.

When considering the total amount of irrigation fees collected throughout the three agricultural seasons, i.e., in one year, we note that, on average, SIPs collected approximately 100,000 BDT (1162 USD[15]). As SIPs in the South-West are more often operated in the non-*boro* season, they are able to generate higher revenues from irrigation; the average revenue is 112727 for SIPs located in the South-West versus 97840 for SIPs in North-West (Figure 31). Yet, in spite of more diversified revenue in the South-West than in the North-West, we still note the high dependence of SIP incomes from the *kharif* 1 season and the *boro* crop. In North-West, 90% of the fees collected come from the *kharif* 1 season. While lower in the South-West (70%), the dependence on *boro* for the financial sustainability of the SIP is still clear (Figure 31).

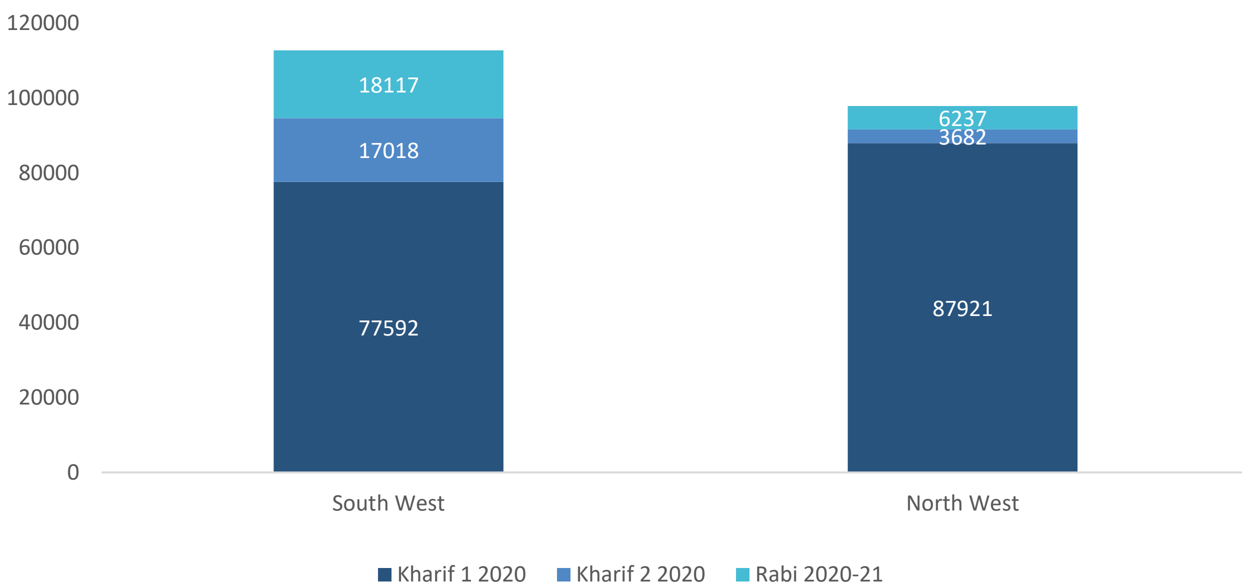


Figure 31 – Revenue from irrigation fees by season and locations

[15] Conversion date at March 17th 2022: 1 USD = 86.05 BDT

5.6.3. Operation and performance

We noted earlier that some SIPs are not operated throughout the year, and even if this is the case, SIPs are not delivering irrigation service every day. While in North-West, during the *boro* season, the SIPs are operational for more than 87 days, the average is as low as 14 days during the *rabi* season (Figure 32).

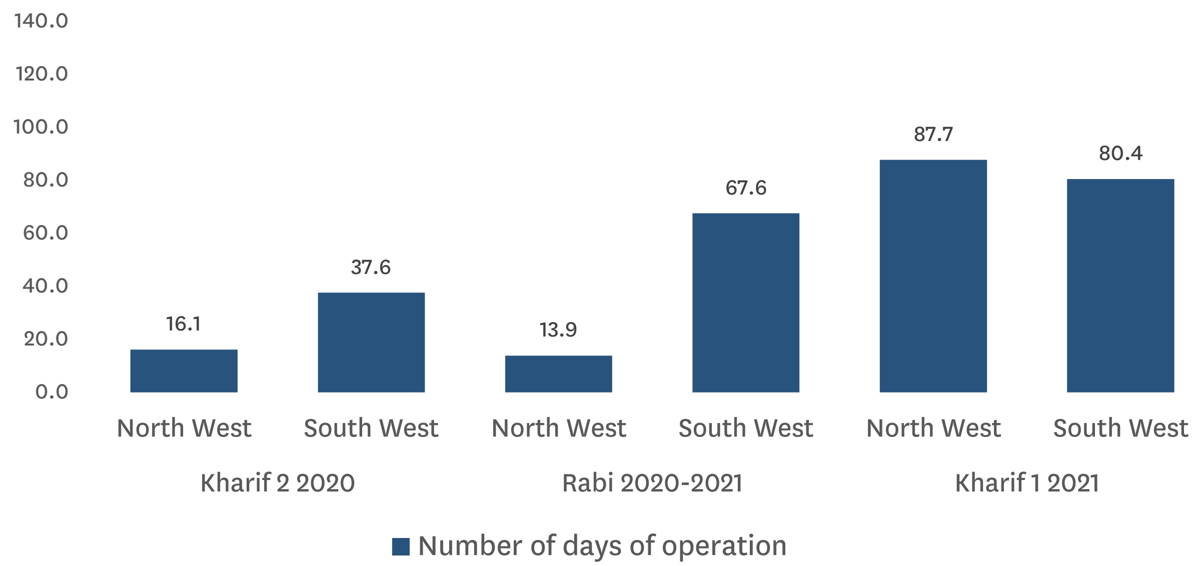
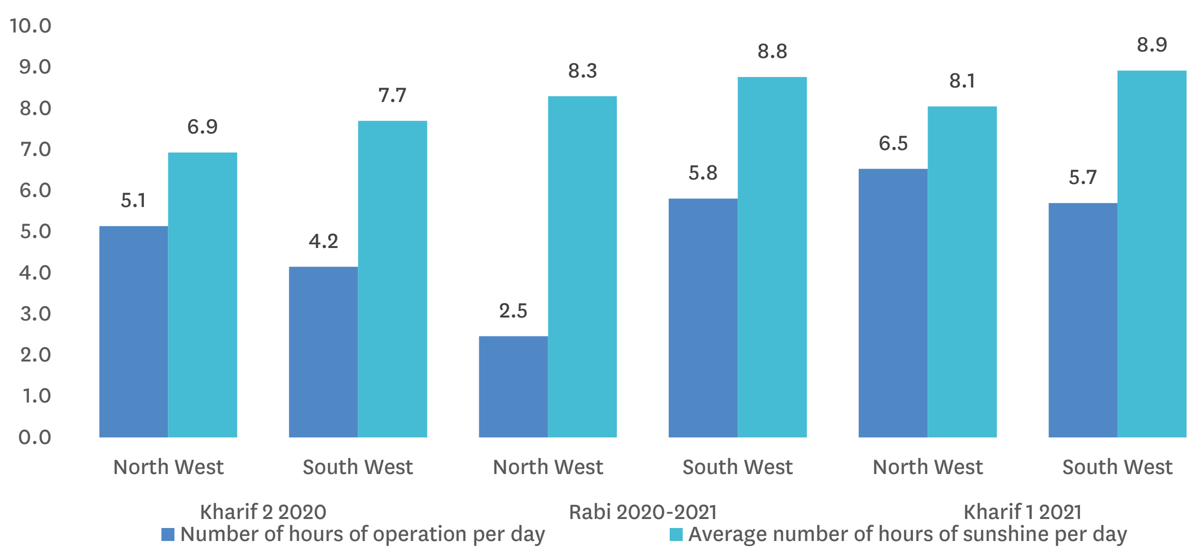


Figure 32 – Number of days of operation



Source: Number of hours of sunshine per day per division from https://en.climate-data.org/asia/bangladesh/

Figure 33 – Number of hours of operation per day

Similarly, during the days of operation, the pump is not operated from sunrise to sunset, and there is a relatively large gap between the number of hours of sunshine and the actual number of hours of operation of the SIP (Figure 33).

Comparing the total number of hours for which energy can be generated with the number of hours the pump is actually being used, we estimate that the SIP operation uses 25% of the energy generation potential in the North-West and 27% in the South-West. These estimates confirm the huge potential for increasing the performance of the solar panels, be it through using the electricity produced for providing other services or through selling the excess energy to the grid. In both cases, increasing the performance ratio would translate into improving the financial sustainability of the SIPs with additional revenue generated and relaxing the dependency on the *boro* irrigation fees.

While some SIPs propose additional services using the energy generated by the farmers (husker, floor, and oil grinder), those remain quite limited, and none of the SIPs selected in this representative sample had these services in 2020-2021.

5.6.4. SIP and shocks

SIPs and natural disasters

The first round of the SIP survey followed two important natural disasters in Bangladesh. First, cyclone *Amphan* hit the country in May 2020, resulting in 149,000 hectares of agricultural land and 1 million people affected. Second, in July and August of the same year, excessive rainfall resulted in floods affecting 159,000 hectares of agricultural land and 1.2 million farmers.

We checked if SIPs were damaged and if these natural events disrupted their operation. In the *kharif* 2 season of 2020, only 2 SIPs surveys recorded damages on their panels after the cyclone. These were only minor damages that were rapidly repaired and had very limited effects on the operation. With the floods, two SIPs had their command area flooded in July and August 2020. While it did not directly affect the operation of the SIPs, and no damages were recorded, operators mentioned that the excessive rainfalls meant no demand for irrigation during this season.

SIPs and COVID-19

The first round of the SIP survey in October 2020 also followed the restrictions put in place as a consequence of the first wave of the COVID-19 pandemic in Bangladesh. SIP operators were asked to assess the consequences of the induced measures for the farmers located in their command area (Figure 34) and for their tasks as SIP operators (Figure 35).

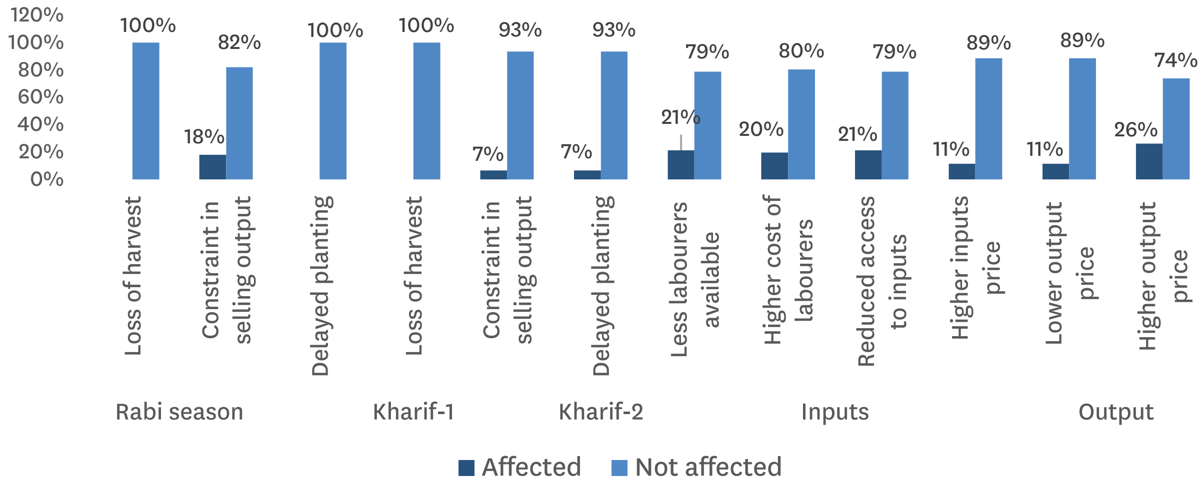


Figure 34 – Consequences of COVID-19-induced measures on SIP farmers perceived by SIP operators

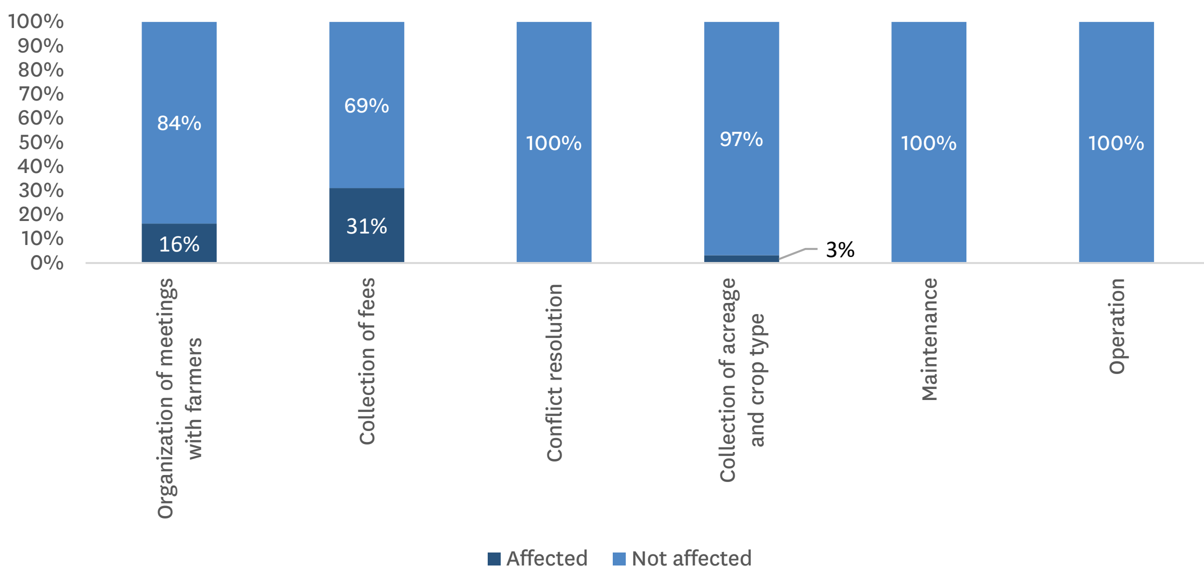


Figure 35 - Consequences of COVID-19-induced measures on SIP operators' tasks

In general, their assessment is that there have been limited effects of the COVID-19-induced measures on the SIPs communities. Most of the consequences were related to the access and costs of inputs and labor. For example, 21% of the operators indicated that the access to inputs was reduced for the farmers of their location in 2020 as a result of COVID-19 measures. Some of the effects were also positive for farmers, as 26% of the operators noted that the farmers benefitted from higher output prices than usual years.

The operation of the SIPs, as well as the tasks of operators, were relatively unaffected by the COVID-19-induced measures. 31% of the operators mentioned that the collection of the fees was affected, but with 92% of the *rabi* fees collected in October 2020, we assume that these tasks were only delayed and that operators managed to catch up when the restrictions were lifted.

5.6.5. SIP's operators

Characteristics, responsibilities, and benefits of operators

Data on the operator was collected in the second round of the SIP survey in April 2021. Confirming insights from qualitative data and field visits, we note that the operator is often the owner of the land where the SIP is located (65%) or a relative of the landowner (29%). Half of them were water sellers before the SIP was installed and were operating in the same command area with a diesel pump. Only 14% of them still own this diesel pump, and 2% still sell water. Most of the operators are farmers themselves, and the income they generate from SIP operations accounts for 40% of their total income. Operators usually (89%) receive a fixed wage from the sponsor for the tasks related to SIP operation, and they also have an incentive through a percentage of the fees collected.

Beyond financial benefits, some of them also receive other advantages (Figure 36). They use the land for housing purposes (58%) or for growing vegetables (62%). Some of them (7%) also admitted accessing irrigation at a discounted rate. Finally, there are a few SIPs where the operators run other businesses benefitting from the solar panels' infrastructure (poultry raising) or the water access (aquaculture)

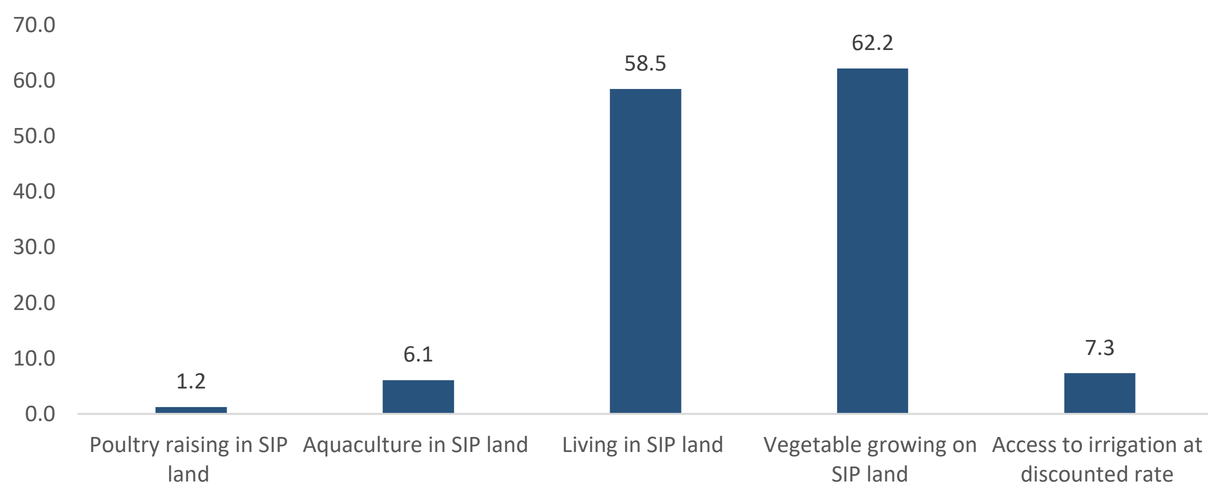


Figure 36 - Percentage of SIP operators receiving other benefits

The operators are responsible for the daily operation and maintenance tasks (Figure 37) from the beginning of the season with the collection of acreages, crops, and farmers' lists to the end with the collection of due fees. They are responsible for cleaning the panels and the plot, but other maintenance responsibilities such as the maintenance of the pump and the cleaning of pipes and risers are shared with the sponsor manager. Some of the operators are also supported by a helper for cleaning tasks (panels, plot, pipes). While they operate the pump and manage water needs between the plots in the command area, most of the operators do not establish water schedules in advance (Figure 37). Instead, they assess water needs on an ad-hoc basis or by responding to farmers' demands.

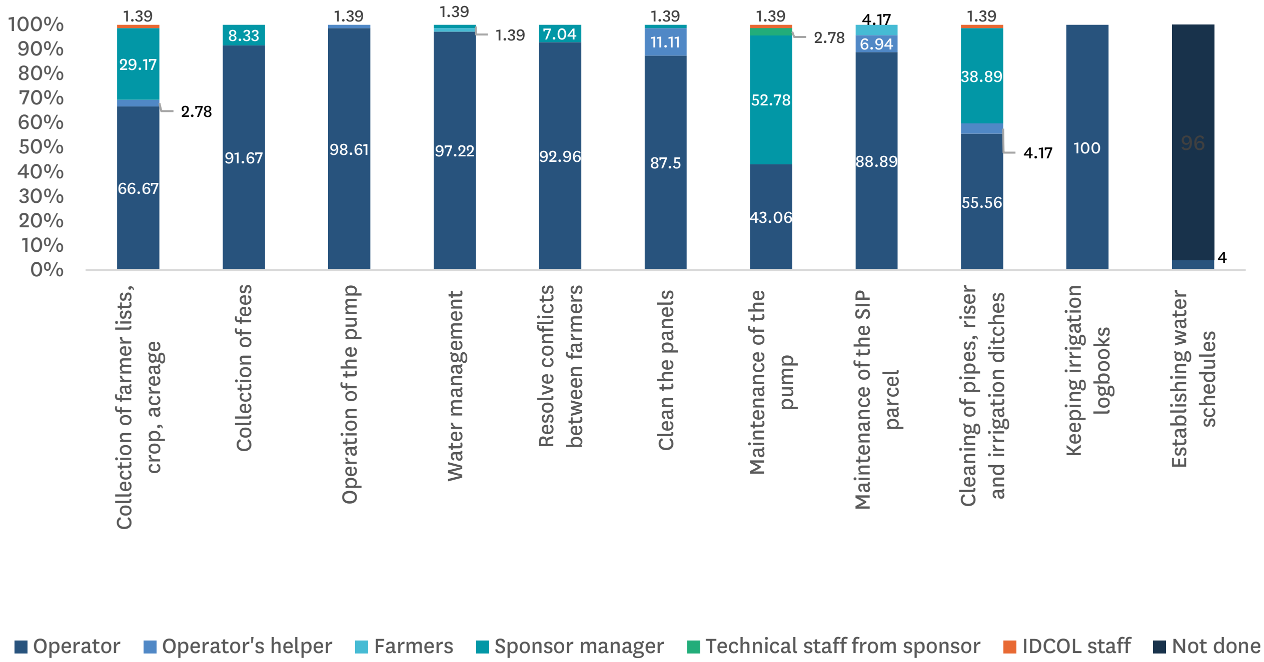


Figure 37 – SIP operation and maintenance responsibilities

A group of women farmers in a field (*photo* : Waresul Haque, NGO-Forum)

Training and operators as extension agents

Operators confirm that most of them received due training to respond to their responsibilities (Figure 38). In addition to pump operation and maintenance, they have been trained on improved agricultural practices, water management, and conflict resolution. Still, when asked about potential future training, there still to be high demand, with 70% of the operators considering that new training would be 'very useful.'

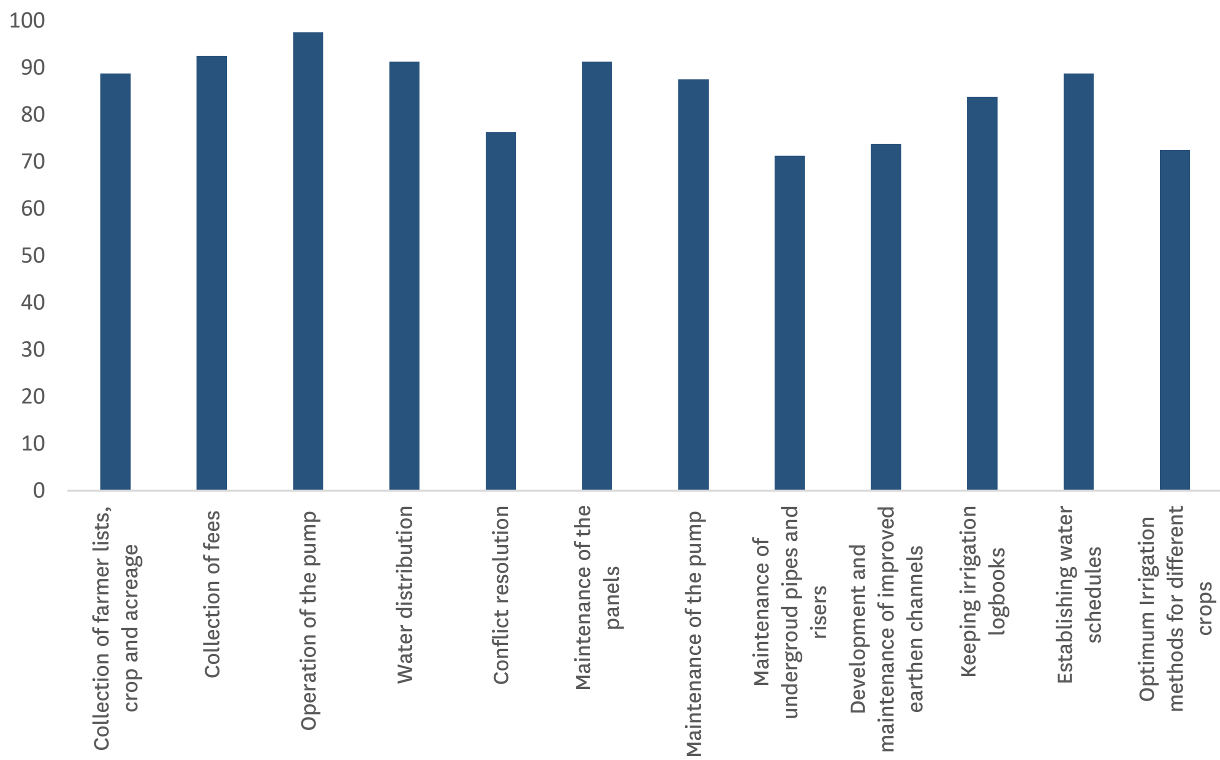


Figure 38 – Percentage of operators trained on different components of SIP operation and maintenance

By delivering irrigation services, the farmers also become points of contact for other farmers cultivating in the same command area, and there are therefore asked to provide advice beyond the irrigation service as shown in Figure 39.

For example, more than 30% of the operators 'often' provide advice to farmers on seed selection, choice of crops, insect, and pest management, or even access to agriculture credit. They, therefore, act as model farmers or extension agents. Their position as influential farmers who were previously selling water within the command area and historical ties with other farmers from the same community likely legitimize their positions and the value of their advice. This informal arrangement could be further strengthened so that SIPs become a hub for various agricultural services. This is also the case in some SIP with sponsors linking irrigation services with inputs or credit access services. Yet, this would require targeted training for operators. For example, marketing and post-harvest transformation are topics on which operators have been rarely trained, and yet they are asked to provide advice to farmers on those topics.

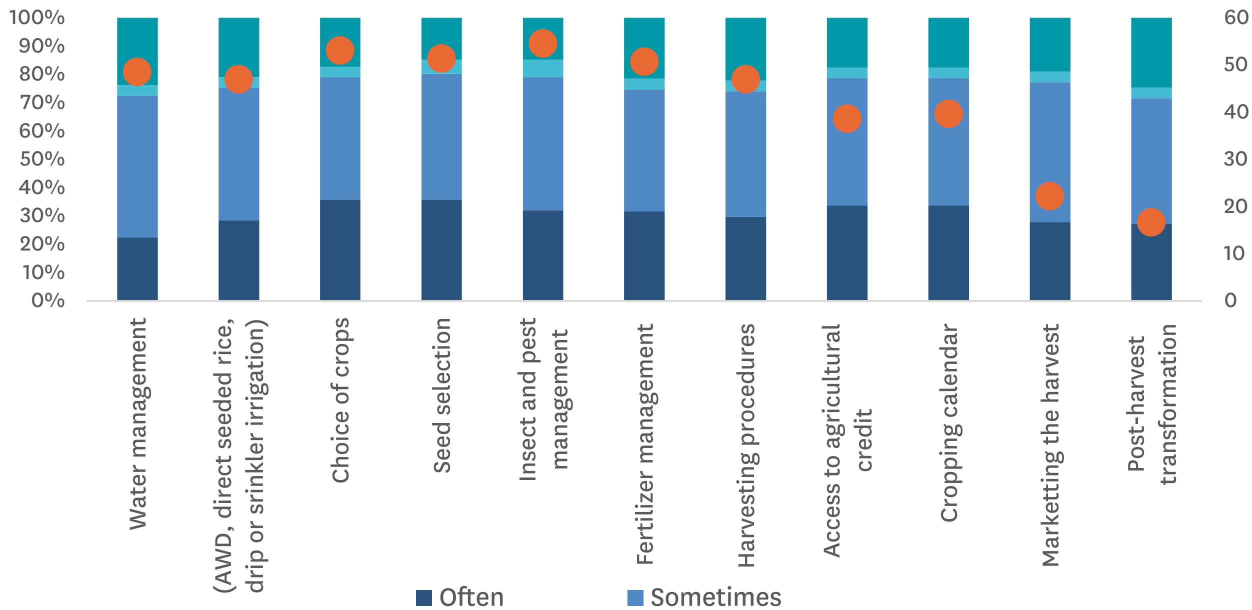


Figure 39 - Operators' advice to farmers and training

A farmer working in his paddy field (*photo* : Waresul Haque, NGO-Forum)

6. Summary findings

This section aims to revisit the research questions by combining the findings from the household and the SIP baseline surveys to highlight the learnings. One caveat to underline is that these results emerge from descriptive analysis and are therefore not causal. Econometric analysis needs to follow to confirm these first findings as well as insights from the follow-up surveys to be conducted in 2022 and 2023.

The first rationale for SIPs deployment is the mitigation of greenhouse gas emissions through the replacement of diesel pumps. We here confirm that SIP farmers reduce their diesel consumption while being specialized in *boro* cultivation and even increasing their cultivated area in the last five years. Indeed, SIP farmers who were previously irrigating from 100% diesel (from own pump or buying) now have 70% of their total irrigated area from solar sources in *kharif* 1, 95% in *kharif* 2 and 51% in *rabi*. From the SIP and the household baseline surveys, we still note that diesel pumps are used within the SIP command area. In about 53% of the SIPs there was some diesel pump irrigation within the command area in *kharif* 2. The main reason for this is the higher agility of diesel pumps in responding to limited (in area, quantity of water) and specific irrigation needs during the *aman* and *rabi* seasons as well as for some supplementary irrigation needs to support the SIP system during the peak irrigation demand of *boro* often coinciding with foggy weather. This should be considered to further reduce emissions but also for the adaptation to climate change and support diversification strategies of some farmers.

When considering the co-benefits in the form of time-saving and satisfaction from the irrigation services, our results confirm the positive impact of getting access to a SIP for farmers. We find that the time spent for irrigation is significantly lower if irrigation is bought from a fee-for-service IDCOL solar pump (1.3 hours/day) as compared to irrigating using own diesel pump (2.6 hours/day) or hired diesel machines (1.8 hours/day). Interestingly, the savings in time comes from the fact that the solar pumps in our sample are an irrigation service business. Translated in monetary terms, a water buyer from an IDCOL SIP saves in terms of lost wages around 1170 BDT/ season as compared to own diesel pump user and 450 BDT/season as compared to hired diesel machine users. In addition, the cost of irrigation from SIP users is lower than that of farmers buying from a diesel pump water (approximately 2000 BDT per acre difference in seasonal contracts for *boro*). We also find that SIPs have clearly higher satisfaction levels amongst water buyers in terms of timing and cost of irrigation over electric pumps and diesel pumps. While in terms of quantity and quality of irrigation, the satisfaction level is similar between electric and solar pump buyers, and they are strictly better than diesel pump water buyers.

The impact of those short-term benefits on development outcomes, including food security, poverty, and vulne*rabi*lity to shocks, will have to be established with an econometric analysis and using the follow-up survey. Yet, we so far note that the SIP villages and the future SIP villages tend to be better off than control villages. This can be due to the impact from the SIP operation or because of the fact that villages and beneficiaries selected for IDCOL SIP sites are fundamentally different from an average diesel water buyer; these two explanations cannot be distinguished at this stage.

In terms of equity in access to irrigation, our results establish that SIPs serve marginal farmers and tenant farmers through the fee-for-service model. Diesel pump owners tend to be larger farmers, followed by SIP users, while diesel water buyers cultivate smaller areas on average. There is a higher proportion of smaller farmers in the sample of group C villages compared to groups A and B. From the SIP survey, we also note a decline in the share of marginal farmers from the first round in *kharif* 2 2020 to the third round in *kharif* 1 2021. Yet, we cannot conclude yet if this difference is related to the SIP itself or not. The household survey and the SIP data also concur on the presence of active land markets in the SIP command areas and villages. There is a higher share of tenant farmers in the SIP command area of SIP villages than in pipeline and control villages, and the share of tenant farmers is also higher than that of from secondary data from the same geographies. Similarly, SIP irrigated plots are more likely to be under sharecropping or leasing agreements than diesel irrigated plots.

The cropping patterns of SIP users are dominated by *boro* crop as the IDCOL SIPs have been primarily designed to respond to the high water requirement of the water-intensive crop. Yet, two regional scenarios appear: North-West is more dependent from *boro* while there is more diversification toward other crops and higher gross areas irrigated by the SIP in South-West of Bangladesh. Comparing the data collected in 2021 with recall data from five years back, we show that SIP users have increased their area cultivated, whereas farmers irrigating from their own diesel pump did not. The share of farmers cultivating *boro* (and areas) is also significantly higher for SIP and electric pump users, and in the last five years, the increase in the share of farmers cultivating *boro* has been slightly higher for SIP users as compared to non-SIP users.

While the number of irrigations and the duration of irrigations are significantly lower for SIP users, once weighted by the estimated average flow rate of solar and diesel pumps, water application on SIPs is 7% more than all diesel irrigated plots but the difference is not significant and not consistent across different types of diesel irrigated plots. We also find that access to SIP favors the use of supplementary irrigation in the monsoon season, enabling adaptation against raising rain uncertainty. For example, water application in highland plots irrigated by SIPs is 2412 m3/acre, which is 9% more than that of diesel pump owners (2207 m3/acre) and 8% lower than that applied by diesel water buyers (2626 m3/acre). Similarly, in lowland plots irrigated by SIPs, water application is 2180 m3/acre, which is 18% more than what is applied by diesel pump owners (1855 m3/acre) and 4% higher than that applied by diesel water buyers (2101 m3/acre). In SIP irrigated plots, 22% of the farmers gave irrigation during *kharif* 2 season, which is significantly higher than 18% of plots irrigated for those buying water from diesel pumps.

Considering the current operation of the SIP systems, the IDCOL fee for service model is financially dependent on *boro* cultivation, but there is a potential for alleviating this dependency thanks to grid integration or additional energy services. We confirm that, on average, 80% of the income generated from the irrigation service comes from *boro* cultivation. So far, the recovery rate of irrigation fees is relatively high, even if some delays in payments were observed for some seasons (*rabi* 2020-21). Calculations on the performance of solar panels comparing the potential for energy generation to the number of days of operation and number of hours of operation (at 26%) confirm the potential for increasing the performance of the panels as well the revenue generated by the sponsors by using the excess energy for providing additional services to farmers and by selling it to the grid.

Finally, operators play a key role in the operation and maintenance of the SIPs, but their role could be expanded toward agricultural extension services to allow SIPs to become agricultural multi-service hubs. SIP farmers themselves would benefit from additional and better-targeted training on irrigation efficiency

and climate-smart agricultural practices. From the SIP survey and the household survey, we note that SIP operators and officials from the sponsor organizations/IDCOL have become a source of advice or information on agricultural-related questions for farmers in IDCOL SIP villages; there is, therefore, a scope to extend their training to be able to answer to these queries and allow them to provide additional agricultural services. For farmers, the share of those who received training on agricultural topics (and especially irrigation-related ted ones) is low in general, and this is the case even in IDCOL SIP villages where training on improved agricultural and irrigation practices was initially organized. In the view of active land markets, the targeting of these training may therefore need to be considered more carefully.

REFERENCES

BBS (2013). District statistics 2011. *Ministry of Planning, Government of The People's Republic of Bangladesh*.

BADC. (2020). Organization Wise Summary of Irrigation Equipment Used, Area Irrigated and Benefited Farmers. http://www.badc.gov.bd/

Islam, M., & Hossain, M. (2022). Economic Feasibility of Solar Irrigation Pumps: A Study of Northern Bangladesh. *International Journal of Renewable Energy Development*, *11*(1).

Sapkota, T. B., Khanam, F., Mathivanan, G. P., Vetter, S., Hussain, S. G., Pilat, A. L., and Krupnik, T. J. (2021). Quantifying opportunities for greenhouse gas emissions mitigation using big data from smallholder crop and livestock farmers across Bangladesh. *Science of the Total Environment*, *786*, 147344.

ANNEX A - Sample size and power analysis

Indicator	Mean	Standard deviation	Intra-cluster correlation	Number of clusters	Number of SIP clusters	Number of non SIP clusters	Number of units per cluster in SIP clusters	Number of units per cluster in non SIP clusters	Sample size	Minimum detectable effect size
Household level										
Cropping intensity	195.051	76.551	0.199	80	30	50	20	20	1600	19.998
	195.051	76.551	0.199	80	30	50	15	15	1200	20.756
	195.051	76.551	0.199	70	25	45	20	20	1400	21.600
	195.051	76.551	0.199	70	25	45	15	15	1050	22.419
	195.051	76.551	0.199	60	20	40	20	20	1200	23.714
	195.051	76.551	0.199	60	20	40	15	15	900	24.613
Proportion of households cultivating *boro* paddy	0.43	0.44	0.56	80	30	50	20	20	1600	0.163
	0.43	0.44	0.56	80	30	50	15	15	1200	0.166
	0.43	0.44	0.56	70	25	45	20	20	1400	0.176
	0.43	0.44	0.56	70	25	45	15	15	1050	0.180
	0.43	0.44	0.56	60	20	40	20	20	1200	0.193
	0.43	0.44	0.56	60	20	40	15	15	900	0.197
Yield of *boro* paddy, kg/acre	1763.36	604.33	0.15	80	30	50	20	20	1600	140.087
	1763.36	604.33	0.15	80	30	50	15	15	1200	146.511
	1763.36	604.33	0.15	70	25	45	20	20	1400	151.311
	1763.36	604.33	0.15	70	25	45	15	15	1050	158.250
	1763.36	604.33	0.15	60	20	40	20	20	1200	166.122
	1763.36	604.33	0.15	60	20	40	15	15	900	173.741
Plot level										
Number of irrigation for *boro*	34.0678	23.08469	0.39011	80	30	50	120	120	39600	7.516
	34.0678	23.08469	0.39011	80	30	50	90	90	29700	7.552
	34.0678	23.08469	0.39011	70	25	45	120	120	35400	8.118
	34.0678	23.08469	0.39011	70	25	45	90	90	26550	8.157
	34.0678	23.08469	0.39011	60	20	40	120	120	31200	8.913
	34.0678	23.08469	0.39011	60	20	40	90	90	23400	8.956

ANNEX B – List of villages sampled in the household survey

Zilla	Upazilla	Union	Village	Group	
Bogura	Gabtali	Nepaltali	Akanda Para	Group C	Site without SIP
Bogura	Gabtali	Nepaltali	Dhananjay	Group B	Site with future SIP
Bogura	Gabtali	Nepaltali	Kadamtali	Group B	Site with future SIP
Bogura	Gabtali	Nepaltali	Porapara	Group B	Site with future SIP
Dinajpur	Biral	Dhamair	Kashidanga	Group A	Site with SIP
Dinajpur	Biral	Sahargram	Gaganpur	Group B	Site with future SIP
Dinajpur	Biral	Sahargram	Harekrishnapur	Group A	Site with SIP
Dinajpur	Biral	Sahargram	Katihari	Group C	Site without SIP
Dinajpur	Biral	Sahargram	Khod Shibpur	Group C	Site without SIP
Dinajpur	Biral	Sahargram	Sahargram	Group B	Site with future SIP
Dinajpur	Birganj	Nijpara	Boro Bochapukur	Group A	Site with SIP
Dinajpur	Birganj	Nijpara	Chhota Bochapukur	Group A	Site with SIP
Dinajpur	Birganj	Nijpara	Nijpara	Group A	Site with SIP
Dinajpur	Birganj	Paltapur	Bhogdoma	Group C	Site without SIP
Dinajpur	Birganj	Paltapur	Kajol	Group B	Site with future SIP
Dinajpur	Birganj	Paltapur	Modhubanpur	Group C	Site without SIP
Dinajpur	Birganj	Sujalpur	Rangao	Group B	Site with future SIP
Dinajpur	Bochaganj	Atgaon	Atgaon	Group A	Site with SIP
Dinajpur	Bochaganj	Atgaon	Sylhet	Group A	Site with SIP
Dinajpur	Bochaganj	Chhatail	Banahara	Group C	Site without SIP
Dinajpur	Bochaganj	Chhatail	Belbash	Group B	Site with future SIP
Dinajpur	Bochaganj	Chhatail	Maherpur	Group A	Site with SIP
Dinajpur	Bochaganj	Chhatail	Pachpara	Group A	Site with SIP
Dinajpur	Bochaganj	Chhatail	Ramnagar	Group C	Site without SIP
Dinajpur	Bochaganj	Ishania	Dakchai	Group C	Site without SIP
Dinajpur	Bochaganj	Ishania	Khanpur	Group C	Site without SIP
Dinajpur	Bochaganj	Ishania	Maheshail	Group C	Site without SIP
Dinajpur	Bochaganj	Ishania	Muraripur	Group C	Site without SIP
Dinajpur	Bochaganj	Ishania	Pashchim Barsha	Group C	Site without SIP
Dinajpur	Bochaganj	Ishania	Ronoti	Group C	Site without SIP
Dinajpur	Bochaganj	Ishania	Uttar Krishnapur	Group B	Site with future SIP
Thakurgaon	Baliadangi	Aamjankhor	Thukrabari	Group A	Site with SIP
Thakurgaon	Baliadangi	Bara Polashbari	Dokkhin Duari (Boro Jiabari)	Group A	Site with SIP
Thakurgaon	Baliadangi	Barabari	Barakot	Group C	Site without SIP
Thakurgaon	Baliadangi	Barabari	Belhara	Group C	Site without SIP
Thakurgaon	Baliadangi	Barabari	Goalkari	Group C	Site without SIP
Thakurgaon	Baliadangi	Barabari	Haripur	Group C	Site without SIP
Thakurgaon	Baliadangi	Barabari	Mohajanhat	Group B	Site with future SIP
Thakurgaon	Baliadangi	Barabari	Sorbo Mongla	Group A	Site with SIP
Thakurgaon	Baliadangi	Barabari	Uttar Baliadangi Hindu Para	Group B	Site with future SIP
Thakurgaon	Baliadangi	Charol	Charol Molanipara	Group B	Site with future SIP
Thakurgaon	Baliadangi	Dhantala	Banagaon	Group C	Site without SIP
Thakurgaon	Baliadangi	Dhantala	Dhokkhin Dhantala	Group B	Site with future SIP
Thakurgaon	Baliadangi	Dhantala	Dhukurjhari	Group C	Site without SIP
Thakurgaon	Baliadangi	Dhantala	Nageshwarbari	Group C	Site without SIP
Thakurgaon	Baliadangi	Dousou	Bengrul Jiabari	Group A	Site with SIP
Thakurgaon	Baliadangi	Paria	Bongovita	Group B	Site with future SIP
Thakurgaon	Baliadangi	Paria	Jaunia	Group B	Site with future SIP
Thakurgaon	Baliadangi	Paria	Machhkhuria	Group B	Site with future SIP
Thakurgaon	Baliadangi	Paria	Mesni	Group B	Site with future SIP
Thakurgaon	Pirganj	Jabarhat	Barabari	Group B	Site with future SIP
Thakurgaon	Pirganj	Jabarhat	Chanduria	Group A	Site with SIP
Thakurgaon	Pirganj	Sengao	Danajpur	Group B	Site with future SIP

Thakurgaon	Pirganj	Sengao	Dostompur	Group A	Site with SIP
Thakurgaon	Pirganj	Sengao	Harsua	Group A	Site with SIP
Thakurgaon	Pirganj	Sengao	Sasour	Group A	Site with SIP

ANNEX C – List of sites sampled in the SIP survey

Zilla	Upazila	Union Name	Village Name
Bogura	Dhunat	Nimgachi	Nandiarpara
Bogura	Gabtali	Baliadighi	Tayerhat
Bogura	Shibganj	Maidanhata	Polashi
Bogura	Sonatala	Pakulla	Huakhua
Bogura	Sonatala	Pakulla	Poschim Poddopara
Chuadanga	Alamdanga	Hardi	Boddanathapur
Chuadanga	Alamdanga	Vangbaria	Sekhpara
Chuadanga	Alamdanga	Vangbaria	Vogail
Chuadanga	Jibannagar	Andulbaria	Nischintopur
Chuadanga	Jibannagar	Andulbaria	Paka
Chuadanga	Jibannagar	Shimanto	Horihornogor
Chuadanga	Jibannagar	Uthali	Dayapur
Dinajpur	Biral	Dhamoir	Kasirdangao
Dinajpur	Biral	Sohorgram	Akor Gram
Dinajpur	Biral	Sohorgram	Fulbari
Dinajpur	Birganj	5 No Sujalpur	Purbo Chakay
Dinajpur	Birganj	3 No Sotogram	Nondaigaon
Dinajpur	Birganj	6 no Nijpara	Boro Bochapukur
Dinajpur	Birganj	Nijpara	Bolorampur
Dinajpur	Birganj	Nijpara	Damrai Kandar
Dinajpur	Birganj	Nijpara	Nichu para
Dinajpur	Birganj	Nijpara	Telipara
Dinajpur	Bochaganj	Atgao	Molla Para
Dinajpur	Bochaganj	Atgao	Sylet
Dinajpur	Bochaganj	Shatoil	Madobpur
Dinajpur	Bochaganj	Shatoil	Madobpur
Dinajpur	Khansama	Bherbheri	Mondalpara
Gaibandha	Saghata	Jumarbari	Kamarpara
Gaibandha	Sadullapur		Moagari
Jhenaidah	Jhenaidah Sadar	Modhuhati	Chorkol
Jhenaidah	Kaliganj	Raygram	Gomrail
Jhenaidah	Maheshpur	Shyamkur	Anontapur
Jhenaidah	Maheshpur	Soroppur	Kusodanga
Jhenaidah	Mahespur		Sonagari Math
Jhenaidah	Sadar Jhenaidah	Kalicharanpur	Bogobannogor
Kushtia	Daulatpur	Doulotpur	Chua Mollikpara
Kushtia	Daulatpur	Doulotpur	Doulatkhali
Kushtia	Daulatpur	Refayetpur	Lokkhikola
Kushtia	Daulatpur	Refayetpur	Sitlai Chondipur
Kushtia	Mirpur	Amla	Burapara
Kushtia	Mirpur	Amla	Burapara
Kushtia	Mirpur	Fulbaria	Shimulia
Kushtia	Mirpur	Satian	Kalinathpur
Meherpur	Gangni	Mothmura	Kumaridanga
Meherpur	Gangni	Saharbati	Saharbati

Meherpur	Gangni	Tetulbaria	Uttorvorat
Meherpur	Meherpur Sadar	Kutubpur	Romidaspur
Meherpur	Meherpur Sadar	Pirojpur	Boliarpur
Dinajpur	Birganj	3 No Sotogram	Rangalipara
Dinajpur	Birganj	Mohammapur	Rosulpur
Dinajpur	Bochaganj	Shatoil	Maherpur
Dinajpur	Bochaganj		Mojati Bazar
Dinajpur	Biral	Mongolpur	Uttar Madobpur
Dinajpur	Biral	Shohorgram	Gorugram
Dinajpur	Bochaganj	Shatoil	Maherpur
Gaibandha	Saghata	Kochua	Amratoli
Gaibandha	Gobindaganj	Shalmara	UjirparaBaiguni
Gaibandha	Gobindaganj	Shalmara	UjirparaBaiguni
Panchagarh	Boda	5 No Boro shoshi	Mayapara
Panchagarh	Debiganj	4 No Pamuli	Pamuli
Panchagarh	Boda		Ghoramara Kandor
Panchagarh	Boda		Katonhari Kandor
Panchagarh	Panchagarh Sadar		Barthan Kandor
Rangpur	Badarganj	Bishnupur	Dolua Purbopara
Rangpur	Badarganj	Kutubpur	Airmari, Nataram
Rangpur	Badarganj	Lohanipara	Sajanogram
Rangpur	Badarganj	Kutubpur	Rustamabad
Rangpur	Badarganj	Badarganj	Sarkarpara
Rangpur	Badarganj	Kutubpur	Kutubpur
Thakurgaon	Haripur	Gedura	Maradhar
Thakurgaon	Ranisankail	Dhormogar	Vorniya Moshaldangi
Thakurgaon	Ranisankail	Mujhahidabad	Pamuli
Thakurgaon	Baliadangi	Baliadangi	Thukrabari
Thakurgaon	Baliadangi	Baliadangi	Dokkhin Duari
Thakurgaon	Baliadangi	Baliadangi	Bengrul Jiabari
Thakurgaon	Haripur	Gedura	Poschim Atghoria
Thakurgaon	Baliadangi	Baliadangi	Sorbo Mongla
Thakurgaon	Pirganj	7 No Hazipur	Sasour
Thakurgaon	Pirganj	9 No Sengao	Horshua
Thakurgaon	Ranisankail	Dhormogar	Velapukur
Thakurgaon	Pirganj	Jaborhat	Chondroriya
Thakurgaon	Pirganj	Shengaon	Rostompur

ANNEX D – Survey questionnaires

The Household survey questionnaire and the SIP-survey questionnaire are available on the SoLAR project website. Click on the links to read more about these.

ISBN 978-92-9090-949-1

IWMI
International Water Management Institute

IWMI is a CGIAR Research Center

The International Water Management Institute (IWMI) is an international, research-for-development organization that works with governments, civil society and the private sector to solve water problems in developing countries and scale up solutions. Through partnership, IWMI combines research on the sustainable use of water and land resources, knowledge services and products with capacity strengthening, dialogue and policy analysis to support implementation of water management solutions for agriculture, ecosystems, climate change and inclusive economic growth. Headquartered in Colombo, Sri Lanka, IWMI is a CGIAR Research Center with offices in 14 countries and a global network of scientists operating in more than 30 countries.

International Water Management Institute (IWMI)
Headquarters
127 Sunil Mawatha, Pelawatta
Battaramulla, Sri Lanka

Mailing address:
P. O. Box 2075
Colombo, Sri Lanka
Tel: +94 11 2880000
Fax: +94 11 2786854
Email: iwmi@cgiar.org
www.iwmi.org

Published: March 2023