Solar Irrigation in Bangladesh

A Situation Analysis Report

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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 main goal of the project 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.

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Project

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Infrastructure Development Company Limited (IDCOL)

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List of Abbreviations

GHG	Green House Gas
NDC	Nationally Determined Contributions
IDCOL	Infrastructure Development Company Limited
PV	Photo Voltaic
BDMI	Barind Multipurpose Development Authority
SIP	Solar Irrigation Pump
BREB	Bangladesh Rural Electrification Board
BADC	Bangladesh Agricultural Development Corporation
IARC	International Agency for Research on Cancer
SREDA	Sustainable And Renewable Energy Development Authority
BMDA	Barind Multipurpose Development Authority
RDA	Rural Development Authority
WHO	World Health Organisation
BAU	Business as Usual
BPC	Bangladesh Petroleum Corporation
STW	Shallow Tube Wells
BERC	Bangladesh Energy Regulatory Commission
GBM	Ganges-Brahmaputra-Meghna
HYV	High Yield Varieties
UIC	Upazilla Irrigation Committee
DTW	Deep Tube Wells

Executive Summary

This report presents a synthesis of Bangladesh's solar irrigation policies, highlights the current issues faced by the energy and groundwater sector in the context of solar irrigation, and describes how the SDC-SoLAR (Swiss Development Corporation-Solar Irrigation for Agricultural Resilience) project led by the International Water Management Institute (IWMI) aims to navigate these complex issues through its research activities.

Bangladesh achieved self-sufficiency in food grains production due to the steady agricultural growth in the 1990s and 2000s, which was made possible through the proliferation of high-yielding paddy varieties and expansion of small-scale groundwater irrigation. The import of inexpensive diesel shallow tube wells from China and India in the early 1990s enabled the cultivation of *boro* paddy at a large scale during the dry season through groundwater irrigation. *Boro* paddy, in turn, drove the agricultural growth in the country and helped to achieve food self-sufficiency by 1999-2000. But the irrigation sector became dependent on imported diesel, resulting in high fiscal pressures. In 2012-13, subsidies for petroleum products rose to US$ 1.6 billion, a large part of which was for diesel. Roughly 3.5 million metric tonnes of CO_2 emission in Bangladesh in a year is from diesel-based irrigation, which is 4.4% of total annual production-based CO_2 emissions of 78.9 million tonnes.

Bangladesh is committed in its Nationally Determined Contributions (NDCs) to reduce its Greenhouse Gas (GHG) emissions - unconditionally by 5% by 2030 and up to 15% conditional on appropriate international support. Accordingly, the Renewable Energy Policy of Bangladesh, 2008, set a 10% renewable energy target by 2020. Bangladesh's NDC roadmap specifically identifies solar pumps as 'immediate means of reducing GHG in the agricultural sector by switching from diesel-based pumps'. The Infrastructure Development Company Limited (IDCOL), the largest financier for solar irrigation pumps (SIPs), targets installing 50,000 SIPs by 2027. Based on that target, our calculations suggest that these SIPs can be expected to help avoid CO_2 emissions from diesel irrigation by up to 0.83 million tonnes per year. Thus, SIPs have a great potential of mitigating carbon emissions in Bangladesh's irrigation sector.

So far, a total of 1969 solar irrigation pumps (SIPs) across 25 districts (installed capacity at 46.98 MW) have been set up, mainly by IDCOL. IDCOL, the primary agency working for mainstreaming of solar pumps in Bangladesh, uses the fee-for-service model. In this model, an NGO/private entrepreneur (sponsor) gets a 50% grant and a 35% loan from IDCOL to set up SIPs in the villages. Then, these sponsors sell irrigation services to farmers in exchange for a fee. Farmers benefit from this SIP model since it is cheaper, reliable, and better than diesel-based irrigation.

The average pump size in IDCOL locations is 15.3 kW, with the average solar panel capacity at 29.7 kW, and it serves 30 to 50 farmers in each location. The main reason for excess panel capacity is to maintain a high discharge rate throughout the day so that during peak irrigation season in the winter months (*boro* cultivation), larger areas can be served. Large pump sizes with excess solar PV capacity means that the project costs are also higher. Therefore, the sponsors need to generate sufficient revenue to be able to pay back the loan. The ability of sponsors to generate adequate revenue depends on the type of crops farmers are growing. If farmers grow water-intensive crops like *Boro*, the demand for irrigation is high, and sponsors can collect higher total irrigation fees. As a result, this irrigation service provision business is susceptible to changes in farmers' crop choices that can be affected by external shocks like a fall in the market price of *Boro*.

Another critical factor for solar irrigation in Bangladesh is that most of these solar pumps currently remain idle for a substantial time because irrigation season is limited to 110-150 days a year. Some IDCOL sponsors have started using that energy to provide additional agricultural services like husking, threshing, running cold storage, running oil press etc. Despite developing alternative solar power uses, these are not enough to absorb all the energy generated. Connecting the solar panels to the national electricity grids to sell excess energy is another option. The Bangladesh government has already approved the grid connection policy and SDC-SoLAR project in partnership with IDCOL. The sponsors will pilot a few grid-connected SIPs as a part of this project.

Apart from IDCOL, there are a few other organisations promoting SIPs in Bangladesh. For example, the Barind Multipurpose Development Authority (BMDA) works in the Barind region, which is characterised by declining groundwater. One of their objectives is to encourage the use of surface water for irrigation. In addition, Bangladesh Rural Electrification Board (BREB), through an ADB financed project called Solar Photovoltaic Pumping for Agricultural Irrigation, plans to install 2200 solar pumps in Bangladesh under the individual ownership model. The targeted beneficiary of this model is primarily small farmers, with pump sizes in the range of 2-5.5 kW. This project also plans to connect the individual SIPs to the grid, which is expected to boost the demand for these individual SIPs.

As the PV technology is new in agriculture, given the complexity of the agriculture system in Bangladesh, there will be no single path to scale up SIP for inclusive growth. Therefore, there is a need for a coordinated approach in the energy-water-food sector if it has to be scaled up. Solar pumps also need to be made financially attractive to users by providing better terms and finding alternative energy uses like grid integration.

1. Introduction

Bangladesh, located in South Asia, is one of the world's largest deltaic countries and is one of the most densely populated regions of the world. Bangladesh is primarily an agrarian economy where the agricultural sector contributes to 13.6% of its GDP and employs approximately 40.6% of total employed labour (Finance Division: MoF, 2019). Given the size of its population and, in comparison, very limited availability of fertile land for agriculture, ensuring food security is the government's highest priority. As a result, the country has witnessed steady growth in agriculture to achieve self-sufficiency in cereal production. For example, food grains production increased from 100.5 lakh metric tonnes in 1971-72 (Chen & Chaudhury, 1975) to 249.07 lakh metric tons in 1999-2000 and 415.74 lakh metric tons in 2018-19 (Finance Division: MoF, 2005, 2019). This impressive agricultural growth was made possible because of an increase in total cultivated land and yield of paddy through the proliferation of high-yielding and stress-tolerant variety (from 16.1% in 1971-72 to 94.3% in 2017-18) and expansion of small scale groundwater irrigation (0.4 million hectares of minor irrigated area in 1971-72 to 5.6 million hectares in 2018-19) (BADC, 2020; Mottaleb et al., 2019). Currently, 88% of total food grain production in Bangladesh is rice, with *boro* rice being the most important one (47%) (Finance Division: MoF, 2005, 2020). *Boro* has been crucial for Bangladesh's food security since it is not as susceptible to flood or other natural calamities as *Aman* or *Aus* rice and ensures that the domestic food demand can be met. Through the 1980s and 1990s, Bangladesh faced chronic food deficits and depended on import and foreign aid, which finally ended in 1999-2000 when it became food self-sufficient (Rahman & Rahman, 2009). The following two decades saw Bangladesh achieve food self-sufficiency as total food grain production became sufficient for the domestic requirement. However, some food grain (especially wheat) is still imported.

The role of large-scale use of groundwater irrigation for achieving this growth in Bangladesh's agricultural production is well-documented (Hossain, 2010; Mottaleb et al., 2019; Rahman & Rahman, 2009). Bangladesh receives abundant rainfall during the monsoon season, but almost no rains between January to May, when *boro* paddy is cultivated. Post-independence, the government's focus on minor irrigation expansion for groundwater and surface water was through Bangladesh Agricultural Development Corporation (BADC), which rented out Low Lift Pumps to farmers and provided them with subsidised diesel and managed Deep tubewells (Mottaleb et al., 2017). However, restrictions on importing diesel engines and rules on tubewell spacing meant that the expansion of groundwater irrigation could not happen at full speed. After the devastating floods of 1988 and the cyclones of the early 1990s, the government liberalised irrigation equipment imports to boost the agricultural sector (BADC, 2020). As a result, the Bangladesh market was flooded with inexpensive diesel STWs from China and India (Hossain, 2010); and the number of STWs increased from 0.4 million in 1993 to 1.2 million in 2006 and about 1.4 million in 2018 (Figure 1). These cheap STWs were easy to install and maintain, making them popular among farmers (BADC, 2020).

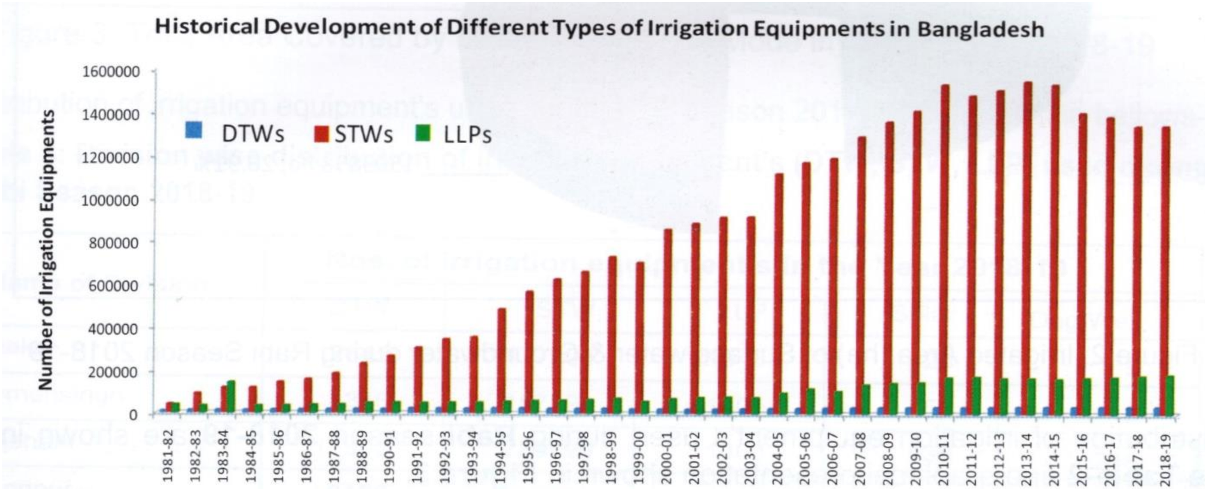


Figure 1 - Historical Development of different types of pumps in Bangladesh
Source: Bangladesh Agricultural Development Corporation (BADC, 2020)

Due to the expansion of diesel STWs, 73% of irrigated area in Bangladesh is irrigated using groundwater. Almost 87.5% of total groundwater withdrawal is used in irrigation (31.5BCM out of 36 BCM). Despite using groundwater for irrigation, heavy rainfall during the monsoon season recharges the aquifers sufficiently in most areas of Bangladesh, except a few pockets, especially the Barind region and north-central region near Dhaka city, which are witnessing a permanent decline of groundwater (BADC, 2020; Dey et al., 2017; Rahman et al., 2016). We discuss Bangladesh's groundwater situation in more detail later in Section 0. The success of increased access to irrigation in propelling the agricultural sector towards growth and food security becomes clear as we see that the *boro* area expanded rapidly in the 1990s from 2.6 million hectares in 1993 to 4.3 million hectares in 2006. After that period, growth in the *boro* area slowed down, and it climbed to just 4.8 million hectares in 2014-15.

The rapid growth in the number of STWs made the irrigation sector entirely dependent on imported diesel. Moreover, with economic growth, the energy requirement of Bangladesh's irrigation sector is expected to increase even more. According to one estimate, the annual diesel consumption for groundwater extraction is of the order of 4.6 billion litres, costing USD 4.0 billion in aggregate (Qureshi et al., 2014).

Moreover, the use of `dirty' fuel for power generation becomes unsustainable in the future, given that Bangladesh is committed to reducing its Greenhouse Gas (GHG) emissions to achieve its Nationally Determined Contributions (NDCs). Despite diesel being expensive and harmful for the environment and human health, farmers continue to use diesel operated pumps in the absence of grid-connected electricity supply in many corners of the country till recently. Diesel exhaust contains harmful emissions of nitrogen oxides (NOx) and particulate matter (PM) known as *'black smoke'*, which are dangerous to human health and a large body of evidence indicates that it causes cancer (Frondel & Vance, 2014). In fact, in 2012, the International Agency for Research on Cancer (IARC), part of the World Health Organization (WHO), had classified diesel engine exhaust as carcinogenic to humans. This was based on findings that there is sufficiently strong evidence for diesel exhaust to cause lung cancer and limited evidence of increased bladder cancer risk (IARC, 2012).

With the dual aim of achieving energy security and reducing GHG emissions, the Renewable Energy Policy of Bangladesh, 2008 (GoB, 2008) had set the target to meet at least 10% of its energy production through renewable sources by the year 2020, using diverse sources like solar, hydropower, wind energy, biomass and biogas plants.

2. Current scenario of solar irrigation in Bangladesh

To achieve 10% renewables by 2020 would require an installed capacity of approximately 2000 MW. But according to the Sustainable & Renewable Energy Development Authority (SREDA) website records, only 650.53 MW of renewable energy has been installed until the end-2020. This is only 2.93% of total electricity generation (SREDA, 2020), showing Bangladesh has missed its renewable energy generation targets of 10% by 2020.

Out of the total installed capacity of renewables, 64% is from solar, and 35% is from hydropower. According to the National Database of Renewable Energy from SREDA, till 2020, 1969, solar irrigation pumps have been launched across 5 Divisions and 25 districts of the country, with a total installed capacity of 46.98 MW (Figure 2). While this is substantial progress, it still falls short of the target set in the 500 MW Solar Power Generation Plan launched in 2012, which envisaged 500 MW of solar generation capacity by 2016, out of which 150 MW of capacity will be from solar irrigation systems. Moreover, the progress has been slower, as the SREDA database indicates that the total installed capacity for solar by December 2020 is 416.6 MW, still below the 500 MW target (SREDA, 2020). For context, this number of solar pumps in Bangladesh is minuscule if we compare it with 1.24 million diesel pumps irrigating approximately 3.0 million hectares and 0.34 million electric pumps covering 2.3 million hectares in 2018-19 (BADC, 2020). Despite a steady increase in electricity pumps over the years, historically, there have been several bottlenecks in connecting farmers to the grid: insufficient production, poor operational practices, inadequate transmission capacity, grid stability and dispatch efficiency, etc. However, the government had set a target of providing electricity for all by 2021 as part of its 'Vision 2021' of Bangladesh (Taheruzzaman & Janik, 2016), and already 96% of the population have access to electricity (Finance Division: MoF, 2020).

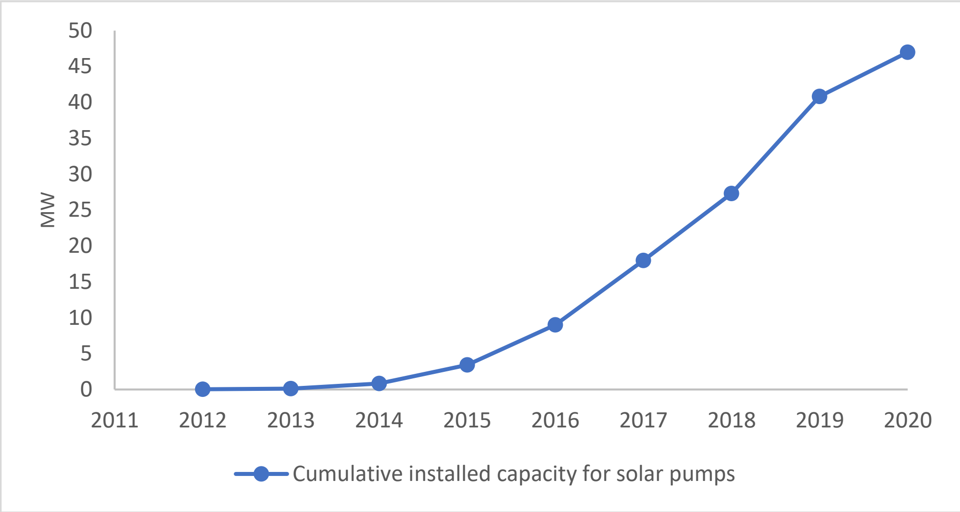


Figure 2 - Cumulative installed capacity for solar pumps in Bangladesh

Infrastructure Development Company Limited (IDCOL), a government-owned financial company, is currently the primary agency working to mainstream SIPs in Bangladesh. Most of the donor aid and government funding for the promotion of solar irrigation in Bangladesh goes through IDCOL, which finances the purchase of solar pumps through a mix of loans and grants. As we can see (Table 1), almost 95% of the total installed capacity in SIPs are financed through IDCOL. Until 2020, the company had installed 1515 pumps and aims to set up 10000 pumps by 2027. All the solar pumps installed by IDCOL are primarily in the Rangpur and Rajshahi divisions in the Northwest and Khulna divisions in the Southwest (Figure 3). The location of these SIP sites has been chosen based on regions with less flooding, less arsenic, high demand for Boro cultivation and high density of diesel pumps.

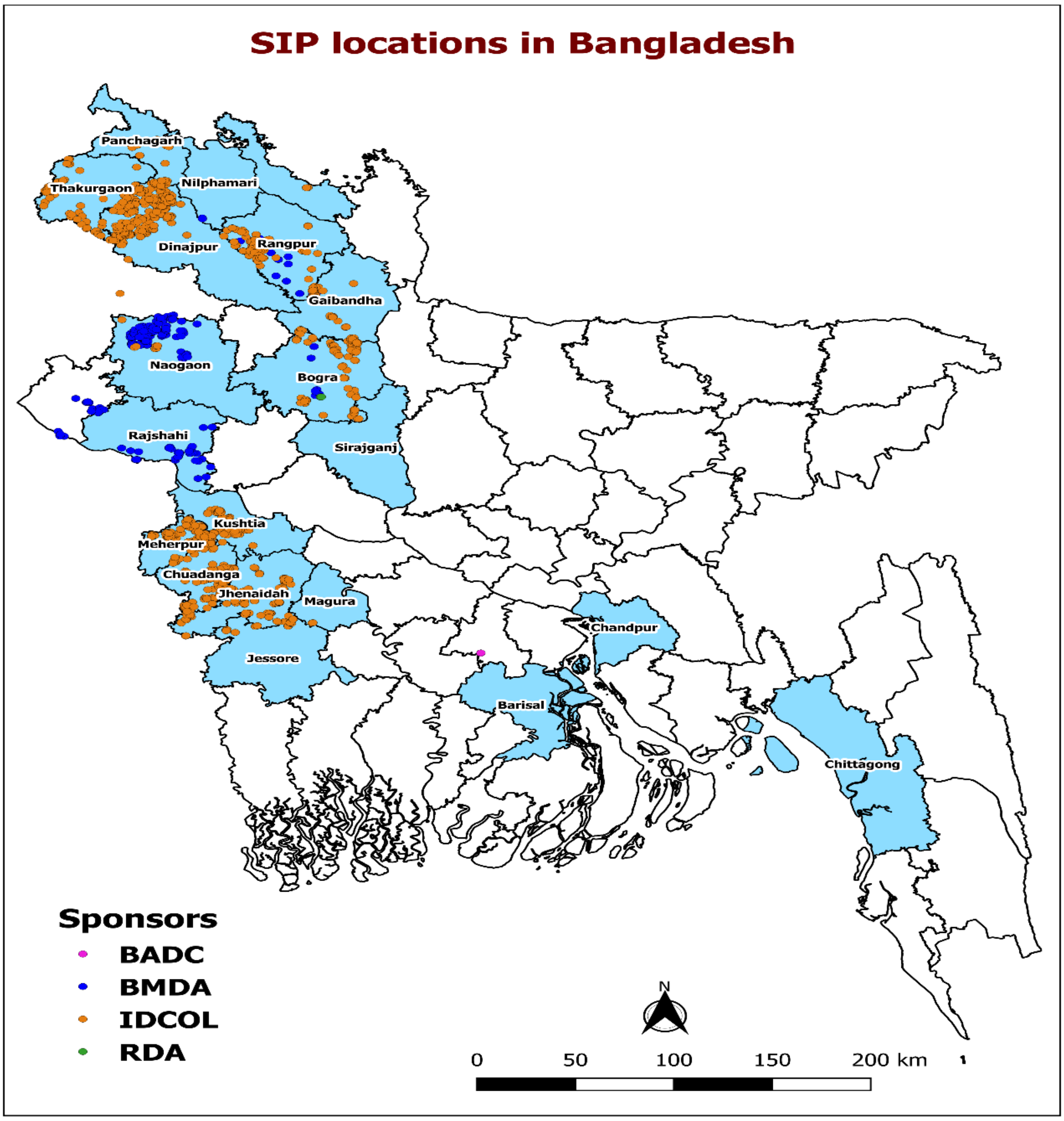


Figure 3 - SIP locations in Bangladesh

However, apart from IDCOL, a few other organisations promote SIPs in Bangladesh (Table 1). Barind Multipurpose Development Authority (BMDA) is the next most important agency working to promote solar irrigation. BMDA works in the Barind region characterised by declining groundwater. One of their objectives is to encourage the use of surface water for irrigation. Till 2020, BMDA has installed 453 solar pumps, including a few deep tubewells, and the rest are surface irrigation schemes.

Rural Development Authority (RDA) had previously two solar irrigation programmes called *'Multi-storied Agriculture with Solar Power Irrigation'* and *'Direct operation of DTW (15 kW) by solar power and uploading electricity to overhead grid the appropriate metering system'* financed by the

Bangladesh Government. Currently, RDA has 35 solar irrigation pumps. Similarly, Bangladesh Agricultural Development Corporation (BADC) has also installed 249 solar pumps that are now operational. Still, their primary objective has been to familiarise farmers with the solar pump technology and not creating full-fledged solar irrigation programs per se. The solar pumps of BADC are primarily financed through grants, and they are operated and maintained by water user groups that collect some nominal fees from their members. BADC has a target of installing 1000 pumps by 2023. Bangladesh Rural Electrification Board (BREB) is Bangladesh's major power distribution company responsible for rural electrification. They had previously installed around 40 solar schemes in Bangladesh before 2013. BREB has an active 50-million-dollar project financed by ADB to install 2000 solar pumps in Bangladesh. This project is called 'Solar Photovoltaic Pumping for Agricultural Irrigation', with pump capacity varying from 2.2 kW to 11 kW.

As the PV technology is new in agriculture, given the complexity of the agriculture system, such as fragmentation of land, a multitude of marginal farmers, an abundance of tenancy cultivation, and market failure due to weak institutional structure; there is no single path to scale up SIP for inclusive growth. Given such variance in agriculture, these organisations are piloting SIP implementation with different financial and institutional modalities during this dissemination phase. Therefore, it is crucial to understand these different modalities of SIP implementation that are already running or have been planned but are to be implemented. A majority (83%) of SIP implemented till now follow the *fee-for-service* model of IDCOL, but we also discuss the details of other modalities in this section. In the SDC-SoLAR project, we also plan to undertake detailed studies comparing these different SIP modalities.

	Fee for service model	**Ownership model**	**Group ownership model**
Sponsor	IDCOL	BREB	BMDA#, BADC, RDA, and others
Financial modalities (Grant: Loan: Down payment by farmer or sponsor)	50: 35:15	55: 35: 10 (not finalized)	The majority of 100% grant and few have a small proportion of equity payment depending on the organisation*
Repayment time	10 years	10 years	-
Average capacity per SIP (kW) [min-max]	28 [2 – 46]	5 [2- 15]	6 [2 - 22]
Total installed capacity (kW)	44845.48	~11000 (target)	1816.28
Target group	Sponsors who will serve marginal, small, and medium-sized farms	Small farmers	Very small and marginal farmers

Purpose	Irrigation	Irrigation	Irrigation + Drinking purpose
Grid connection	Off-grid[a]	Grid-Connection	Off-Grid
Division covered	Kushtia, Rangpur, Thakurgaon	Rangpur, Rajshahi, Dhaka Chattogram, Mymensingh Khulna	Barisal Rajshahi Rangpur

Table 1 - Different SIP modalities in Bangladesh

 # BMDA also tried a model similar to the fee-for-service model with 2 SIP units, where the ownership of the SIP is under BMDA and sells water to farmers on fixed charges.
** In BADC, 65% grant and 35% as a loan, and in RDA, only 10% is equity payment need to be paid in 15 years.*
'a'- IDCOL has selected 9 SIP units under the fee-for-service model to pilot grid connection.

2.1 Fee-for-service model

IDCOL has taken the lead to implement the Fee-for-service model. It finances the intermediator called *sponsor* who invests in SIP equipment and owns and operates the SIP (Figure 4). The sponsors receive grants from IDCOL, i.e., up to 50% of the total cost of SIP, of which IDCOL financed 35% as a loan, and 15% was supposed to be made as a down payment by the sponsor. The loan taken is supposed to be repaid within a maximum of 10 years at a 6% interest rate. The sponsor buys solar pumps from suppliers, takes land on lease from a farmer in the village and sets up a SIP system following all the technical and project specifications as mandated by IDCOL. Each system has a buried pipeline network of 3,000-3,500 feet with 15-25 risers from which water is delivered through open field channels. The sponsor also generally employs a local person or farmer as the operator of the pump.

The sponsor then supplies water to farmers around the deliverable area in exchange for a fee (for example, 35.4 USD[1]/Bigha during Boro rice season). Sponsors make revenue from selling water and repay loans taken from IDCOL and cover operation costs. However, the price at which sponsors sell water is regulated based on the cost of diesel-based irrigation. These sponsors can be NGOs and private organisations. Currently, 56% of the total installed SIPs under this model are private organisations. After the loan has been paid back to IDCOL, the sponsor becomes the owner of the SIP system.

The SIP units under this model target small and medium farms. These SIPs have an average capacity of 28 kW (Table 1). As these are off-grid SIP, the excess energy generated in these systems is often used for other agri-business activities like running mills, poultry, and cold storage. Under this, IDCOL has targeted to install 10000 SIPs under these modalities by 2027.

[1] Taking the exchange rate of 1 USD = 84.67 BDT on 04/12/2020

There are several advantages to the fee-for-service model:

- Given the huge investment cost of SIP and a large number of marginal and tenancy farmers in Bangladesh, it is not easy to convince the farmers to adopt SIP. This obstructs market uptake and upscaling. The fee-for-service model brings an intermediator to invest in SIP, which helps farmers get irrigation slightly lower than diesel.
- In addition, the energy used for irrigation is clean. Thus, it leads to a win-win for businesses and eases implementing off-grid SIP in the country.
- The average capacity of mounted PV panels is of medium capacity and often more than sufficient to meet irrigation demands. In addition, the excess energy can be easily routed for other agri-business activities such as cold storage and milling.

However, there are several challenges in this model as well:

- As the irrigation requirement in the country is about 110 -150 days in a year (ADB, 2020), there is a large potential to use the excess energy for alternative use. However, since SIP sites under this model focus on off-grid areas, additional investment is needed for infrastructure development from the sponsor/state to use the excess energy.
- Given the water price charged to farmers is regulated to be lower or on-par with the cost of diesel pumping, and the sponsors earning only from selling water makes the fee-for-service model's financial viability weak.
- One of the guidelines to install this model is that there are no electric grids nearby. However, given the Government of Bangladesh aims to bring 97% of the population under grid connection (99% in rural areas), following the same guidelines to reach the targeted 10000 SIPs in the future is challenging.

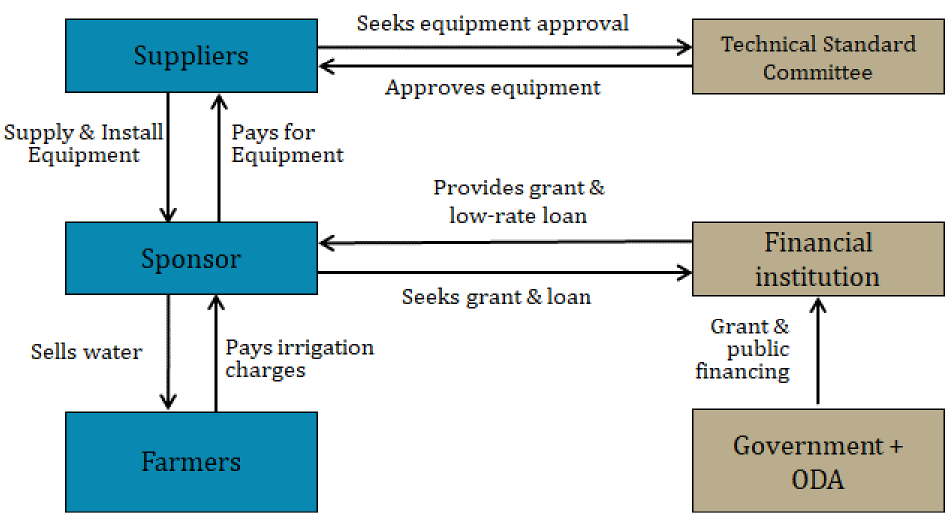


Figure 4 - Fee-for-Service modalities (source: ABD, 2020, Roadmap for solar in Bangladesh)

2.2 Ownership model: Group and individual ownership

In the group ownership model, farmers through irrigation committees invest, own, and operate SIP. Financial institutions like BREB, BMDA, BADC, and RDA provides financial assistance to this group to procure the SIP equipment. The model covers small and marginal farmers who cannot invest and take long years to repay the loan. Therefore, the majority of the financial institutions under the group ownership model installed SIP under a 100% grant basis, except under BADC, where farmers are responsible for 35% of the total cost. Once the SIP unit gets approved, the group is linked to suppliers/manufacturers by the financial institution to get the recommended capacity of SIP equipment. The operation and maintenance costs are also covered under the grant. Since the finances of these models are on a grant basis, the acceptance of the technology is quick.

The average capacity of the system is low, with a range of 2 to 15 kW, which is enough for small-scale irrigation and drinking water projects. Less than 5 kW pumps are mostly installed for dug wells, where farmers use them for drinking water and vegetable farming. The system capacity of more than 5 kW is exclusively used for irrigation purposes. The farmers in the group share the ownership of SIP, irrigate the member's field on a rotation basis, and sell the water to other farmers and share the profit. Unlike in diesel irrigation, farmers under group-owned SIP face almost zero marginal cost. They receive a grant on SIP that decreases the irrigation cost and is expected to increase income and intensify production.

According to SREDA data, BMDA installed 327 units with a total capacity of 1758.2 kW under this model. RDA and BADC installed two units, each with a capacity of 28 kW and 30 kW, respectively. We learnt that BREB and GiZ have also installed SIP under this modality for drinking water and small-scale irrigation through discussion with the officials. The SIP under this model is operational mainly in Barisal, Rajshahi, and Rangpur divisions. There are several challenges to this group ownership model:

- Although operation maintenance cost is covered, farmers are not sufficiently trained and equipped to manage the SIP system and access to timely repair is an issue. Therefore, they require rigorous training, capacity building, and extensive extension education on SIP.
- Since marginalised farmers require financial assistance, mainly covering all costs through grants to adopt SIP, implementing this model is costly.
- Group ownership throws several challenges such as user rights among the members, conflicts, irrigation rotation, elite control within the group, etc.

In the individual ownership model, individual farmers own the SIPs. However, to cover the large proportion of irrigated area under SIP, Bangladesh and ADB, in cooperation with BREB, has planned to implement around 2200 SIPs in the country, covering 6 out of 8 divisions to demonstrate the SIP technology to farmers and replacing the diesel pumps. This is a flagship program of BREB funded by the ADB's Strategic Climate Fund and Clean Energy Financing Partnership Facility.

In contrast to the fee-for-service model, farmers individually invest, own, and operate the SIP system in the individual ownership model. Farmers get 55% of the total cost as a grant from ADB, and the remaining 45% needs to be paid by the farmer. Of the equity proportion, 10% is a down payment while installing the SIP, and 35% is given as a loan that the farmers can choose to repay in 10 or 120 instalments in 10 years. But given the ground situation of low demand for solar pumps from individual farmers, the subsidy-loan and equity components are being updated to make it more affordable for individual farmers. The targeted beneficiaries of this model are mostly small farmers; therefore, the calibrated capacity of the system will be in the range of 2-5.5 kW.

A unique feature of the SIP system under the BREB funded individual ownership model is that it is planned to connect the SIP to the grid at a specified tariff. The cost of grid connection is taken care of by BREB. The tariff structure is not yet finalised. However, BREB believes the grid connection is needed to make SIP competitive against electric pumps. Besides, farmers will be better off earning additional income free of climatic risk, increasing their likelihood of SIP adoption.

This model is expected to finalise the contract with 400 farmers in the first phase covering Rangpur, Rajshahi, Dhaka, Chattogram, Mymensingh, and Khulna divisions. This model is anticipated to create a strong awareness about the benefits of SIP, which helps in the acceptance of SIP technology in agriculture and is a push strategy to activate the demand. However, this model's main challenge is that since it deals with individual farmers, it requires handholding until the local capacity and knowledge on SIP is established.

IDCOL being the dominant market leader in renewable energy, specifically solar irrigation in Bangladesh, it becomes imperative to study this *fee-for-service* model in more detail. Moreover, their way of operation has a significant implication on how successfully solar pumps are adopted in the country in future and how widely its benefit reaches all sections of the society. Therefore, we discuss in more detail how IDCOL's model is functioning later in the report.

3. Freedom from diesel – the potential of solar irrigation as a solution

Bangladesh Government's priority in promoting solar irrigation in Bangladesh has been to reduce dependency on diesel for irrigation. Therefore, the guidelines in Solar Powered Development Programme, 2013(Power Division, 2013) specifically mention that the potential sites for solar irrigation should have the 'presence of diesel-powered irrigation but an absence of grid electricity.'

Reducing diesel-based irrigation can reduce GHG emissions in Bangladesh as 1 kg of diesel-burning is estimated to emit 3.186 kgs of CO_2 in the atmosphere (WRI, 2015). According to Bangladesh Petroleum Corporation, 1.09 million metric tons of diesel (high–speed diesel -HSD) have been sold to the agricultural sector in 2017-18, primarily used for diesel pumps. Thus, approximately 3.5 million metric tonnes of CO2 emission were just from diesel used in irrigation in a year. This accounts for almost 4.4% of Bangladesh's total annual production-based CO2 emissions of 78.9 million tonnes as estimated in 2017 (Ritchie & Roser, 2017).

Bangladesh has committed in its Nationally determined contributions (NDCs) under UNFCCC to reduce its Green House Gas (GHG) emissions in the power, transport and industry sectors unconditionally by 5% below Business as Usual (BAU) levels by 2030 and conditionally up to 15% below BAU levels by 2030 subject to appropriate international support (Ministry of Environment Forest and Climate Change, 2018). In Bangladesh's roadmap, it is mentioned that solar pumps should be supported as an 'immediate means of reducing GHG in the agricultural sector by switching from diesel-based pumps.'

The dependence of irrigation on diesel also has a huge implication on the government exchequer. Bangladesh Petroleum Corporation (BPC) imports crude oil and refined oil (including HSD) based on domestic demand. More than 90% of HSD used in Bangladesh is imported and costs around 2.6 billion US$. Not only does it imply the spending of precious foreign exchange to import diesel, but in case of a rise in international oil price, the government needs to subsidise BPC incurring huge costs on the exchequer. In 2012-13, the amount of subsidy given to BPC for importing petroleum products rose to US$1.6 billion (Table 2), a large part of which was for diesel (Finance Division, Ministry of Finance 2018). Due to the fall in international oil prices after 2015, the subsidy given to imported oil has become zero. But as global oil prices are rising again, BPC has started incurring losses that would require subsidies from the government. Therefore, if the dependence of the irrigation sector on imported diesel can be reduced, it will also reduce the government's overall oil subsidy burden. Solar-powered irrigation is seen as a promising alternative to diesel-based irrigation that would serve the dual purpose of reducing GHG emissions and the government's subsidy burden on imported diesel.

FY	The total import cost of Petroleum (billion USD)[2]	The total amount of subsidy for petroleum import (USD billion USD)	Diesel, Octane, JET A1 --- The proportion of import cost	Diesel, Octane, JET A1 --- Imported quantity ('000 MT)[3]	Petroleum consumption in Agriculture ('000 MT)
2009-10	1.96	0.11	73%	2634	766[a]
2010-11	3.50	0.47	72%	2488	869[a]
2011-12	4.49	1.01	71%	3410	-
2012-13	4.12	1.6	63%	2827	-
2013-14	4.32	0.29	64%	3158	-
2014-15	3.19	0.071	69%	3404	929
2015-16	1.77	0	74%	3337	947
2016-17	2.34	0	73%	3871	906
2017-18	3.54	0	78%	4892	1091
2018-19	3.63	-	76%	4282	1075

Table 2 – Amount of Subsidy given to BPC.

Source: Bangladesh Economic Review 2020, Collected from BPC website (BPC, 2020)*;*
[a]: Author's calculations from the BIDS report (Mujeri et al., 2013)

To get a rough estimate of CO_2 emission per hectare of diesel irrigated area, we consider the total amount of diesel sold to the agricultural sector in 2017-18 as 1.09 million metric tons. Minor irrigation survey (BADC) report of 2017-18 estimates that 1.23 million diesel operated pumps (STW+DTW+LLP) irrigated about 2.97 million hectares of land during Rabi season 2017-18. Assuming that total diesel sold to the agricultural sector is primarily used for irrigation, we estimate that 366 kg (i.e.,440 litres) of diesel is used per hectare of irrigated area[4]. Since 3.186 kg CO_2 is emitted per kg of diesel burnt, our rough calculation shows approximately 1166 kg CO_2 emission per hectare of diesel irrigated area in a year in Bangladesh. On average, the net area irrigated by each IDCOL SIP is 7.6 hectares. Most of this is the area irrigated during the peak irrigation season of Boro. This average is estimated based on the sample of 825 IDCOL solar pumps operating since 2019 or before. If 7.6 hectares were to be irrigated by diesel pump, approximately 8.9 tonnes of CO_2 would have been emitted per year (based on our above calculation showing 1166 kg CO_2 emission per hectare of

[2] Converted from BDT using fixed exchange rate of 1 USD = 84.67 BDT on 04/12/2020. This is not actual USD cost incurred by BDT Government.
[3] ~90% is diesel among Diesel, Octane, JET A1 on average
[4] This also matches roughly the diesel use estimates that we got through focus group discussions with farmers at IDCOL sites – approximately 50 litres of diesel per Bigha for Boro (i.e., 374 litres per hectare).

diesel irrigated area)[5]. Since SIP sites in Bangladesh are targeted in areas with diesel irrigation, we can then assume that each SIP site of IDCOL, on average, avoids approximately 8.9 tonnes of yearly CO_2 emissions.

Given that many of these SIPs have started their operation recently, the coverage is expected to expand in future. If planned coverage of 14.2 hectares per SIP is achieved, each SIP can be expected to avoid almost 16.6 tonnes of yearly CO_2 emissions. Furthermore, IDCOL targets installing 10,000 solar pumps by 2027. It can help prevent CO_2 emissions by up to 0.17 million tonnes per year (assuming these new SIPs are of similar size and installed in areas dependent on diesel irrigation). According to BADC Minor Irrigation Survey, 1.07 million diesel operated STWs irrigated 1.96 million hectares of area in 2018-19; i.e., approximately 1.83 hectares were irrigated by one diesel STW. Although there is some variation in the density of diesel pumps across Bangladesh, Table 3 shows the regions where IDCOL SIP replaces four diesel pumps on average. The data from BADC suggests that one diesel shallow tubewell services 8.75 farmers on average, which implies four diesel pumps would service approximately 35 farmers. This is very close to the average number of farmers serviced by an IDCOL solar pump currently, which is 39.

Division	**(A)** **Average net irrigated area of IDCOL's pumps (hectare)**	**(B)** **Average Density of diesel STW per hectare of diesel irrigated area**	**(C) = A*B** **The average number of diesel STW within the current coverage area**
Rajshahi (Bogura)[6]	5.6	0.675	3.8
Rangpur	8.5	0.509	4.3
Khulna	6.4	0.624	4.0
Country Average	7.6	0.546	4.1

Table 3 - Average density of diesel pumps across Bangladesh

Thus, solar pumps have great potential to restrict the use of diesel in Bangladesh's irrigation sector. As prepared by the Ministry of Environment, Forest and Climate Change, the NDC roadmap for Bangladesh highlight this immediate role of solar-powered pumps in shifting away from diesel-based irrigation. But they also caution that the 'actual installation and uptake of these pumps is likely to be small over the standard power planning time-horizons'. This is because the Bangladesh government is also committed to providing grid electricity to all corners of the country. Therefore, it is expected

[5] The above calculation assumes that the average diesel use in Bangladesh is representative of the regions where the Solar pumps of IDCOL are situated. We do not have data on regional disparities in diesel use, but from Table 3, we can see that the average density of diesel pumps in Bangladesh is approximately equal to regions where IDCOL sites are located.

[6] For Rajshahi, we consider only Bogura district since almost all active SIP sites in Rajshahi are in Bogura district.

that in those regions, diesel pumps will be replaced with grid electricity.

According to the annual report of the Bangladesh Power Development Board, agriculture constituted 2.81% of the total retail electricity consumption of 62037 Mkwh in the country, i.e., approximately 1743 Mkwh (million units) consumed for irrigation purposes. Moreover, 2.34 million hectares were irrigated using electricity in 2018-19 according to the BADC minor irrigation survey report, implying approximately 745 units consumed on average per hectare of electricity irrigated area. Electricity generation in Bangladesh is mainly from natural gas (68%) and furnace oil (16%) or imported (10%) from other countries. Thus, the CO_2 emissions from grid electricity in running irrigation pumps are likely to be less than diesel[7]. However, irrigation will still depend on 'dirty fuel' if diesel pumps are replaced with electricity from thermoelectric power plants.

Electric irrigation is cheaper than diesel-based irrigation. Still, the electricity tariff for agricultural pumps has been steadily increasing in Bangladesh from 0.027 US$ per unit in 2012 to 0.049 US$ per unit in 2020 (Bangladesh Energy Regulatory Commission). Thus, the gap in the cost of irrigation between diesel and electricity is narrowing in Bangladesh. However, there is a need for coordinated energy planning to ensure that farmers adopt solar-powered pumps and that SIPs are not out-competed by "dirty" electric pumps. Also, connecting solar pumps to the grid for selling electricity, wherever feasible, can help reduce dependence on diesel and coal for energy and help achieve the government's goal of producing 10% electricity from renewable energy.

4. Using excess energy: Grid integration and other alternative uses

IDCOL, the primary organisation for the expansion of solar irrigation in Bangladesh, has typically large pumps and solar panels installed at their sites since they run as businesses to sell water to many farmers. The average pump size in IDCOL locations is 15.3 kW (with 90% of the pumps between 7.4 to 18.5 kW). The average solar panel capacity is 29.7 kWp (90% of the panel capacity at IDCOL locations are between 11 to 43.52 kWp). The pumps are getting larger over time, with an even larger solar panel capacity, as shown in Figure 5. While the average pump capacity was 8.4 kW for pumps in IDCOL SIP projects approved till 2014, it steadily increased to 18.5 kW in 2019. The solar panel capacity increased even faster, from around 14 kWp till 2014 to 42.3 kWp in 2019.

[7] According to IEA website, 39 million tonnes of CO2 emitted from electricity and heat generation sector in Bangladesh in 2018. 62037 million units of electricity sale would imply 0.63 kg of Co2 emission per unit of electricity. So, if as calculated 745 units consumed per hectare for irrigation, then 468 kg CO2 emitted per year from electricity irrigated areas, which is much less than our rough estimate of 1226 kg CO2 emission per hectare of diesel irrigated area.

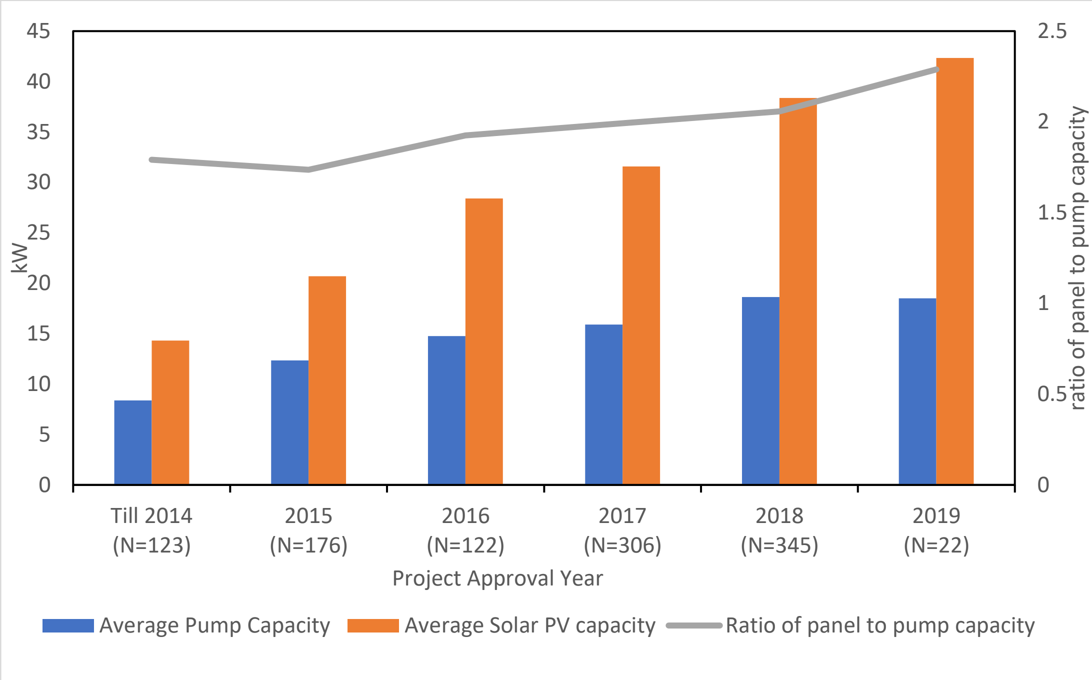


Figure 5 - Average Pump and Panel capacity in IDCOL locations over time

One reason for the increase in pump size and panel capacity is because the coverage area for the SIP sites has been increasing over the years. For example, the designed command area was approximately 9.5 hectares on average for projects till 2014, and it grew to 15.8 hectares for projects approved in 2018. In addition, it is also evident that the average length of buried pipelines and number of risers have been rising over the years from approximately 1593 feet of buried pipeline and eight risers on average for projects till 2014 to up to 3484 feet of pipeline and 17 risers on average for projects approved in 2018. This trend of increasing pump capacity and excess solar PV capacity can be observed in the north-west (Rangpur, Rajshahi) and southern regions (Khulna), where most IDCOL locations are situated.

Division	**Average Pump Capacity (kW)**	**Average Solar PV capacity (kWp)**	**The ratio of the panel to pump capacity**	**Discharge (Kilolitre/day)**
Khulna *(N=358)*	15.54	29.02	1.84	1607417
Rajshahi *(N=88)*	16.07	30.47	1.81	1652682
Rangpur *(N=687)*	15.43	30.98	2.02	1713295
Total *(N=1134)*	15.51	30.30	1.95	1673924

Table 4 - Average Pump and Panel capacity in IDCOL locations across regions

The increase in pump and panel capacity over the years has meant that the ratio of Solar PV capacity to installed pump capacity (kWp /kW) has increased from 1.79 in 2014 to 2.28 in 2019. Also, the ratio of the panel to pump capacity is slightly but significantly higher in the Rangpur division (2.02) as compared to Rajshahi (1.81) and Khulna divisions (1.84) (Table 4). Thus, there is substantial excess panel capacity in the IDCOL SIP locations - approximately 45% of schemes have an excess capacity ratio above 2.0. The main reason for this excess panel capacity is to maintain a high discharge rate throughout the day. During peak irrigation season in the winter months, larger coverage areas and more farmers can be serviced only if high discharge can be maintained throughout the day. The need for maintaining high discharge is especially true for areas where Boro rice is cultivated, and water demand is very high. Thus, it is necessary to build excess panel capacity to serve for longer hours and larger areas. As shown in Figure 6, the water discharge rate is significantly and positively correlated with excess panel capacity.

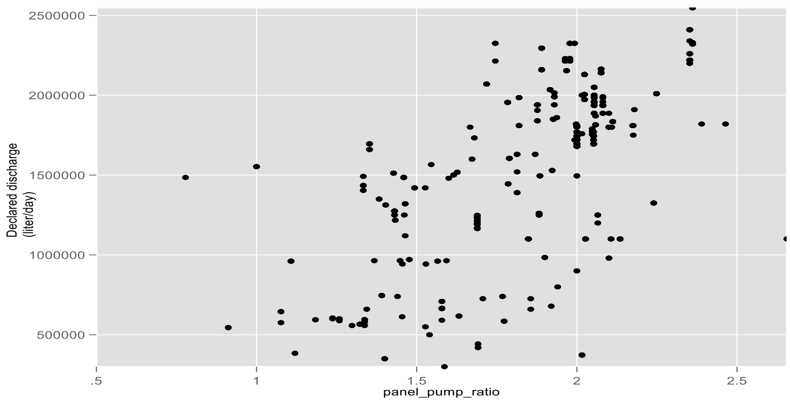


Figure 6 - Correlation between excess panel capacity and Discharge rate

Larger pump sizes with excess solar PV capacity means that the project costs are also higher. Therefore, the sponsors who have taken a loan to set up these SIP sites need to generate more revenue to pay back the loan. But most of these solar pumps currently remain idle for a substantial time during the year except for a certain number of peak irrigation days. So, the electricity generated in these high-capacity panels gets wasted for most of the year, and hence grid connection of SIPs is urgently needed.

The cultivation of boro paddy in the IDCOL SIP command area is crucial for the fee-for-service model of SIP expansion. The sponsor's ability to charge the farmer depends on what alternative sources of irrigation the farmers have access to. Farmers can always shift to diesel. So, the sponsor's ability to set the irrigation charges for a particular crop depends greatly on what it will cost to irrigate using a diesel pump. High irrigation charges per bigha can be set for crops requiring a lot of water, such as Boro. Overall, for the SIPs, 65-70% of the revenue share is from Boro, followed by Aman, Aus and Maize. This is even starker in the Northern region (i.e., Rangpur and Rajshahi), where the revenue share from Boro is often above 80%. Thus, the business will succeed provided farmers are cultivating water-intensive crops, for which they can be charged a higher price. If, due to external shocks like a fall in the market price of Boro, farmers shift to a less water-intensive crop, then the sponsors will be unable to earn sufficient revenue. Thus, there is a need to have alternative revenue streams for the sponsor from additional services and grid integration for this model to survive. Having additional revenue might also enable the sponsors to charge a lower price on irrigation in the future.

As discussed in the previous section, one of the reasons that the ratio of the panel to pump size is large in IDCOL SIPs is because sponsors need to provide sufficient water throughout the day to Boro farmers during peak irrigation season. Therefore, larger panels enable sponsors to service larger areas and more farmers during Boro season. However, the total project costs also go up with larger panels.

To ensure that the solar energy generated does not go to waste, some operators in Bangladesh have started using solar energy to run other types of machinery and provide additional agricultural services at their SIP locations to earn extra revenue. The services range from operating rice husking machines, oil-grinders, flour grinders, running cold-storages, renting out tractors and harvesters, providing credit and selling other inputs to farmers and marketing their products, practising fish farming, poultry and vermicomposting at the centre etc.

Integrating such additional activities and irrigation services optimise the use of solar panels and enable them to use other inputs in their business optimally, i.e., the land where the SIP has been set up and the operator hired to run the pumps. Moreover, it can make these SIP businesses viable by earning more revenue for the sponsors and creating additional employment in the village. But for the farmers, these integrated service centres at SIP locations can become a one-stop centre for various agricultural services.

Figure 7: Agri Machinery services at SIP location, Dinajpur

Figure 8: Vermicomposting at SIP location in SIP Dinajpur

Figure 9: Poultry farming below solar panels, Khulna

Figure 10: Solar Powered Rice husking machine, Dinajpur

One such example is in a SIP site, where the sponsor has developed a poultry shed below the solar panels on an experimental basis to effectively use the land below the panel and create more revenue streams for the sponsor. Using the solar panels as a roof reduces the cost of poultry shed construction substantially, protecting the birds from the heat – something that would have required additional investments in a conventional shed. The installed solar panels meet both the electric and water demands for maintaining such poultry sheds. The operator employed for looking after the irrigation service is also responsible for looking after the poultry. This serves two purposes. Firstly, this is another revenue source for the operator, and secondly, the operator stays at the pump much more often and can address the needs of his customers better. This is one ingenious example of how sponsors are trying to have alternative uses of all the inputs used in setting up the irrigation business to make the whole enterprise commercially more viable. These are important examples of using the full potential of solar panels in off-grid areas and can be adopted in other South Asian regions. SDC-SoLAR has also supported one such project through its Innovation Funds.

4.1 Grid Integration of Solar Irrigation Pumps

Despite developing these alternative solar power uses at SIP locations; these are not enough to absorb all the energy generated and wasted on most days except during the peak irrigation period. One way to use the excess capacity is to connect the solar panels to the national electricity grids and then sell the extra electricity back to the power company. Bangladesh government is planning to purchase the excess electricity from solar pumps, and accordingly, the government finalised a policy on Grid Integration Guideline for Solar Irrigation Pumps-2020. The guideline explicitly mentions that grid integration aims to promote renewable energy in Bangladesh and enable appropriate utilisation of excess electricity. The guideline highlights that irrigation use for electricity should be prioritised, and only the excess amount can be sold to the grid. Also, the sale of electricity would be one-way, i.e., electricity can never be drawn from the grid for running the pump. The Bangladesh Energy Regulatory Commission (BERC) determined 33 kV bulk rate would be the price of electricity sold to the grid, and it will be paid every month. This rate is currently at around 0.047 US$ per unit. The guideline allows both and multiple SIP systems to connect to the grid.

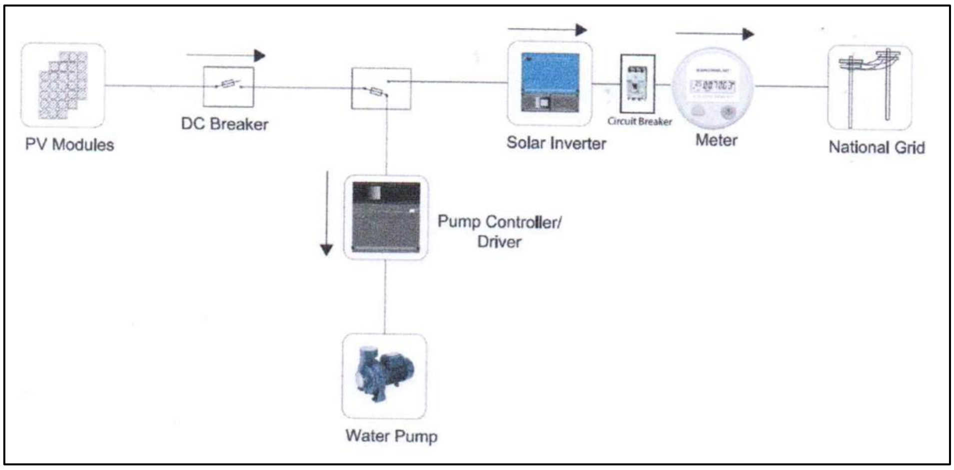
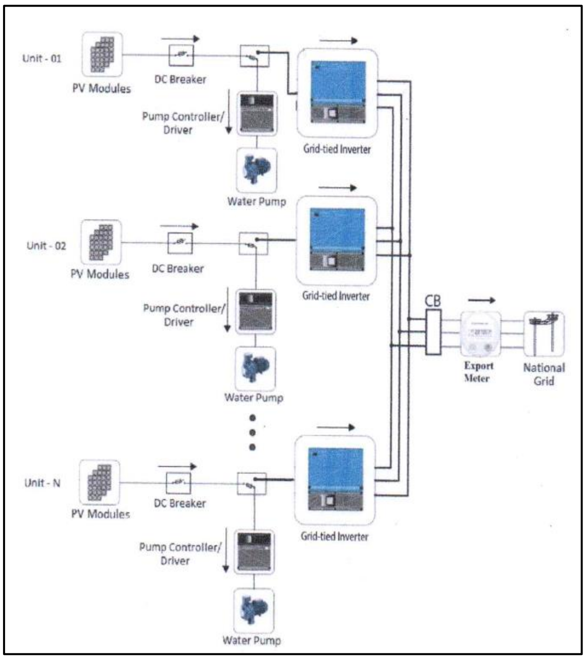


Figure 11 - Grid connection for a single off-grid SIP system



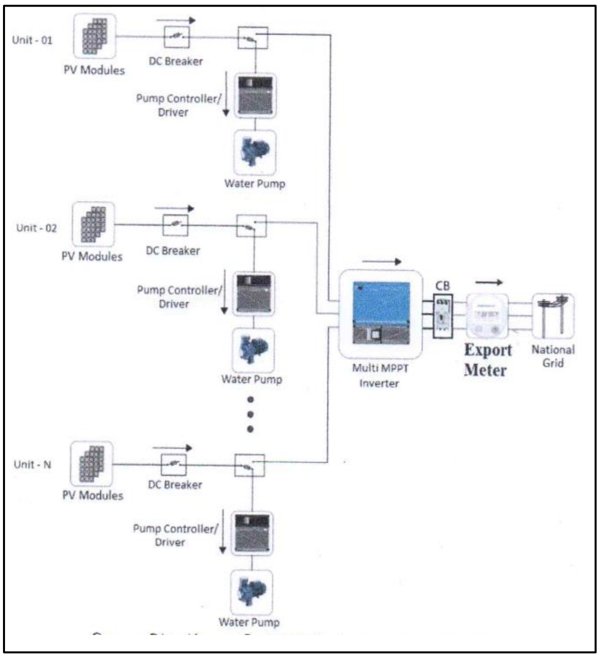


Figure 12 - Grid connection for multiple SIP systems using multiple inverters

Figure 13 - Grid connection for multiple SIP systems using one multi MPPT inverter

Image Source: "Grid Integration" Guideline for Solar Irrigation Pumps-SREDA 2020"

For grid integration of solar irrigation systems (both single or jointly) into a three-phase distribution network, the maximum allowable output (AC) is 10 MW. While connecting into a single-phase network, each system can have at most 50 kW output. If there are no three-phase distribution network within a 200 m radius of the SIP system, it can only be connected to a single-phase network. The guideline further lists all the technical specifications required for grid connection, including the need for non-islanding grid-tied inverters.

IDCOL has identified 8 SIPs in the Rangpur division and 5 SIPs in Khulna Division as potential sites for grid integration, with panel capacity between 24 to 44 kWp. 11 out of these 13 have panel capacity to pump capacity ratio being two or above. Out of these 13 sites, some will be chosen based on their application for a grid connection pilot on a cluster basis. Piloting grid connection is an important activity of the SDC-SoLAR project. These schemes of solar power buyback through grid integration will undoubtedly be a much-needed extra source of revenue for sponsors and is expected to make the solar irrigation business viable. It will also contribute to the Bangladesh government's target of producing 10% energy through renewable sources. In addition, it can also incentivise sponsors to give more active training to farmers on improved irrigation practices that increase water use efficiency so that less water is used per hectare of irrigation.

5. The groundwater situation in Bangladesh

In most of Bangladesh, unconsolidated near-surface Pleistocene to recent fluvial and estuarine sediments formed by the deposition of the Ganges-Brahmaputra-Meghna (GBM) river system generally form prolific aquifers (GED, 2018). Groundwater is abstracted intensively with an estimated annual abstraction of 32 km^3, of which 90% is used for irrigation and 10% for domestic and industrial purposes combined (Shamsudduha et al., 2020). There has been an intensive use of groundwater for irrigation, which started accelerating in the 1960s and the 70s with the introduction of High Yield Varieties (HYV) seeds to support food demand for a growing population. Intensive groundwater irrigation and high yielding varieties of crops have been vital factors making Bangladesh self-sufficient in rice production today. As a result, the national paddy output increased by over 15 million tonnes in the last two decades and has played an important role in poverty alleviation by providing jobs and small business opportunities in rural areas (GED, 2018).

5.1 Groundwater irrigation

Of the gross cropped area, almost half is irrigated, with the intensity of irrigation being higher in north-central and western divisions of Dhaka, Mymensingh, Rajshahi, Rangpur and Khulna (Figure 14 A), which supports high cropping intensity in these areas (199-219 %) (Figure 14 B) (BBS, 2020). Of the total irrigated area, groundwater irrigation covers approximately 80% of the total irrigated area, with the rest covered by surface irrigation sources. Groundwater is most extensively used in north-central and north-west divisions of Dhaka, Mymensingh, Rajshahi, Rangpur and Khulna (Figure 14 C). In these divisions, approximately 94 % of the total irrigated area is presently irrigated with groundwater.

Boro paddy makes up most of the irrigated area, taking up almost 60% of the total irrigated area

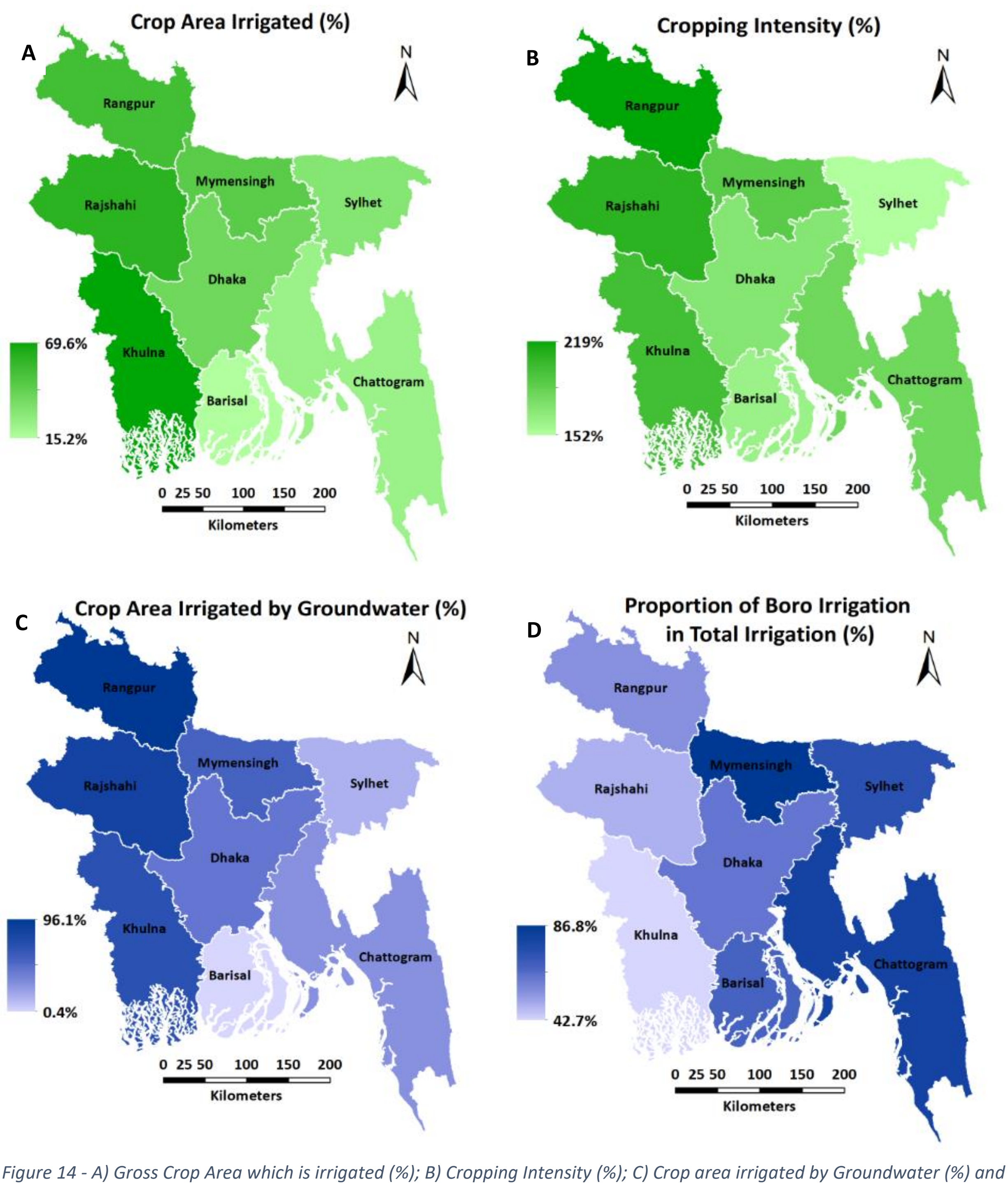


Figure 14 - A) Gross Crop Area which is irrigated (%); B) Cropping Intensity (%); C) Crop area irrigated by Groundwater (%) and D) Proportion of Boro irrigation in total irrigation (%)

[Data source: Yearbook of Agricultural Statistics-2019 (BBS, 2020)]

(Figure 14 D) (BBS, 2020). Except for western divisions of Khulna, Rajshahi and Rangpur, Boro rice takes up 70-87 % of the total groundwater irrigation in the country (Figure 14 D). In western divisions, there is more diversification, with boro rice taking only 42-54 % of irrigation and the rest going to other crops, including vegetables and wheat.

5.2 Surface water vs groundwater for irrigation

Bangladesh has plenty of surface water resources. The country receives ample monsoon rainfall and has an extensive network of rivers and tributaries. The total length of rivers in Bangladesh is approximately 22,000 km. The three major rivers system basins are the Ganges, the Brahmaputra and the Meghna (Figure 15 A), covering about 80% of Bangladesh (Rahman and Rahman, 2011). Internal renewable surface water resources are estimated to be about 84,000 Mm^3, much more than the 21,000 Mm^3 of groundwater resources (Qureshi et al., 2014). However, almost 85% of rainfall happens during the monsoon months of June and October, which inundates low lying areas of the country, and as a result, a large part of Bangladesh is prone to flood risk (Figure 15 B).

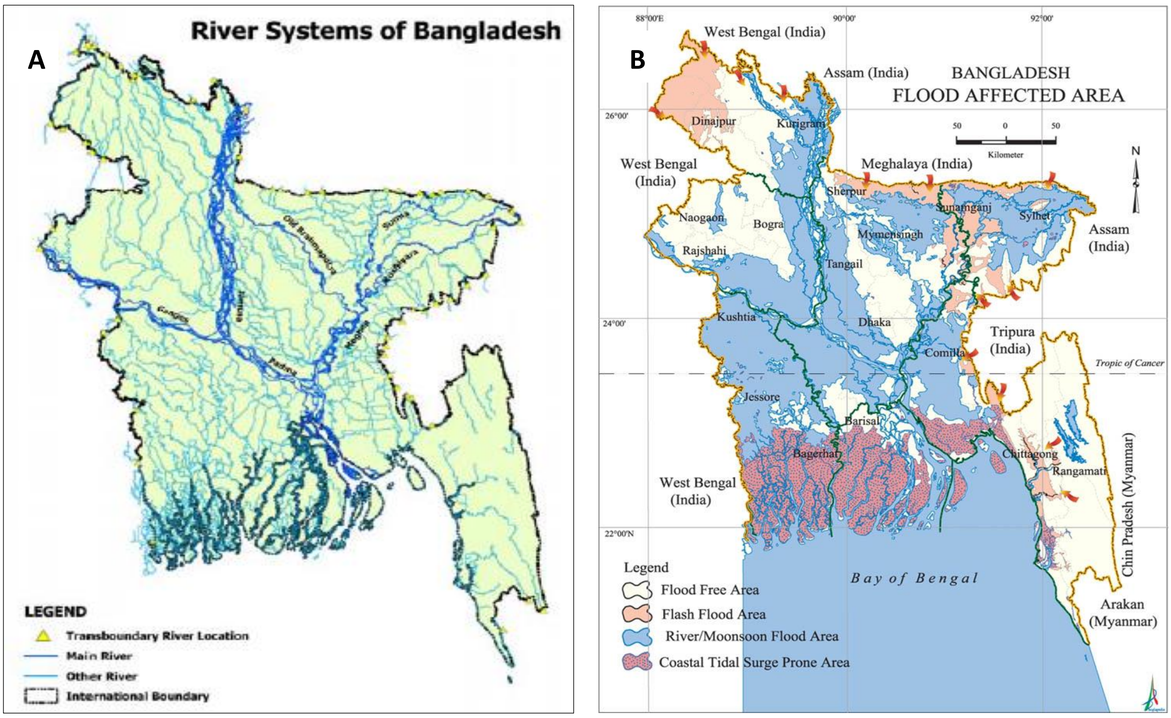


Figure 15 - A) River network in Bangladesh (Rahman and Rahman, 2011); B) Flood affected area map of Bangladesh

(Source: http://en.banglapedia.org/index.php?title=File:NaturalHazardFloodAffectedArea.jpg)

Although plenty of surface water resources, only about ~ 20 % of irrigated area is covered by surface water (BBS, 2020). In fact, there has been a continuous decline in the area irrigated with surface water from 60-65 % in 1983-82 to 20-25 % by the late 2010s. In contrast, groundwater irrigation has increased from 40% to almost 80% (Figure 16 A) (BADC, 2020). The area under surface water irrigation is considerably higher in the northeastern and south-central regions. However, the intensity is lesser than groundwater irrigation in the northwestern parts of the country (Figure 16 B) (BBS,2020).

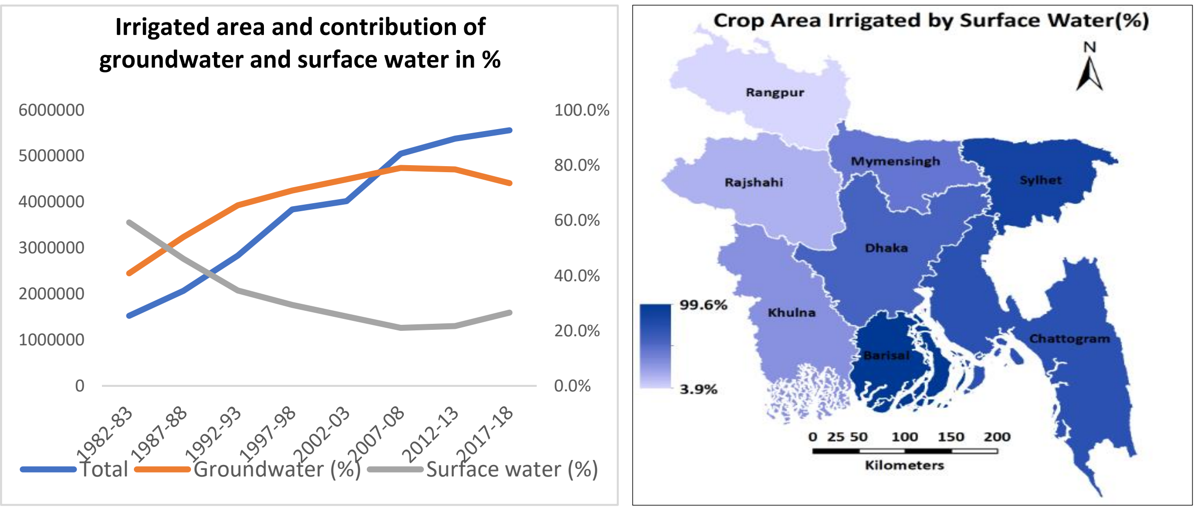


Figure 16 - A) Time series of irrigated area in Rabi season in ha and contribution of surface and GW in it (Minor irrigation survey report 2018-19) and B) Proportion of irrigated area from surface water

[Data source: Yearbook of Agricultural Statistics-2019 (BBS, 2020)]

Some of the reasons for low coverage of surface irrigation and its steady decline include:

- Intra year variability (~ 80-90 % of the rainfall is received during monsoons) leads to surface water scarcity in the dry season. Also, much of the river flows originate outside the country, introducing uncertainty in surface water availability. (GED, 2018; Qureshi et al., 2014)
- Groundwater irrigation with its buffer storage ensures a round-the-year supply and provides higher flexibility, certainty, and reliability. In addition, there is high spatial variability during monsoon months, where groundwater ensures higher resilience; therefore, farmers prefer groundwater irrigation.
- Due to low dry season levels in the Ganges and other rivers where operations to extract water are made difficult due to water levels going significantly below the level for which the pumps were designed (GED, 2018)
- There is added cost of dredging silt annually from the Ganges to the pump house, which can be up to one million cubic meters (GED, 2018)
- Due to poor maintenance and management and negligence in the maintenance and development of surface water infrastructure, the importance of surface irrigation has decreased (Qureshi et al., 2014) as opposed to groundwater irrigation which is mostly private-led.

However, there is considerable scope to expand surface water irrigation utilising ample rainfall and river flows highlighted in the National Water Policy (MoWR, 1999) to reduce stress on groundwater

(GED, 2018). A recent assessment of surface water irrigation potential from a network of vastly underutilised rivers and natural canals has been done by Krupnik et al. (2017). They assessed the surface water irrigation potential in lower Eastern Indo-Gangetic Plains covering Southern Bangladesh divisions of Khulna, Barisal, and parts of Dhaka, Chattogram and Rajshahi. In the Southern region, expanding groundwater might not be economically viable because of salinity in shallow groundwater and the high cost of tapping deeper aquifers. They used remote sensing data to analyse agricultural land and surface water availability with soil and salinity data to examine the extent of winter fallows and low productivity rainfed cropland that small-scale surface water pumps could irrigate. Results show that at least 20,800 and 103,000 ha of fallow and rainfed cropland, respectively, can be brought into intensified double-cropping using surface water irrigation, more so in the division of Barisal (Figure 17), which has currently very low level of irrigation (Figure 14 (A)).

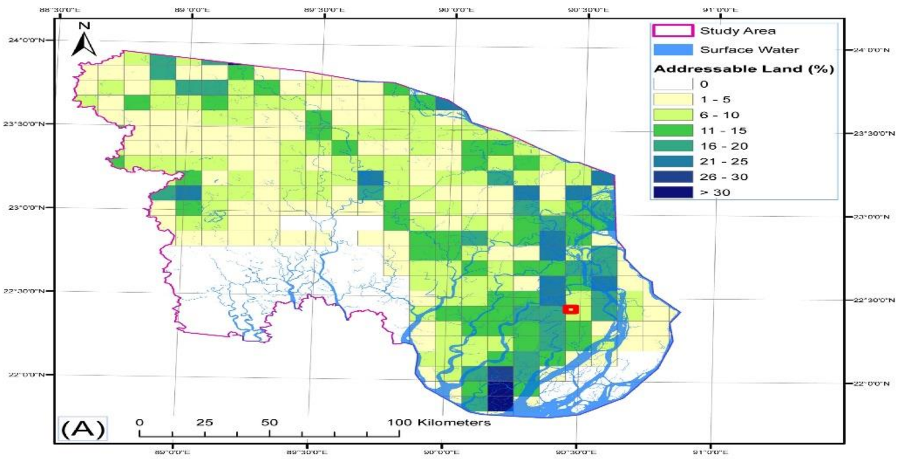


Figure 17 - Agricultural land suitable for surface water irrigation expressed as a percentage of total cropland area in 100 km2 imposed grids. Low- and marginal potential croplands were excluded
(Source: Krupnik et al. (2017))

Results show a good potential to develop surface water irrigation in areas where groundwater is constrained by quality issues (salinity or arsenic). In addition, efforts to recharge groundwater in areas where groundwater is the most preferred and abstracted hugely (north-central and western divisions) can relieve the stress on groundwater sources and contribute towards long term groundwater sustainability.

5.3 Types of well and energy use

Shallow tube wells (STW) and Deep tube wells (DTW) for groundwater pumping and low lift pumps (LLP) for surface irrigation are primarily used in Bangladesh. In addition to that, there is a small (and increasing) number of solar pumps coming up. In 2018-2019, there was a total of 1.6 million pumps in Bangladesh. It is dominated by STW, which constitutes 85.7 %, followed by LLP (11.8 %) and DTW (2.4 %), respectively (BADC, 2020). As is the case of irrigation coverage, most pumps are in northwestern and western divisions of Rangpur, Rajshahi and Khulna (Figure 18 A), which together have two-thirds of the total pumps installed. In these divisions, pumps are dominated by STW (Figure 18 B). Rajshahi division has the highest number of DTW. On the other hand, LLPs are popular in Barisal (Figure 18 B).

Almost 80 % of the pumps in Bangladesh are operated with diesel, and the remaining 20% use electricity. Despite subsidies on electricity, diesel pumps are being preferred by farmers due to low capital cost and ease of mobility within small and fragmented farmlands (Qureshi et al., 2014). However, increasing diesel prices are making electric pumps more popular in recent years. In divisions of Khulna, Barisal, and Sylhet, most of the pumps are run on diesel (> 90 %) (Figure 18 C). In contrast, other divisions have about a quarter of the pumps running on electricity (Figure 18 D).

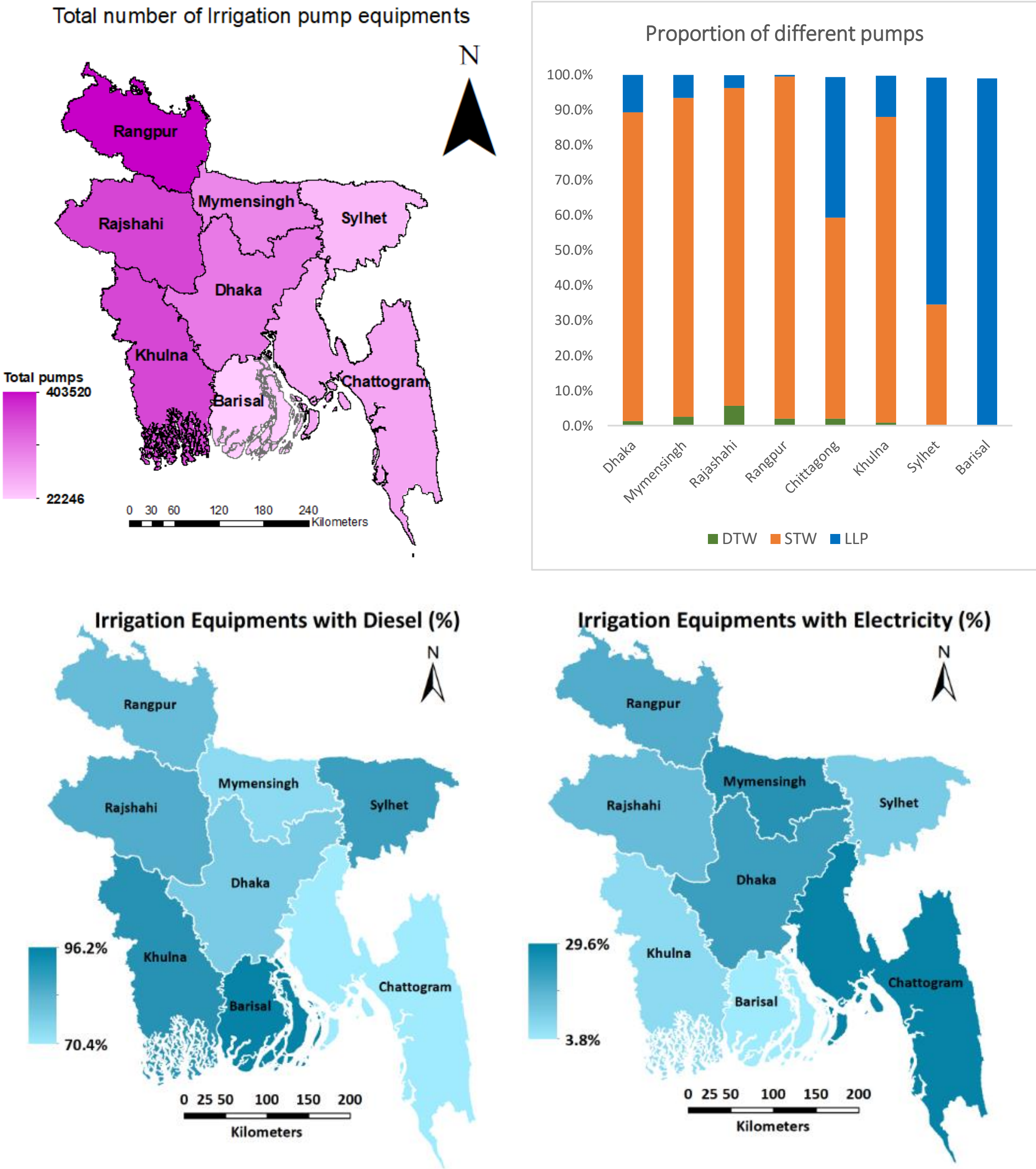


Figure 18 - A) Total number of irrigation pump equipment's, B) Proportion of electric and diesel pumps in each division, C) Irrigation equipment's with diesel (%)] and D) Irrigation equipment's with electricity (%)

[Data source Minor irrigation survey report 2018-19]

5.4 Groundwater sustainability

The sustainability of groundwater resources in Bangladesh is threatened by hydrological and socioeconomic factors such as over-abstraction, poor water quality, inadequate governance, and impacts of changing climate that is not well understood (Shamsudduha et al., 2020)

5.5 Groundwater quantity

Dry season irrigation depends on ample recharge during monsoon months. Source of recharge includes rainwater (principal source), flood water which overflows the river and stream banks and surface water from permanent water bodies (rivers, canals, wetlands, ponds, irrigated fields etc.) (GED, 2018). A study conducted by Shamsudduha et al. (2011) estimated long term groundwater recharge (1985–2007) (Figure 19), which showed that recharge (net) is higher (300 – 600 mm) in northwestern and western parts, which are also the regions with high groundwater abstraction. Recharge is also high (300–600 mm) along the rivers Brahmaputra and Ganges. In the south-eastern GBM Delta and Sylhet regions, net annual recharge is estimated to be considerably lower (<150 mm). Their estimate of recharge post-groundwater-fed irrigation indicated that groundwater-fed irrigation was making space for more recharge. These increases in the net recharge are observed more in northwestern regions. Their estimates of net recharge show that mean recharge in Bangladesh has increased from 132 mm/year over a period from 1975 to 1980 to approximately 190 mm/year for the period 2002–2007.

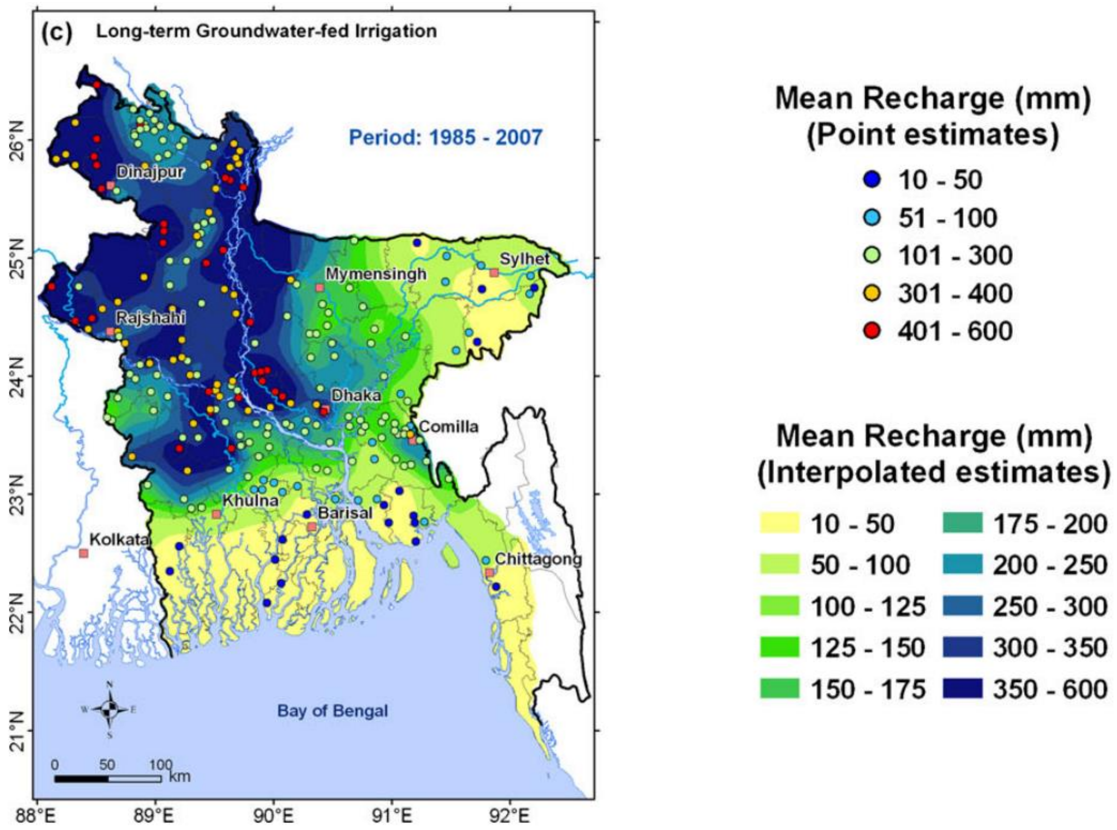


Figure 19 - Mean annual recharge in Bangladesh for the period 1985-2007.

[Source: Shamsudduha et al. (2011)]

With ample recharge taking place all year round, no permanent decline of the water table is observed except in urban areas and the Barind tract (GED, 2018). In most of Bangladesh, groundwater is shallow, even in the dry season, with the most area having groundwater depth of less than 8 m (which is the limit for surface pumps suction limit) except some areas in the Northwest (Figure 20). The shallow groundwater table rises nearly to the surface across Bangladesh during the monsoon season, with abundant rain and flooding rivers recharging the aquifers. The impact of intensive groundwater irrigation in the dry season in north-central and western regions is more visible through higher seasonal water table fluctuation when pumping for use and discharge to the rivers (which are at low levels in the dry season) deplete the aquifers. The seasonal fluctuation is low or even nil near the coastline, where groundwater usage is negligible due to salinity problems in upper aquifers (GED, 2018). In the south, water tables remain generally shallow and remain consistent for most of the year, except for slight increases during the monsoon season (Qureshi et al., 2014).

However, extensive irrigation, though not leading to high declines, leads to a drawdown of water tables during the peak irrigation period (GED, 2018). Qureshi et al. (2014), using Bangladesh Water Development Board (BWDB) data, determined that areas with water tables less than 8 m in depth has increased from ~4 % in 1998-2002 to ~ 14 % in 2012 (Figure 20). The most affected areas lie in the north-west (e.g., Barind Tract) and north-central (i.e., Madhupur Tract) regions where intensive groundwater irrigation takes place (Figure 14 (A) & (C)).

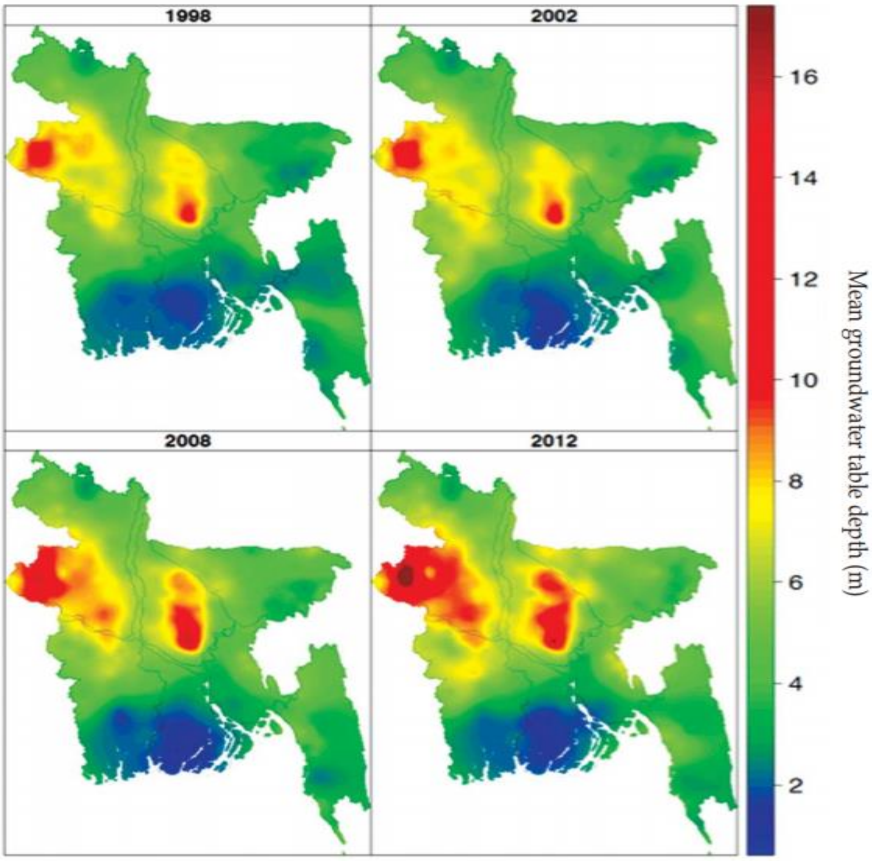


Figure 20 - Mean groundwater table depth in Bangladesh for the dry season.
[Source: Qureshi et al., 2014]

In a more recent assessment, groundwater trends for the northwestern region were determined by Mojid et al. (2019). They analysed 350 monitoring wells for the period from 1985 to 2016. They found that 65.7% of the monitoring wells had a significant falling trend for annual maximum depths showing a continuous increase in groundwater abstraction. The main implications were that groundwater tables remained below the suction limit (> 6 m), making STWs that represent the majority of tube wells technically inoperable for the whole year in 15.1% of the monitoring wells (Figure 21). They conclude that groundwater extraction in many locations now needs tapping deeper. Hence, measures such as artificial recharge to the aquifers and water-saving technologies are recommended.

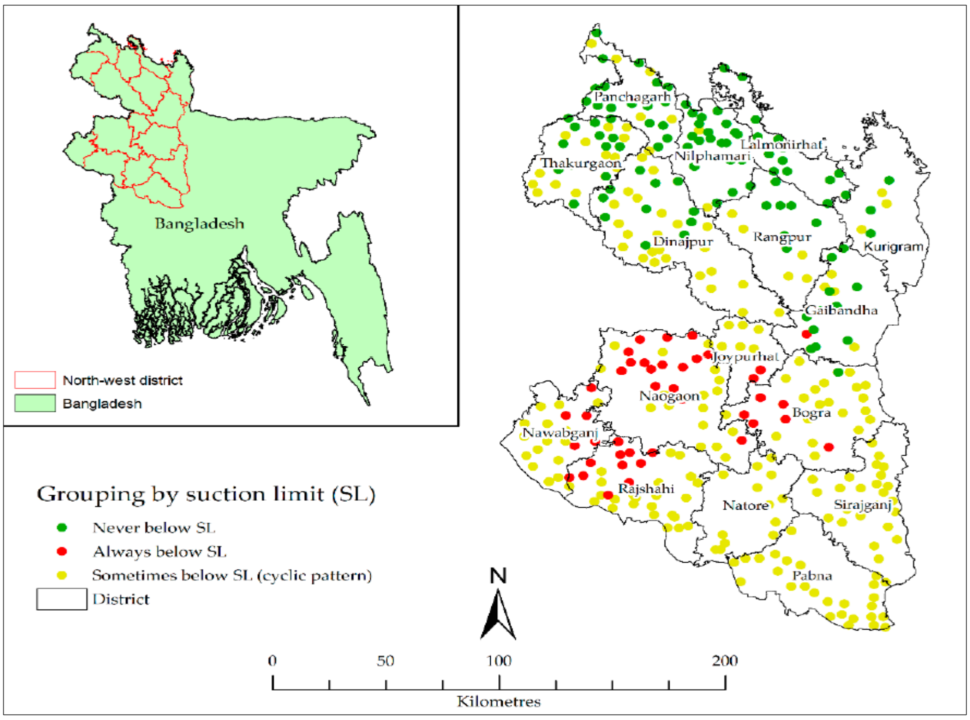


Figure 21 - Monitoring wells duration during which their groundwater levels remain below the suction limit of 6 m.

[Source: Mojid et al. (2020)]

There have also been efforts from the Bangladesh Government to curb the excessive use of groundwater for irrigation. As early as the mid-1980s, the government passed The Ground Water Management Ordinance, 1985, which made it mandatory to get a license for groundwater use for irrigation. However, this act was revoked in 1992. The Water Act of 2013 legislated that a high-level committee (Executive committee) can designate an area as suffering from a water crisis and manage it accordingly. The executive committee was also given the power to set the minimum limit of groundwater level and decide if restrictions can be placed on the abstraction of groundwater based on their calculation of safe yield. Under this act, a high-powered National Water Resources Council was formed, with the Prime Minister heading the council. This law was suspended following significant drought events in 1987-88 and had led to massive increases in the number of STWs, making Bangladesh food self-sufficient by 1999.

Recently passed Underground Water Management Law, 2018 reintroduced the licensing requirement of Groundwater Ordinance of 1985. Under this law, local government bodies were entrusted with the issuance of licenses. The Upazilla Parishad has to form the Upazilla Irrigation Committee (UIC), which will conduct field inspections to ensure that the irrigation pump-set is eligible for a license. Based on their recommendation, licenses can be issued to farmers. Unlicensed use of pumps can attract a maximum fine of 10,000 BDT and even imprisonment. The policy also makes it mandatory for existing pump-set owners to get a license. In particular, the law mandates a minimum area to be serviced by each pump depending on the discharge. For deep tube wells, two cusecs of discharge can irrigate up to 24 hectares of land; 1.5 cusecs of discharge can irrigate up to 18 hectares; 1 cusec of discharge can irrigate up to 12 hectares, and 0.5 cusecs of discharge can be used for irrigating 6 hectares of land. This translates into the minimum distance of 800 meters between two pumps with two cusecs discharge, while 250 m distance is needed between two pumps of 0.5 cusecs discharges. In addition, the law requires that pumps be a minimum of 2 km away from the perennial river source.

Given the huge number of existing farmers with installed pumps, it will be challenging to implement this licensing retroactively. There are also other reasons which will make the implementation onerous. Firstly, the law mandates a minimum area serviced by a pump depending on the discharge, and for STWs, this minimum command area should be 6 hectares. But the current density of STWs is already much higher than what is mandated in this policy. Therefore, if this policy is implemented retroactively, it will be at odds with Bangladesh's stated principle of agricultural self-sufficiency. Secondly, the licensing will be implemented through the Upazilla level committee. However, there is a severe lack of knowledge and skill to make the correct decision in issuing licenses. Without proper capacity development, this licensing of pumps could face serious challenges.

5.6 Groundwater quality

In Bangladesh, groundwater arsenic is highly prevalent with more severity in the southern and south-eastern regions (Figure 22). Out of 64 districts, 61 are affected more or less, with about three million shallow tubewells (10 – 50 m) having groundwater with arsenic concentrations more than the Bangladesh drinking water standard of 50 µg/l (GED, 2018). An estimated 35–77 million people have been chronically exposed to arsenic via drinking water (Qureshi et al., 2014). Then there are concerns of arsenic intake via food chain with arsenic building in soil when irrigating with high arsenic groundwater. Studies have shown that food pathways can be a significant source of arsenic intake in arsenic affected areas and can also impact those drinking safe water otherwise (Heikens, 2006; Huq et al., 2006). There is, therefore, an urgent need to better understand the added and relative risk from the intake of arsenic through food and its sources and how to mitigate the same. Several mitigation options already exist. These include better field water management through application of lesser quantities of arsenic-contaminated water, use of arsenic

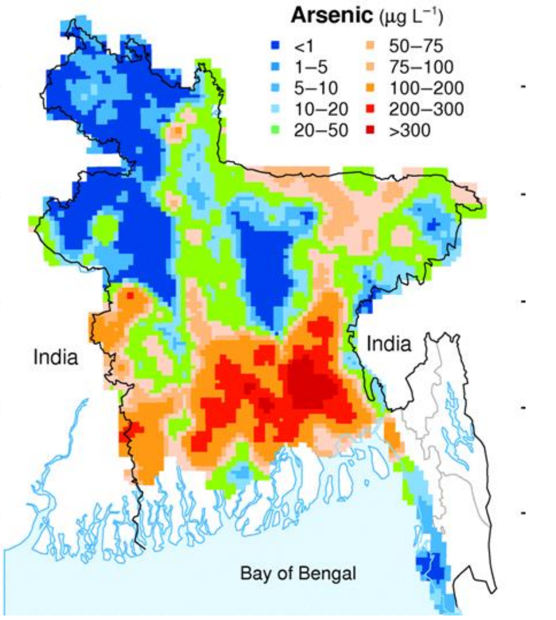


Figure 22 - Distribution of Arsenic in Bangladesh. Source: BGS and DHPE, 2001

(Source: https://www2.bgs.ac.uk/arsenic/bangladesh/)

tolerant varieties of paddy, growing crops that take up lower amounts of arsenic from the soil, cooking contaminated rice with arsenic-free water and providing vulnerable people with suitable dietary supplements to reduce uptake of arsenic (Senanayake & Mukherji, 2014).

6. Conclusion

Solar irrigation provides a great opportunity in Bangladesh to replace diesel pumps in off-grid areas with a cleaner energy alternative, thereby reducing the GHG emissions from diesel use, which is harmful to human health and the environment. In addition, it can contribute to Bangladesh's target of achieving 10% power generation from renewable sources. Moreover, substituting diesel with solar will reduce the government's subsidy burden on imported diesel.

Farmers are also benefitting from solar irrigation because it is cheaper than diesel-based irrigation. Our interactions with farmers revealed that they also value the reliability and quality of irrigation provided by solar pumps. Further, giving irrigation service for a fee at IDCOL SIP locations means much less hassle for farmers. They are no longer required to buy diesel from the market. Instead, they carry a pump to the field, maintain boring and pumps, etc. All this extra work can be avoided if an irrigation service is purchased from SIPs.

Currently, the primary model of promoting solar pumps in Bangladesh is the *fee-for-service* model promoted by IDCOL. Under this model, an NGO/private entrepreneur (sponsor) takes a loan (with grant) from IDCOL to set up the solar pump in the villages and then offers irrigation service to farmers in exchange for a fee. However, the ability of sponsors to generate sufficient revenue depends on the type of crops farmers are growing. For example, if farmers grow water-intensive crops like Boro, the demand for irrigation is high, and farmers can be charged a higher fee. But farmer's crop choice depends on various market conditions, and as a result, this irrigation service provision business is susceptible to changes in farmers' crop choices.

Uncertainties arising from farmers' decision not to grow boro paddy are a threat, mainly because the project cost for these IDCOL SIPs is very high, and revenues from selling water for boro paddy contribute to the lion's share of total revenue. One of the reasons for the high cost is the excess panel capacity that has to be installed to provide adequate water during the peak irrigation days of the winter months for Boro cultivation. But the revenue from irrigation that the sponsors could earn is not always sufficient to repay the loan they took from IDCOL. This is because the demand for irrigation services is limited to a certain number of days in the year, while the panels are kept idle for the rest of the year. Therefore, there is a need to find alternative uses for this excess energy produced by the panels to help the sponsors earn additional revenue and make the solar irrigation business viable. One such alternative is the grid-connection of solar pumps to sell excess power back to the grid. The Bangladesh government has already approved the grid connection of SIPs. In addition, some sponsors also use solar energy to provide additional agricultural services like husking, thrashing, running cold storage, running oil press, etc. If revenue earnings can be increased through these interventions, it will make the irrigation business model viable and help promote solar irrigation in more parts of the country. The SDC-SoLAR project will evaluate the impact of SIPs on farmers livelihoods and pilot grid-connected SIPs.

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