

Sub-Project ID - 001

**Program Based Research Grant (PBRG)**  
**Sub-project Completion Report**

on

**Up-scaling and Application of Solar Photovoltaic Pump  
for Smallholder Irrigation and Household Appliances in  
the Central Coastal Region of Bangladesh**



**Sub-Project Duration**  
**15 February 2018 to 31 January 2022**

**Coordinating Organization**  
**Agricultural Engineering Unit**  
**Natural Resources Management Division**  
**Bangladesh Agricultural Research Council**



**Project Implementation Unit**  
**National Agricultural Technology Program-Phase II Project**  
**Bangladesh Agricultural Research Council**  
**Farmgate, Dhaka-1215**

December 2021

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Pump for Smallholder Irrigation and Household  
Appliances in the Central Coastal Region of  
Bangladesh**

**Implementing Organization**



**Farm Machinery and Postharvest Process Engineering Division**  
**Bangladesh Agricultural Research Institute (BARI)**

**&**



**Irrigation and Water Management Division**  
**Bangladesh Rice Research Institute (BRRI)**

**Project Implementation Unit**  
**National Agricultural Technology Program-Phase II Project**  
**Bangladesh Agricultural Research Council**  
**Farmgate, Dhaka-1215**

**December 2021**

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## Abbreviation and Acronyms

BADC	Bangladesh Agricultural Development Corporation
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BRAC	Bangladesh Rural Advancement Committee
BRII	Bangladesh Rice Research Institute
BSMRAU	Bangabandhu Sheikh Mujibur Rahman Agricultural University
DC	Direct Current
DTW	Deep Tube Well
FAO	Food and Agriculture Organization
FMPE	Farm Machinery and Postharvest Process Engineering
Hp	Horsepower
HYV	High Yielding Variety
IDCOL	Infrastructure Development Company Limited
IRR	Internal Rate of Return
IRRI	International Rice Research Institute
IWM	Irrigation and Water Management
kW	Kilowatt
kWp	kilowatt Peak
LLP	Low Lift Pump
LSP	Local Service Provider
NGO	Non-Government Organization
NPV	Net Present Value
PSEOP	The Benefit of Portable Solar Energy Operated Pump
PV	Photovoltaic
RDF	Rural Development Foundation
RPM	Revolution Per Minute
SAAO	Sub-Assistant Agriculture Officer
SHS	Solar Home System
SREDA	Sustainable and Renewable Energy Development Authority
STW	Shallow Tube Well

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## Executive Summary

Production of solar photovoltaic power is recognized as a vital part of future energy generation as it is available in abundance and free of cost, environment friendly, and highly reliable. The use of solar power is increasing in developing countries at a faster rate for its cost-effectiveness and “clean” solution to increase agricultural productivity. To promote solar irrigation pumps, Bangladesh government has targeted to install about 15,000 numbers of solar pump by 2025 and has taken the ‘Master Plan for Development in the Southern Region’ to increase cropping intensity on currently fallow and rain-fed crop land using surface water. Geographically, surface water is perceived abundant in parts of the southern region where the river and canal networks have perennial flow, and salinity levels do not cross crop-damaging thresholds. Moreover, the solar radiation ranges between 4.0 and 6.5 kWhm<sup>-2</sup>day<sup>-1</sup>, and the bright sunshine hours vary from 6 to 9 hours/day revealing the suitability of using solar appliances in Bangladesh. About 82% of irrigation is covered by engine-operated pumps that consume more than half a million tons of diesel per annum and is a source of CO<sub>2</sub> emission that pollute the environment. Using solar pumps on a large scale, energy demand in irrigation systems can be reduced substantially. But to make the solar PV system more profitable, emphasis has been given to use the system for household appliances after irrigation season. Thus the sub-project was designed and approved to upscale the solar PV system for irrigation in the dry season and household uses during the rest of the year in the southern region of the country.

The sub-project was designed with a coordination component at BARC to assess, monitor, and evaluate all activities of the other two components, one at the FMPE Division of BARI and the other at the IWM Division of BRRI, in addition to all activities of coordination component. At the beginning of the sub-project, BARI conducted a baseline survey in sub-project areas of Kalapara and Galachipa of Patuakhali district, Barguna Sadar and Amtali of Barguna district, and Char Fasson and Lalmohon of Bhola district. BRRI conducted the survey in Uzirpur and Bakerganj of Barishal district, Sadar and Nalcity upazila of Jhalkati district and Sadar and Nazirpur upazila of Pirojpur district. Three sets of questionnaires were prepared for each of the components and finalized at the coordination unit, BARC- one for solar pump users, one for solar pump service providers and the other for general farmers in the sub-project areas. In each upazila, 30 farmers from 2-3 villages were interviewed through pre-tested interview questionnaires. Secondary information was collected from Upazila Agriculture Office, internet, available reports, journals, etc.

Planning and designing of solar panel, pump and associated components of solar PV system were done based on information obtained from the baseline survey. The required materials for solar PV systems were purchased, fabricated, and tested individually by BARI and BRRI components. The coordination unit of BARC monitored all the activities and imparted necessary instructions to them. BARI component used 4 panels (1.3 kW<sub>p</sub>) for each larger pump (180 l/min.) to irrigate non-rice crops like tomato, brinjal, chilli, watermelon and pumpkin. A new mini solar pump of 280W motor capacity and 40 L/min flow rate was also designed, fabricated and installed by this component ahead of the Rabi crops season of 2020-2021 and a total of 12 such pumps (each 40 L/min. flow rate) were set in farmers’ fields within the sub-project areas. Since the BRRI component irrigated Boro rice, they used 8 solar panels (2.64 kW<sub>p</sub>) for higher capacity pumps (6.5 L/s). The whole system was made portable. Each of the BARI and BRRI components used only one panel each to run the household appliances like the LED bulb, DC fan, Mobile charger and TV. BRRI component also used the panels to run the paddy thresher.

Data in respect of panel characteristics and performance, pump capacity and efficiency, home application and water supply, crops cultivated and soil characteristics, incident solar radiation and its conversion to electrical power, etc. were generated practically by both BARI and BRRI components. Finally, analysis of data was done for technical and economical feasibilities of the designed solar PV systems.

On-station test of the larger solar pump by BARI revealed that drip irrigation saved about 52% water over furrow irrigation for tomato and 45% for brinjal in the first year (2018-2019) and in the second year (2019-2020), the same method saved about 52% and 34% irrigation water for tomato and brinjal, respectively. In farmers' fields, water savings from alternate furrow and drip irrigation methods for tomato were 33% and 47% and those for brinjal were 35% and 47%, respectively. About 20% of crops were damaged by cyclone Amphan. BARI and BRRI used their designed solar PV systems for irrigation, home electrical appliances and water supply. BRRI also operated power thresher for paddy using solar energy to run the thresher. The designed solar PV systems by BARI and BRRI were found technically feasible as the farmers, service providers and mechanics could easily set, operate and maintain the systems for irrigation, home electrical appliances and domestic water supply. All the systems worked properly with little or no machinery problems. On receipt of training from the sub-project, the above incumbents acquired adequate knowledge to handle the new solar PV systems.

The benefit-cost ratio (BCR) of multipurpose uses of portable solar panel based solar PV system of BRRI component was found 1.44 which was greater than the BCR (1.12) of single-use of the solar pump for irrigation only and it was also higher than that (1.29) of diesel operated pump for irrigation. The BCR of large and mini solar pumps of BARI component were found to be 1.62 and 1.42 from a commercial scheme of an entrepreneur. This indicates that both the solar PV systems designed by BARI and BRRI were very much economically feasible when these are used for multipurpose uses.

Before the introduction of the sub-project, the farmers and the custom service providers of the study areas were not familiar with the solar irrigation system and now, having trained, they are capable of operating the system on their own. An owner of a solar irrigation system or a local service provider can start this business to earn a substantial profit from high-value vegetable cultivation and power supply for home appliances. The rice growers can use the portable solar PV system for Boro rice irrigation, operate power thresher and run home electrical appliances to get good profits.

The selected farmers in the sub-project areas are using solar panels for lightings, operating fans, supplying drinking water, sanitation, etc. in addition to crop irrigation. Therefore, the solar pump may be recommended for irrigation and operation of household appliances, especially for small and marginal farmers, preferably in off-grid areas. The system users, especially small and marginal farmers, found the technology very much useful for them but at the same time, they found the initial cost of the system too high for them. So, they made a verbal appeal to the government for a considerable subsidy on the solar PV system. To extend the benefits of solar irrigation systems among the farmers and the custom hire service providers, more adoption and dissemination programs should be launched all over Bangladesh.

**Keywords: Solar pump, solar panel, BCR, solar home system, drip irrigation etc.**



## **PBRG Sub – Project Completion Report (PCR)**

### **A. Sub –project Description**

- 1. Title of the PBRG sub-project:** Up-scaling and Application of Solar Photovoltaic Pump for Smallholder Irrigation and Household Appliances in the Central Coastal Region of Bangladesh
- 2. Implementing organization(s):** Bangladesh Agriculture Research Council (BARC), Dhaka, Bangladesh Agricultural Research Institute (BARI), Gazipur-1701 and Bangladesh Rice Research Institute (BRRI), Gazipur-1701.
- 3. Name and full address with phone, cell and E-mail of Coordinator, Associate Coordinator and PI/Co-PI (s):**

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**4. Sub-project budget (Tk.): 2,83,82,520.00**

(Taka two core eighty-three lakh eighty-two thousand five hundred twenty only)

**5. Duration of the sub-project:**

**5.1 Start date (based on LoA signed): 15 February 2018**

**5.2 End date: 31 January 2022**

**6. Background of the sub-project**

Solar photovoltaic power production is recognized as an important part of the future energy generation. Because, it is non-polluting, free in its availability, and is of high reliability. Solar-powered irrigation is increasing in developing countries as it can provide a cost-effective and “clean” solution to increase agricultural productivity (SPIS, 2015). There are about 320 solar power operated irrigation pump available in Bangladesh (Hossain, 2015). In order to promote more solar pumps, the government has targeted to install about 15,000 solar pumps by 2025 (Rahman, 2015). There is about 62% irrigation coverage of which 82% operate on diesel engine and 18% on electric motor operated pumps. The diesel-run irrigation pumps consume more than half a million tons of diesel per annum (Rahman, 2015). In the country, the ranges of solar radiation are between 4.0 and 6.5 kWhm<sup>-2</sup>day<sup>-1</sup> and the bright sunshine hours vary from 6 to 9 hours/day (Islam and Ahiduzzaman, 2011; Biswas and Hossain, 2013). So, solar radiation in Bangladesh is suitable for operation of solar appliances.

Government of Bangladesh has taken the ‘Master Plan for Development in the Southern Region’, to increase cropping intensity on currently fallow and rainfed lands, using surface water irrigation (MoA and FAO, 2012). Geographically, surface water is perceived abundant in parts of the south where river and canal networks have perennial flow, and salinity levels do not cross crop-damaging thresholds. In Bangladesh, most of the farmers in the southern coastal region are small and marginal tenant farmers. There is a limited possibility of ground water utilization for crop cultivation in this region. Farmers usually grow rainfed Aman rice only and the lands remain fallow in dry season. But lack of suitable low lift surface pumps and high irrigation cost, farmers do not show interest in cultivating Boro rice. Solar pump may be an alternative to diesel and electricity operated pumps for irrigating in the off-grid areas. The energy crisis is severe in Bangladesh which is a threat to the economic development. Using solar pumps on a large scale, energy demand in irrigation systems can be reduced substantially. Biswas and Hossain (2013) reported that though the initial cost of solar pump is higher than conventional diesel engine operated pump, solar pump has lower maintenance cost which makes it cost effective over the years. Moreover, solar pump is a pollution free and environment friendly water pumping system in agriculture. Although, initial cost is high, with the advancement of technology, its price has been decreasing remarkably. Sarker et al. (2016) reported that solar pump is still not economically suitable for irrigation in conventional irrigation system compared to electric motor and diesel engine operated pumps due to high initial cost. They suggested that solar pump may be economically viable for its multipurpose uses. Therefore, the proposed sub-project is aligned with the government policy of Bangladesh as well as SDGs of the United Nations.

## **7. Sub-project general objective (s)**

- i. Up-scaling of solar pump for smallholder irrigation in the central coastal region of Bangladesh
- ii. Field trials and demonstrations of solar pump irrigation systems with surface water for high value crops and rice
- iii. Application of solar photovoltaic panel (both portable and non-portable) to operate household appliances round the year during off irrigation period, and
- iv. Analyzing the technical and economic feasibility of solar pump for multiple uses.

## **8. Sub-project specific objectives (component wise)**

### **Coordination Component: BARC**

- i. To build a linkage between coordination component and implementation components
- ii. To coordinate, monitor and evaluate research and development activities of the sub-project

### **Component-1: BARI**

- i. Up-scaling and improvement of solar pump for higher capacity and efficiency
- ii. Test the efficacy of application of solar energy for pumping and household appliances for year-round uses
- iii. Field trials of solar pump for irrigation of high value crops and year-round uses of solar energy in household appliances in the central coastal region of Bangladesh

### **Component-2: BRRI**

- i. Selection and up-scaling of solar pump system (centrifugal or submersible) for smallholder surface irrigation
- ii. Development of portable solar panel and test its efficacy for use with solar pump and household appliances for year-round uses
- iii. Field trials of portable solar pump for irrigation in rice-based cropping pattern and year-round uses of solar energy in household appliances in the central coastal region of Bangladesh

## **9. Implementing location (s)**

Sub-project implementing location for BARI Component were Patuakhali (Kalapara and Galachipa upazila), Barguna (Barguna Sadar and Amtali upazila) and Bhola (Char Fassion and Lalmohon upazila), and for BRRI Component were Barishal (Uzirpur and Bakerganj upazila), Jhalkati (Sadar and Nalcity upazila) and Pirojpur (Sadar and Nazirpur upazila) districts.



**Fig. 1: Implementing location**

## 10. Methodology in brief (with appropriate pictures)

Coordination Component: BARC developed the methodology & implementation strategy for sub-project through series of coordination meetings. At the early stage of the sub-project this coordination component recruited sub-project consultant and staffs on contractual basis for all components within stipulated timeframe. All the reports as required by NATP authority were submitted regularly. Monitoring and evaluation of sub-project activities were done by coordination component through field visit in a body, over phone or online meeting during the sub-project period as a routine work. During visits and subsequent discussion, BARC component reviewed and evaluated sub-project activities and implementation procedures for avoiding any deviation in conducting sub-project's experiments. The coordination component has provided highest endeavor to achieve the sub-project general objectives through the specific objectives of the participated component institutes.

A series of activities were done by both BARI and BRRI components with the coordination from the BARC component. The activities included baseline survey, design for solar PV system including panels, irrigation pumps, home electric appliances, and land-area for irrigation. After design and fabrication, on-station test of the system was done. The final prototype was multiplied as per requirement and installed in farmers' fields. For better use of the technology, training was imparted to the farmers, service providers, and electricians at the farm level. Each of the sub-project components arranged field demonstrations for the neighboring farmers and other interested people. Finally, data in respect of system performance, crop performance and socio-economics were collected and analyzed. These are discussed below.

## 10.1 Baseline survey

The baseline survey was conducted in the sub-project locations to get field level information on availability of electricity, cropping pattern, water availability, existing irrigation systems, water salinity along with socio-economic conditions of the farmers, the suitable sites for installation, operation and testing of solar pumps considering home applications, rice irrigation, irrigable area and availability of fresh surface water for the solar power systems. The coordination component of BARC assisted in developing survey questionnaires and finalized them in consultation with the implementing institutes. Three sets of interview questionnaires were prepared for farmers, irrigation equipment users and solar power dealers (Annexure I). Thirty farmers were randomly chosen from every sub-project location. Data and information were collected by Principal Investigators, Co-Investigators, Scientific Officers and local Sub-Assistant Agriculture Officers (SAAOs). Information was also collected from 10 electric machinery dealers/traders/ electricians from the nearby markets of the selected upazila. Secondary data were collected from books, journal articles, researched reports, internet, etc.

### 10.1.1 BARI Component

The information was collected using the prescribed interview schedule. On discussion with the Upazila Agriculture Officer and Sub-Assistant Agriculture Officer (SAAO), the sites were selected and surveyed in Patuakhali, Barguna and Bhola districts. The locations of surveyed areas in the selected upazilas and districts are given in Table 1. Field data were collected from different types of farmers, solar panel dealers, service providers and users of solar home appliances. The interview schedules were pre-tested in Holdibari village of Kalapara upazila under Patuakhali district. Then these were finalized incorporating some additional information obtained from pre-test survey. Thirty farmers, who used the irrigation equipment for field crops, were chosen and directly interviewed through prescribed interview schedules. This was done for each of the selected upazilas. Photographic views of base line survey are presented in Figure 2.

**Table 1: Selected locations for base line survey in the sub-project areas**

District	Upazila	Union	Village
Patuakhali	Kalapara	Nilganj	Islampur
			Niyamotpur
			Elempur
	Galachipa	Champapur	Masuakhali
			Amkhola
			Charkajol
			Char Biswas
Barguna	Barguna Sadar	Badarkhali	Sathghor- Kumrakhali
			Kumrakhali
	Amtali	Kukuya	Amragasia
			Purbosonakhali
			Jinnago
Bhola	Char Fasson	Char Fasson Pouroshova	Ewaspur
			Dholigowronagar
	Lalmohon	Farajganj	Dholigowronagar
			Asuli



**Fig. 2: Photographic views of base line survey**

### 10.1.2 BRR I Component

With the discussion and assistance of Upazila Agriculture Officer (UAO) and Sub-Assistant Agriculture Officer (SAAO), the sites were selected and surveyed in Barishal, Jhalkati and Pirojpur districts. Baseline survey was conducted in these locations. The interview schedules were finalized incorporating the information collected from pre-tests. Information was collected from different types of farmers, solar power dealers, service providers and users of solar home appliances. Interview questionnaires were pre-tested in Gobindopur village of Bakerganj upazila under Barishal district. Thirty numbers of randomly selected farmers from each of the upazilas who used the irrigation equipment were selected and interviewed through prescribed schedules. Some photographic views of the survey are shown in Fig.3. Locations in details for baseline survey are given in Table 2.

**Table 2: Selected places for base line survey in the sub-project areas**

District	Upazila	Union	Village
Barishal	Uzirpur	Otra	Bagra
		Shikarpur	Bhabanipur
			Barta
	Bakerganj	Rangasree	West Joysree
			Boalia
			Imamkati
Jhalkati	Jhalkati Sadar	Gabkaan Dhanshiri	Deulkathi
		Nobogram	Ramzankathi
	Nalcity	Dopdopia	Dopdopia
		Kusanghal	Manpasha
Pirojpur	Pirojpur Sadar	Kodomtola	Duliari Kodomtola
		Durgapur	Nagarbar
	Nazirpur	Mativanga	Shamontogati
		Sreeramkati	Tarabunia



**Fig. 3: Some photographic views of base line survey**

## **10.2 Up-scaling of solar pump for smallholder irrigation in the central coastal region of Bangladesh**

BARC coordination component constituted a design team composed of experts from BARC, BARI, BRRI and Dhaka University. The team checked the design and prototypes of solar pump and home appliances developed by BARI and BRRI components and rendered suggestions for the improvement.

### **10.2.1 BARI Component**

#### **Solar pump design for the farmers**

Two categories of solar pumps (Large and mini) were designed, fabricated and installed in the selected sub-project sites for SHS (Solar Home System) and irrigation. A solar pump of 910W motor capacity and 180 L/min flow rate was designed and fabricated matching farmers' needs obtained from the base line survey. Another solar pump of 40 L/min flow rate and 280W motor capacity was also designed and fabricated as per affordability and demands obtained from the farmers during field demonstrations in 2019-2020. The performance of the pump was tested at BARI, Gazipur and found very satisfactory. After 1<sup>st</sup> year of field experiments and demonstrations of the large pump, the mini solar pump was designed and fabricated. Both categories of solar pumps and SHS (Solar Home System) were fabricated at Farm Machinery and Postharvest Process Engineering (FMPE) Division, Bangladesh Agricultural Research Institute (BARI), Gazipur. For each pump, the inlet diameter was the same as the outlet diameter. The inlet and outlet diameters of the large and mini pumps were 51 mm and 25 mm, respectively. The large pump was coupled with a 910W DC motor and the mini pump was coupled with a 280W DC motor. A test of SHS (Solar Home System) with the designed solar PV system was done in the mosque of FMPE Division, BARI, Gazipur. The system was found to run smoothly. Pictorial views of newly fabricated solar pumps at Farm Machinery and Postharvest Process Engineering Division, BARI are shown in Fig. 4.



a. Large solar pump (910 W, 180 L/min)



b. Solar panel (1300W<sub>p</sub> @325W)



c. Mini solar pump (280W, 40L/min, 365Wp PV)



d. 365Wp ARCO PV at FMPE Mosque

**Fig. 4: Photographic views of solar pumps testing at Gazipur**

### **Command area calculation for solar pumps**

Command area of solar pump was calculated for southern region. In this region, the soil moisture become optimum (joe condition) for rabi crops later than that of other regions of the country. Before late December, the soil moisture hardly becomes at optimum planting condition. Thus, Rabi crop plantation is pushed back due to excessive moisture content of the cultivable lands. Generally, from last week of December, Rabi crops season starts. Calculations for command area, panel size & number, load etc. were done both for on-station experiments and farmers' field demonstrations.

### **Calculation of command area**

#### **Command Area for Large model (180 L/min):**

Water requirement for vegetables = 250 mm/season = 2500000 L/ha/season

Considering minimum flow rate,  $Q = 180 \text{ L/min} = 45,36,000 \text{ L/season}$

(1 season = 70 days, 1 day = 6 hours)

So, Command area =  $4536000 \div 2500000 \text{ ha/season} = 1.81 \text{ ha/season (approx.)}$

#### **Command Area for mini model (40 L/min):**

Water requirement for vegetables = 250 mm/season = 2500000 L/ha/season

Considering minimum flow rate,  $Q = 40 \text{ L/min} = 10,08,000 \text{ L/season}$

(1 season = 70 days, 1 day = 6 hours)

So, Command area =  $1008000 \div 2500000 \text{ ha/season} = 0.40 \text{ ha/season (approx.)}$

## Selection of panel size

### Panel selection for larger pump

According to the market availability of motor for solar pump to satisfy the desired motor speed (rpm), 48V and 910W<sub>p</sub> are required. Considering the local environmental conditions and market availability, a single panel of 325W<sub>p</sub> was selected. Thus, using 4 panels, 325W<sub>p</sub> (for each panel) ×4 (number of panels) = 1300W<sub>p</sub> was obtained. To get 48 V and 910W<sub>p</sub>, panels (24V each) were arranged in series and parallel connections.

### Panel selection for mini model

According to the market availability of motor for solar pump to satisfy the desired motor speed (rpm), 24V and 280W<sub>p</sub> are required. The total power of solar panel size was calculated as, 365W<sub>p</sub> (for each panel) ×1 (number of panels) = 365W<sub>p</sub>. To get 24V and 280W<sub>p</sub>, panels (24V each) were arranged in series and parallel connections.

### Maximum desired load for farmer's SHS (Solar Home System)

For household uses of solar power, maximum power was calculated based on base line survey data. The calculation for maximum desired load for SHS (Solar Home System) is given in Table 3.

**Table 3: The maximum desired load for SHS (Solar Home System)**

Item	Numbers	Unit load, W	Total load, W	Operating time, hrs./day (assumed)	Total load hour, WH
DC light	04	09	36	06	216
DC fan	02	25	50	05	250
LCD television	01	50	50	02	100
Mobile charger	01	10	10	01	10
Total			146		576

Battery capacity = 100 AH and 12 V, or 1200 WH. Thus, considering the total load requirement of 576 WH, it was needed to supply about 50% charge to battery from solar panels. So, the required battery power was 600 WH. Expected sunshine hours in Bangladesh is 6-9 hours. But considering foggy, cloudy, and rainy days, the effective sunshine hour is assumed 3.7 hours per day.

So, the PV panels needed to produce the power = 600WH ÷ 3.7H = 162.16W of DC electricity. If all the home appliances are operated simultaneously (146W load requirement), then the battery backup time would be: 600WH ÷ 146 W ≈ 4 hours.

### Selection of solar panel for pump and SHS (Solar Home System)

Considering the characteristics of solar panels available in the market and the environmental condition of Bangladesh, the selected solar panel size was calculated out to 162.16 W×2 = 324.32W<sub>p</sub> ≈ 325W<sub>p</sub>. The solar panel of 325W<sub>p</sub> was, thus, used for large model when it was fielded. But later, 365W<sub>p</sub> panels became available in the market when the mini solar pump was designed and installed in farmers' fields. Hence, the solar panel, 365W<sub>p</sub>, was used for mini model. The specification of selected solar panel is given in Table 4.

**Table 4: Specification of selected solar panel**

Type	Poly-crystalline
Brand and make of solar module	Chinaland, China
Model	CHN325-72P
Rated peak power ( $P_{max}$ )	325 $W_p$ / 365 $W_p$
Size of each module	1950 mm×990 mm×40 mm
Rated voltage ( $V_{mp}$ )	37.70 V
Rated current ( $I_{mp}$ )	8.62 A
Open circuit voltage ( $V_{oc}$ )	44.90 V
Short circuit current ( $I_{sc}$ )	9.10 A
Fire rating	CLASS-A

### 10.2.2 BRRI Component

#### Selection of irrigation pump

Based on survey information, 2 Hp or 1.5 kW small centrifugal pump was selected for smallholding farmers to draw surface water. These pumps usually require low operating cost, use less energy, and demand minimum number of solar panels. Fig.5 shows the widely used centrifugal pump for irrigation.



**Fig. 5: Pictorial view of the single phase AC Centrifugal pump**

#### Design of portable PV panel structure

For setting up of the panels and making them portable, a two-wheel drive galvanized mild steel structure was made (Fig.6). Two springs or shock absorbers were used to connect the structure to its wheels. A strong basement, made of heavy duty material, was set for balancing the relative motions between the two. Eight compartments were made for 8 numbers of solar panels using galvanized mild steel and were attached to the basement of the vehicle. The size of each compartment or frame was the same to accommodate each panel comfortably. Out of eight frames, four had the provision to be folded on to the rest four compartments. Panels were attached to the compartments in such a way that the folded panels do not come into direct contact with the surface of the fixed panels. Some rubber gaskets were used between the contact surfaces of the folding panels. The length of the basement of the vehicle was 12 feet and the width was 10 feet. Two rods were used to keep the panel structure horizontal with the wheel (Fig.6). Pump inverter and switch box were kept in two boxes attached to the axle of the portable solar panel. The wheels of the portable panel structure were similar to those used in power tillers. The panel was provided with a folding facility to reduce the coverage of surface area. The main features of the PV panel structure are shown in Table 5.



**Fig. 6: Portable PV panel structure**

**Table 5: Main features of portable PV panel structure**

Main feature	Characteristics
Material	Poly carbon MS Steel and Galvanized
Structure	Mild Steel
Tensile Strength	410MPA
Finishing	Galvanization
Wind load	200km/Hr (Min)
Structure type	Portable with manually Foldable
Carrying wheel	Power tiller type

### **Design of a portable solar pump**

The whole solar pump system consisted of panels, supporting structure with trolley type portable mechanism, electronic parts for regulation, cable accessories, pipes and the pump itself (Fig.7). Solar panels or modules were the main forces to produce electric power from sun light to drive solar pump. The total capacity of 8 panels was 2640W with each panel producing 330W (a maximum of 37.1V and 8.89A) at the rate of 1000 W/m<sup>2</sup>. The panels were connected in series with a single string to increase the voltage up to 296.8V in direct current system. A pump inverter was used to convert panel produced DC electricity into AC current so that the AC pump could operate well in on-grid areas. Inverter rated output power was 2.2kW with a power conversion efficiency of 97% and a power factor of 1. It controlled the pump and motor for low or high voltage and over rated current. AC motors were used to run the pumps as these were mostly available in the market, commonly used, less costly and more powerful. During AC system, single phase 220V and rated current of 11.5A were produced to operate a 2 hp pump. The principal benefit of a portable solar energy operated pump was that it could be moved easily from one place to another for pumping surface water. The system could also be used for operating low duty electrical and electronic household appliances. The panel surface was set at an angle of about 23° with the vertical and the base was kept horizontal along the ground surface. The main features of the portable solar panel based solar pump system are given in Table 6.



**Fig. 7: Pictorial view of the portable solar panel based solar pump**

**Table 6: Main feature of portable solar pump**

Main feature	Characteristics
Suitability	Surface water lifting
Capacity of each panel	330 watt
Dimension of the panel	1.97 m x 1m
Weight of each panel	23 kg
Total panel area before folding	15.76 m <sup>2</sup>
Total panel area after folding	7.88 m <sup>2</sup>
Delivery diameter	76 mm (3 inch)
Suction lift	7.62 m
Capacity of solar panel	2.56 kWp
Inverter capacity	2.2 kWp
Type of motor	AC single phase (220 V)
Power of motor	1.5 KW
Motor speed	2900 rpm
Frequency	50 Hz
Average discharge	6.5 l/s
PV module mounting structure	Two wheel with manually foldable
The price of solar pump system	Tk.1,72,400

### Discharge calculation

Considering 2ha/15 bigha of land,

Total land = 15\*1338 = 20070 m<sup>2</sup>

Depth of irrigation required through the whole irrigation period = 110 cm (for clay soil)

So, total water required = 20070\*1.1 = 22077 m<sup>3</sup>

As we are introducing AWD method, it saves 38% of water use

Now, required water = 22077 \*(1-0.38) = 13687.74 m<sup>3</sup>

As we are irrigating every day (100 days), No. of irrigation = 100

Using hose pipe will result in 0% conveyance loss.

So, total irrigation required = 13687.74 m<sup>3</sup>

Daily irrigation required = 13687.74 /100 = 136.87 m<sup>3</sup> per day

Considering 6 hrs. operating time per day,

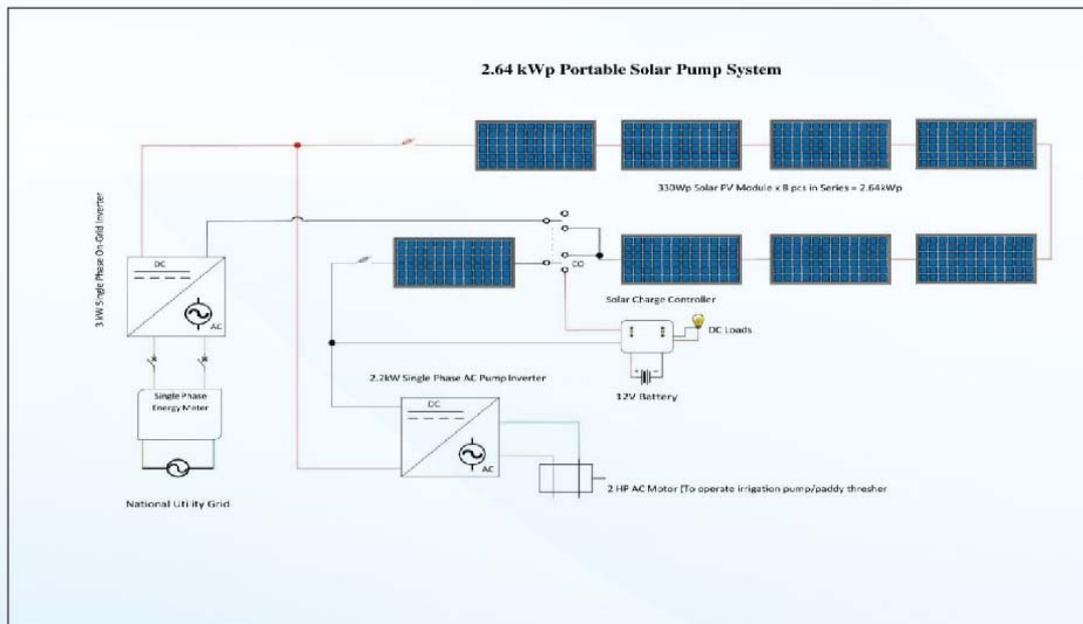
Required discharge = (136.87 /6)\*(1000/3600) = 6.34 l/s

Area coverage per irrigation = 136.87 /(1.1\*0.62) = 200.7 m<sup>2</sup>

So, the required discharge is less than the designed solar pump.

## Design of a portable solar panel based home system

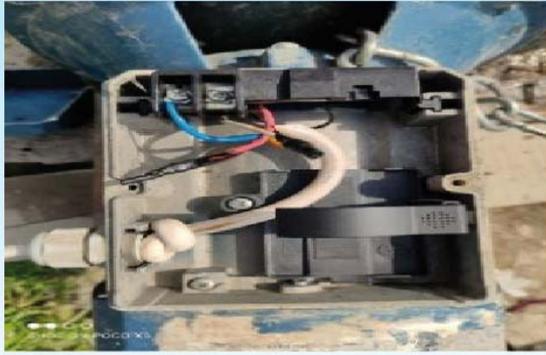
Usually, in the existing solar pump irrigation schemes, the pumps are only used in irrigation season (3-4 months per year) and then it remains idle during the rest period of the year. These solar pump systems cannot be shifted from one place to another. But the farmers could move portable solar panel system from their home to the field easily during irrigation period. After irrigation, solar pump and portable panels were brought back to farmer's house. To make best use of the expensive solar panels, a 2HP (1.49kW) single phase AC motor operated paddy thresher was designed for both on-grid and off-grid solar home systems. The speed of the motor pulley of the thresher ranged from 2800-2961 RPM and rotor/drum pulley speed ranged from 470-480 RPM. Diameters of motor and rotor pulleys were 4.5 and 12 inch, respectively. On-grid solar home system was designed for the grid connected houses. A 3kW AC single phase grid tie inverter was used to supply electricity to the utility point of the grid line in the farmer's house. Seven solar panels were used to produce electricity amounting to about 5-6 kWh/day and the rest of the panel was used as an off-grid system. In this off-grid system, a 100AH lead acid battery was used to store electricity for using at night. A changeover was attached to the system to switch over from on-grid to off-grid and vice versa which facilitated suitable operations of household appliances. In this system, two 5W LED tube lights, one DC 12V and 12W Table Fan and one 5W mobile charger were used in a farmer's house. A flow diagram of panel arrangement of solar powered irrigation system and other home appliances is shown in Fig.8.



**Fig. 8: Flow diagram of portable solar irrigation and home applications**

## Rewinding of single phase induction motor

Some single-phase AC electric motors require a "run capacitor" to energize the second-phase winding (auxiliary coil) to create a rotating magnetic field while the motor is running. Irrigation pump available in the market consists of a run capacitor only. On the other hand, some AC electric motors comprise of both the start and run capacitors. This type of capacitors is used in the paddy thresher. Pump inverter used in the solar irrigation system consists of a capacitor. So during installation, capacitors from both the motors of the pump and the thresher were removed. The connection mechanism is shown in Fig. 9.



a. Single capacitor based motor of irrigation pump



b. Double capacitor based motor of paddy thresher

**Fig. 9: Rewinding of AC induction motor**

### 10.3 On station performance testing of solar pump for irrigation and household appliances

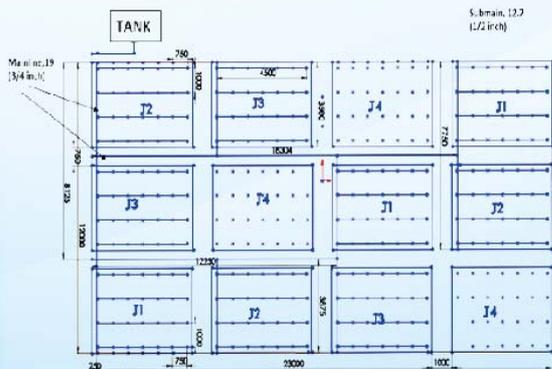
As mentioned earlier, after fabrication of designed solar PV systems, their on-station performances were tested. Both BARI and BRRRI conducted the tests in their respective institutes in Joydebpur. BARI conducted field experiments with brinjal and tomato in FMPE research field.

#### 10.3.1 BARI Component

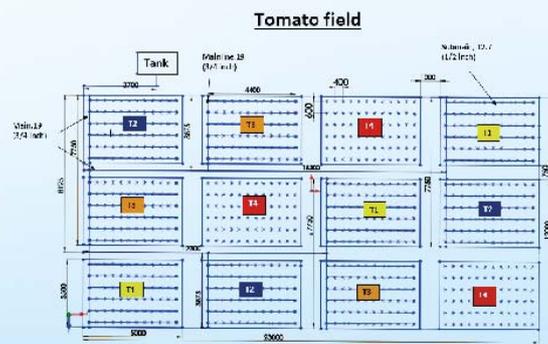
Two field experiments were conducted on solar pump irrigation for tomato and brinjal in the research field of FMPE Division, BARI, Gazipur during the Rabi crop seasons of 2018-2019 and 2019-2020. The experiments were laid out in RCB design with four treatments and three replications. In both the years, the treatments were-

- T<sub>1</sub>= Drip irrigation at 3 days interval
- T<sub>2</sub>= Drip irrigation at 5 days interval
- T<sub>3</sub>= Drip irrigation at 7 days interval
- T<sub>4</sub>= Furrow irrigation (control)

Total land areas including tomato and brinjal fields were 1104 square meters and the individual plot size was 17.5 m<sup>2</sup> (5 m×3.5 m) in both the years. In 2018-2019 Rabi crop season, BARI Begun-8 and tomato (Roma VF) were used in the experiment. In the following Rabi crop season, the same crops and varieties were transplanted in the same research fields. Pictorial views of the field experiments of 2018-19 and 2019-20 are shown in Fig.10, Fig.11 and Fig.12.



a. Layout of brinjal field experiment



b. Layout of tomato field experiment

**Fig. 10: Layout for field experiment**



**Fig. 11: Field experiments of brinjal and tomato in FMPE research field (2018-2019)**



**Fig. 12: Field experiments of brinjal and tomato in FMPE research field (2019-2020)**

### **Irrigation Scheduling:**

Irrigation to tomato field was done by drip and furrow application methods. In drip method, irrigation scheduling was followed by measuring daily crop evapotranspiration. The following equation was used to measure evapotranspiration:

$$ET_{\text{crop}} = ET_0 \times K_c$$

Where,

$ET_{\text{crop}}$  = crop evapotranspiration, mm

$ET_0$  = Reference crop evapotranspiration, mm

$K_c$  = Crop coefficient

Reference crop evapotranspiration ( $ET_0$ ) was calculated by Penman-Monteith equation using FAO developed CROPWAT Software on a daily basis from daily meteorological and geographical data. Drippers developed by BSMRAU and manufactured by local manufacturer (Arfa Engineering, Dhaka) were used in tomato field. The average discharge of a dripper was 3.3 L/h at 2 m head of water. The value of standard deviation and co-efficient of variation were 0.5 and 13.8, respectively. In case of furrow method, depth of irrigation water was measured periodically and it was calculated using water balance method as given in equation.

$$P + I = R + I_f + ET \pm \Delta S$$

Where,

$P$  = precipitation, mm

$I$  = irrigation, mm

$R$  = surface runoff, mm

$I_f$  = infiltration, mm

ET = evapotranspiration, mm and

$\Delta S$  = water storage or depleted from soil root zone, mm.

### **On-station Field Experiments with large (180 L/min) solar pump (2020-2021)**

A field experiment was set with solar pump irrigation system for tomato in the research field of FMPE Division during the rabi crops season of 2020-2021. The experiments were laid out in RCB design with three treatments and four replications. The treatments were-

T<sub>1</sub>= Drip irrigation system

T<sub>2</sub>= Alternate furrow irrigation system

T<sub>3</sub>= Farmers practice (control)

Total land areas including tomato was 250 square meter and individual plot size was 17.5 (5×3.5) square meter. The seedlings of tomato (BARI Tomato-14) were planted on 6 December 2020. Fertilizers were applied as recommended doses (FRG, 2018). The weeding and pesticide spraying were done as and when necessary. The tomato was harvested. Pictorial views of the field experiments are shown in Fig. 13.



**Fig. 13: Field experiments of tomato in FMPE research field (2020-2021)**

### **Setting up of solar home system at BARI**

A solar home system was set in the mosque of FMPE Division, BARI, Gazipur. The system was found to work smoothly to operate the electric appliances. Pictorial views of the solar home system in the mosque of FMPE Division, BARI are shown in Fig. 14.



a. FMPE, BARI SHS testing



b. FMPE, BARI SHS wiring design

**Fig. 14: Photographic views of SHS (Solar Home System) testing at Gazipur**

### 10.3.2 BRRRI Component

#### Testing of solar panel, pump, and home appliances

The hydraulic and energy performances of the centrifugal pump were tested at the pump testing bed of BRRRI experimental field. The capacities of the pump at different dynamic heads were compared. Apart from pump test, the performance of the designed portable solar panel system was also tested in regards to home applications and small agricultural machinery operations. All the tests were conducted at BRRRI, Gazipur. The testing arrangements are elaborated below:

##### a. Construction of bamboo tower for pump testing

A bamboo tower was constructed (Fig.11) to raise the centrifugal pump above the ground surface to create required suction lifts and it was constructed just beside a water reservoir. The tower was a 25 feet tall vertical structure and consisted of 10 platforms or steps. These bamboo steps were tied horizontally one above another along the vertical bamboo posts. The steps were used to place the pump at different heights. The vertical distance from one step to another was 2.5 ft. A rope, running over a hook at the top, raised the pump upward. Operation of the pump was started by placing the pump on the lowest platform. The pump was raised step by step to the highest platform keeping the water surface at the same level. All necessary measures were taken to minimize the vibration of the pump while it was in operating condition. The bamboo structures of variable suction and delivery heads are shown in Fig 15(a) and 15(b), respectively.



a) Constant delivery head



b) Constant suction head

**Fig. 15: Pictorial view of the pump testing structure**

##### b. Water reservoir

The water reservoir of the experimental field of IWM Division was used for pump testing. It was 5 ft. wide and 12 ft. long. The reservoir was constructed by keeping its top at the same level of the ground surface and its bottom was set 6 ft. below the ground surface. When required, the level of water surface was changed by withdrawing water from the reservoir or adding water to it.

##### c. Suction lifts

When a pump remains above the water level, the vertical distance between the pump center line and the water level on the suction side is called the suction lift. When the pump is not running, the suction lift is referred to as static suction lift. In order to assessing the performance of a centrifugal pump under a wide range of suction lifts, the discharge of the pump was measured for different suction lifts, from 2.5 to 25 ft with an interval of 2.5 ft. Thus, the pump was operated against 10 static suction lifts. When water flows through a pipe, it is resisted by the friction force of the pipe internal surface, with a consequent head loss. So, during pumping water at a static suction lift, the pump has to beat this head loss in pipes in addition to the suction lift. Thus, the total suction lift becomes the sum of the actual suction lift and the head loss due to friction. This lift is often

designated as dynamic suction lift. The actual suction lift was measured with a measuring tape. To determine the total suction lift, the head loss due to friction was calculated using the formula (King, et al., 1948):

$$h_f = f * (L/D) * (V^2/2g),$$

Where,

f = Friction factor

$h_f$  = head loss due to internal friction of the pipe, ft.

L = length of pipe, ft.

D = internal diameter of pipe, ft.

V = velocity of water in the pipe, ft/sec.

G = acceleration due to gravity, ft/sec<sup>2</sup>

#### **d. Delivery head**

In Bangladesh, most of the irrigated lands are supplied with water from underground source or surface canals placing the pump on the ground surface when STW or LLP is used. So, there is no need to install a delivery pipe. For this reason, delivery head was not considered in this study. The only delivery head was the vertical distance between the center of the impeller and the outlet of the casing (0.2 m). This delivery head was common for all suction lifts.

#### **e. Flow meter for discharge measurement**

A flow meter (Fig. 16) having inlet and outlet diameter of 3 inches was used to measure the volume of water. The volume of water was measured at one-hour interval during the operation of the pump. The operating time was recorded and then dividing the volume of water pumped by the time, the discharge rate (ft<sup>3</sup>/sec.) was calculated. This China made flow meter is available in the local market.



**Fig. 16: Water flow meter**

#### **f. Suction and delivery pipes**

A 7.62 cm (3 inch) diameter suction hose pipe having thickness of 4.5 mm and made of polyvinyl chloride was used to lift water. The suction pipe was kept straight as much as possible to minimize the bending loss. At the bottom of the suction pipe, a foot valve (Fig. 17) was attached which was a non-returning type check valve. The valve was connected to the end of the suction pipe keeping it submerged in water during operation of the pump. It allowed water to flow in the pipe in one direction only. The valve prevented the pump from losing priming and allowing easy starting of it. It was made up of heavy-duty copper so that it would not get rusted while remaining under water. It has an inlet strainer, which prevented picking up large debris that could clog or jam the foot valve in its open position. The delivery pipe used in the test was made of Canvas Flexible Fire Hose Pipe that could never hold pressure or create vacuum. So, the pressure at which the pump delivered water was nothing but the atmospheric pressure. A flow meter was connected to the delivery pipe to measure the flow rate.



**Fig. 17: The foot valve**

### **g. Pump operation**

Before starting the pump, it was primed. Necessary measures were taken to ensure that the joints of the pump and the suction pipe were sealed well. A person, standing on the platform of the bamboo tower where the pump was set, started the pump by plugging the line and playing the system on by a switch.

Pump flow rate was calculated directly from the flow meter reading, vol (m<sup>3</sup>) divided by the respective time (sec) measuring by a stopwatch.

### **h. Tachometer**

The speed of the pump was measured with a tachometer (Fig. 18). As the pump was directly coupled with the shaft of the motor, the rpm of the pump was equal to that of the motor. A white sticker was fixed to the shaft of the pump. An electric ray was thrown from the tachometer to the sticker of the shaft and recorded the digital reading as RPM. The measuring range of the tachometer was 0 to 10000 rpm. The speed of the pump was taken at every 15 minutes during operating time.



**Fig. 18: Digital Tachometer**

### **i. Pyranometer**

SP Lite2 Pyranometer designed for longer life was used in the tests which was suitable under all weather conditions and needed simple maintenance. SP Lite2 is ideal for use with the METEON handheld display and data logger for field tests.



a) Pyranometer

b) Data logger

**Fig. 19: SP Lite2 Silicon Pyranometer**

### Testing of BRR I Open Drum Thresher

BRR I open drum paddy thresher was selected to test the performance of the portable solar panel. All the tests were done at FMPHT workshop at BRR I following test criteria. A 2 hp single phase AC induction motor was attached to the basement of the thresher (Fig. 20).



**Fig. 20: On station performance testing of solar thresher**

Motor and rotor/drum pulley speeds were fixed according to the designed pulley sizes. The main features of portable solar energy operated paddy thresher are given in Table 7.

**Table 7: Main feature of the paddy thresher**

Main feature	Characteristics
Open drum thresher, Model: BRR I	48 inch
Drum sheet	16 gauge
Thresher shaft	1.25 inch
MS wire	4 mm
Angle bar	15 inch x 15 inch x 4 mm
Sheet	18 gauge
Bearing	6206 ZZ
Thresher bearing	UCP 206
Motor	2 hp single phase AC 220 volt
Diameter of motor pulley	9.5 inch
Diameter of rotor/drum pulley	12 inch
Thresher motor pulley speed	2800-2961 RPM
Rotor/drum pulley speed	470-480 RPM
V belt (Korea)	B52 and B57

### Setting up of on-grid solar home system at BRR I

On-grid solar home system is applicable where grid electricity is available. Thus, before setting up the solar PV system in farmers' fields, a grid tie inverter was set at IWM Division building, BRR I, Gazipur (Fig. 21) for testing its performance. During off season, the portable panel was directly connected to the grid line of the office building. During this time, the pump inverter was disconnected and the grid tie inverter was connected through a panel connector to the grid inverter.



**Fig. 21: On station set up of on grid solar home system in IWM Division, BRR I, Gazipur**

This inverter contains an energy meter, circuit breaker and other accessories. The daily electricity production from portable solar panel was recorded in the energy meter during day time only. In holidays, a part of the produced electricity contributed to the national grid when there was no use of electricity in the office. No maintenance was needed for the plug and play system, and grid feeding. The main features of the inverter are shown in Table 8:

**Table 8: Main feature of the on-grid solar home system**

Main feature	Characteristics
1. AC Output power ( $P_{ac}@Cos\theta=1$ )	3000 watt
2. Waveform	Pure sine wave
3. AC Voltage range	180-270 V
4. AC Grid Frequency Range	47-53/57-63Hz
5. Maximum Output Current	13A
6. Total harmonic Distortion	<3%
7. Max. Efficiency	97.2%
8. DC input MPPT voltage range	100~500Vdc
9. Min. No of MPPT	01
10. Strings per MPPT tracker	01
11. Max. input current per MPPT tracker	15A
12. Power factor ( $Cos \phi$ )	1 (adjustable plus minus 0.8)

#### Setting up of off-grid solar home system at BRRRI

According to the demand of the local farmers and more efficient use of solar home appliances, there was provision for the panels to supply electricity in off-grid system during off irrigation season at BRRRI, Gazipur (Fig 22). In the system, one 330-watt panel was used to produce DC current and a 100 AH lead acid battery was used to store electric power. A charge controller was also used to protect the battery from overcharging. A changeover was used to separate on-grid system to off-grid. In this system, two 5W LED tube lights, one DC 12V and 12W Table Fan and one 5W mobile charger were used which are generally found in a farmer's house. In off-grid situation, electricity was stored in the battery from solar panel that could be used during night.



**Fig. 22: Off grid solar home system at BRRRI, Gazipur**

#### 10.4 Field trials and demonstrations of solar pump systems for surface water irrigation in high value crops and rice

After completion of on-station tests of the designed solar PV systems, both BARI and BRRRI component brought them to farmers' fields in the sub-project sites.

### 10.4.1 BARI component

#### Installation of larger solar pump and SHSs in farmers' fields in 2019-20

Six solar pumps (180 L/min.) and SHSs (Solar Home System) were installed at farmers' fields of Kalapara and Galachipa upazilas of Patuakhali district, Barguna Sadar and Amtali upazilas of Barguna district and Char Fasson and Lalmohon upazilas of Bhola district. Names and addresses of selected farmers for solar pump demonstrations at different locations are given in Table 9.

**Table 9: Names and addresses of selected farmers for solar pump demonstrations**

District	Upazila	Farmer's profile
Patuakhali	Galachipa	Name of farmer: Md. Sohrab Hossen Jomaddar Fathers Name: Altaf Jomaddar; Mothers Name: Moriyom Begum NID: 6866341917; Date of Birth: 08 May 1960 Cell-01771498643, 01857654858 Address: Village: Nijsuhuri, Post- Office: Badura-8640
	Kalapara	Name of farmer: Zillur Rahman Bashir Fathers Name: Md. Hasibur Rahman Boku Mothers Name: Most. Hasna Begum Date of Birth: 05 Oct 1976; Cell-01721187235 Address: Village: Masuakhali, Post- Office: Champapur
Barguna	Barguna Sadar	Name of farmer: Md. Sajahan Mia Fathers Name: Md. Morul Haowlader; Mothers Name: Most. Saleha NID: 2351181272; Date of Birth: 01 Oct 1976 Cell-01794792557 Address: Village: Kumrakhali, Post- Office: Baowalkor-8700
	Amtali	Name of farmer: Nur Alam Fathers Name: Md. Wajed Haowlader Mothers Name: Most. Ojion Begum NID: 0410987250383; Date of Birth: 10 Oct 1973; Cell-01719985151 Address: Village: Amragassiya, Post- Office: Kukuya-8710
		Name of farmer: Shah Alam (SHS only) Fathers Name: Md. Wajed Haowlader Mothers Name: Most. Saleha Begum NID: 0410987250344; Date of Birth: 10 December 1967 Cell-01719985151 Address: Village: Amragassiya, Post- Office: Kukuya-8710
Bhola	Char Fasson	Name of farmer: Fazle Ali Biswas Fathers Name: Mojaffor Ali Biswas; Mothers Name: Nurvanu Begum NID: 091255385208; Date of Birth: 01 Jan 1960 Cell-01745375589 Address: Village: Aowajpur, Post- Office: Sosibhuson- 8340
	Lalmohon	Name of farmer: Nurul Islam Mia Fathers Name: Altafur Rahman; Mothers Name: Sorifa Khatun NID: 0915428964726; Date of Birth: 01 Jan 1969 Cell-01951024682, 01757029438 Address: Village: Dholigouronagar, Post-Office: Dholigouronagar-8330

### Installation of mini solar pumps and SHs in farmers' fields during 2020-21

Twelve numbers of fabricated mini solar pumps (40L/s) and SHSs (Solar Home System) were installed at farmers' fields of Kalapara and Galachipa upazilas of Patuakhali district, Barguna Sadar and Amtali upazilas of Barguna district and Char Fasson and Lalmohon upazilas of Bhola district. Names and addresses of selected farmers for mini solar pump demonstration for irrigation and SHSs (Solar Home System) at different locations are given in Table 10.

**Table 10: Names and addresses of selected farmers for mini solar pump (280W) demonstration**

District	Upazila	Farmer's profile		
Barguna	Barguna Sadar	Name of farmer: Milon Fathers Name: Sofez; Mothers Name: Sufia Date of Birth: 01 Jan 1987 NID: 2803450689; Cell-01726826920 Address: Village: Gazi Mahmud, Post- Office: Nissan Baria-8720		
		Name of farmer: Md. Abdul Rabb Fathers Name: Tojumbor Mirdha; Mothers Name: Rokeya Begum Date of Birth: 07 Aug 1980 NID: 4196196093, Cell-01729326604 Address: Village: kot Baria, Post- Office: kot baria-8700		
	Amtali	Name of farmer: Md. Delowar Fathers Name: Md. Moslem Ali; Mothers Name: Hajera Begum Date of Birth: 03 Jan 1980 NID: 7307620398, Cell-01725729528 Address: Village: East Chunakhali, Post- Office: Had Chunakhali-8710		
		Name of farmer: Md. Abdur Razzak Mia Fathers Name: Md. Chan Mia Haowlader; Mothers Name: Ambia Khatun Date of Birth: 03 April 1970; NID: 3729123806, Cell-01768912667 Address: Village: North Ghotkhali, Post- Office: Ghatkhali-8710		
		Patuakhali	Galachipa	Name of farmer: Md. Bablu Jomadder Fathers Name: Md. Nuru Jomadder; Mothers Name: Most. Shamsunnahar Date of Birth: 10 Oct 1989 NID: 3729123806, Cell-01747146648 Address: Village: South Charbiswas, Post- Office: Charbiswas-8640
				Name of farmer: Md. Firoz Rari Fathers Name: Md. Ali Hossen Rari; Mothers Name: Jahanara Begum Date of Birth: 06 Feb 1981 NID: 4628715445, Cell-01759664282 Address: Village: Boro Char Kajol, Post- Office: Chatkajol-8640
Name of farmer: Sukha RanZan Vhat Fathers Name: Monindra Chandra Vhat; Mothers Name: Kalo Rani Date of Birth: 05 Oct 1987 NID: 3728888615, Cell-01739400305 Address: Village: Soto Siba, Post- Office: Soto Shiba-8640				
Name of farmer: Md. Monir dhali Fathers Name: Atahar Dhali; Mothers Name: Ojupha Begum Date of Birth: 05 Mar 1978 NID: 5516471991, Cell-01728516128 Address: Village: Char Badai, Post- Office: Naluabagi-8640				

District	Upazila	Farmer's profile
		Name of farmer: Md. Delower Hossain Fathers Name: Afsar Uddin Gazi Date of Birth: 12 Aug 1969 NID: 8679753544, Cell-01765817670 Address: Village: Kokaitobok , Post- Office: North Panpotri-8640
	Kalapara	Name of farmer: Md. Joynal Abedin Fathers Name: Late. Md. Ishaque Haowlader Mothers Name: Rubia Begum Date of Birth: 15 Jul 1974 NID: 7816671687074, Cell-01608578923 Address: Village: East-Sonatala, Post- Office: Pakhimara-8650
Bhola	Char Fasson	Name of farmer: Md. Abdul kadir Fathers Name: Md. Jahangir Matbor; Mothers Name: Parul Begum Date of Birth: 01 Jan 1983 NID: 0922508823395, Cell-01724771818 Address: Village: Matabbor bari, Post-office: Char Fasson-8340
	Lalmohon	Name of farmer: Md. Jasim uddin Fathers Name: Md. Abdur Sahid; Mothers Name: Safia Begum Date of Birth: 19 Jan 1978 NID: 1905600233, Cell-01714648278 Address: Village: Dholigouronagar, Post- Office: Dholigouronagar-8330

#### Field Experiments with large (180 L/min) solar pump in 2019-20

During the Rabi crops season of 2019-20, vegetables (tomato and brinjal) were planted in the selected farmers' fields of Patuakhali, Barguna and Bhola districts under solar pump irrigation systems. The selected varieties of tomatoes were Diganto, Super, Raton, Manik and Uttara. BARI Bt Begun-1 was transplanted in all locations. Row to row and plant to plant distances of tomato and brinjal were 100 cm and 80 cm, respectively. Experiments of tomato and brinjal were laid out in RCB design with three treatments and four replications as follows:

T<sub>1</sub>= Drip irrigation system

T<sub>2</sub>= Alternate furrow irrigation system

T<sub>3</sub>= Farmers' practice i.e. every furrow irrigation (control)

Two field experiments were conducted with solar pump irrigation system for tomato and brinjal in the farmers' fields at Barguna Sadar. Total land area including tomato and brinjal was 945 m<sup>2</sup> and individual plot size for each crop was 32 m<sup>2</sup> (8 m×4 m). The seedlings of BARI Bt Begun-1 were planted on 21 January and seedlings of tomato (Roton and Manik) were planted on 25 January. The ages of the brinjal and tomato seedlings were 39 and 40 days, respectively. Fertilizers were applied as recommended doses (FRG, 2018). The weeding and pesticide spraying were done as and when necessary. Tomato and brinjal were harvested from 27 March to 24 April 2020 and from 14 April to 29 May 2020, respectively. Hence, tomato was not affected by the cyclone, Amphan but about 25% brinjal was damaged by the cyclone rampage on 29-30 May 2020 all over Bangladesh. Fig. 23 shows the field experiments of different crops.



a. Tomato field



b. Brinjal field

**Fig. 23: Field experiments at Barguna Sadar, Barguna**

In Amtali, two field experiments were conducted with solar pump irrigation for tomato and brinjal (Fig. 24). Total land area including tomato and brinjal fields was 860 m<sup>2</sup> and the individual plot size for BARI Bt Begun-1 was 32 m<sup>2</sup> (8 m×4 m) and for tomato, 28 m<sup>2</sup> (8 m×3.5 m). The seedlings of BARI Bt Begun-1 were planted on 14 January and those of tomato (Super) were planted on 25 January 2020. The seedling ages of brinjal and tomato were 32 and 40 days, respectively. Tomato was harvested from 2 to 18 March 2020 and brinjal was harvested from 17 April to 23 May 2020. Hence, tomato was not affected by the cyclone, Amphan but about 40% brinjal was damaged by the cyclone. The farmers also irrigated potato field with solar pump.



**Fig. 24: Field experiments at Amtali, Barguna**

In Kalapara, a field experiment was conducted with solar pump (180 L/min) for irrigating brinjal in the farmers' fields during the Rabi crops season of 2019-2020. Total land area of brinjal (BARI Bt Begun-1) was 264 m<sup>2</sup> and the individual plot size was 22 m<sup>2</sup> (6.5 m×3.5 m). The seedlings of 41 days old of brinjal were planted on 23 January 2020. The brinjal was harvested from 01 to 29 May 2020. Hence, about about 20% brinjal were damaged by cyclone Amphan. Pictorial views of the field experiments are shown in Fig. 25.



**Fig. 25: Field experiments at Kalapara, Patuakhali**

Two field experiments were conducted to irrigate tomato and brinjal using solar pump system in farmer's field at Galachipa. Total land area of tomato and brinjal was 785 m<sup>2</sup>. The individual plot size of BARI Bt Begun-1 (brinjal) was 20 m<sup>2</sup> (5 m×4 m) and that of tomato (Uttara) was 32m<sup>2</sup> (8 m×4 m). The seedlings of BARI Bt Begun-1(33 days old) were planted on 15 January 2020 and the seedlings of tomato (42 days old) were planted on 27 January 2020. Tomato was harvested from 5 to 26 March 2020 and brinjal was harvested from 15 April to 28 May 2020. Hence, tomato was not affected but about 25% brinjal was damaged by cyclone Amphan. In Fig. 26 are shown the field experiments of tomato and brinjal.



**Fig. 26: Field experiments at Galachipa, Patuakhali**

In Lalmohon, two field experiments were conducted for tomato and brinjal in farmers' fields. Total land area including tomato and brinjal fields was 596 m<sup>2</sup> and the individual plot size was 41 m<sup>2</sup> (8.2 m×5 m) for BARI Bt Begun-1 and 30 m<sup>2</sup> (7.5 m×4 m) for tomato (variety: Diganto). The seedlings of BARI Bt Begun-1(35 days old) were planted on 12 December and seedlings of tomato (32 days old) were planted on 11 December 2019. Tomato was harvested from 4 February to 18 March 2020 and brinjal was harvested from 10 February to 28 March 2020. A field demonstration was held on 15 March 2020 at Lalmohon of Bhola district with the presence of BARC Sub-project personnel. No tomato and brinjal were affected by cyclone Amphan. The farmer also irrigated potato field with solar pump in addition to the experimental crops, brinjal and tomato. Fig. 27 depicts the field days with crop fields.



**Fig. 27: Field experiments at Lalmohon, Bhola**

In Char Fasson, an experiment was conducted to irrigate brinjal in the farmer's field. Total land area of brinjal was 326 square meter and the individual plot size was 21 (6×3.5) square meters for BARI Bt Begun-1. The seedlings of BARI Bt Begun-1 were planted on 18 January. The age of brinjal seedlings was 36 days. Brinjal was harvested from 25 March to 15 June 2020. Hence, the crop was affected by the cyclone, Amphan and about 15% brinjal was damaged. Pictorial views of the field experiments are shown in Fig. 28.



**Fig. 28: Field experiments at Char Fasson, Bhola**

#### **Field Experiments in sub-project sites with large solar pump during 2020-21**

During the Rabi crops season of 2020-21, vegetables (tomato and brinjal) were planted in the selected farmers' fields of Patuakhali, Barguna and Bhola districts under large solar pump irrigation systems. The selected varieties of tomatoes were Super and Super Bijli. BARI Bt Begun-1 was transplanted in all locations. Row to row and plant to plant distances of both the crops were 100 cm and 80 cm, respectively. The experimental details along with the names of farmers and their addresses are given in Table 11. Experiments of tomato and brinjal were laid out in RCB design with three treatments and four replications. The treatments were-

T<sub>1</sub>= Drip irrigation system

T<sub>2</sub>= Alternate furrow irrigation system

T<sub>3</sub>= Farmers' practice i.e. every furrow irrigation (control)

**Table 11: The name and address of field experiments with large solar pump**

District	Upazila	Farmers Name	Crops	Date of Planting	Crops condition	Unit plot size, m <sup>2</sup>	Total Land Area, m <sup>2</sup>
Barguna	Barguna Sadar	Md. Sajahan Mia	Tomato (Super bijli)	07 Jan 2021	Harvested	20.8 m <sup>2</sup> (5.2 m×4 m)	250 m <sup>2</sup>
	Amtali	Nur Alam	Brinjal (BARI Bt Begun-1)	05 Jan 2021	Harvested	32 m <sup>2</sup> (8 m×4 m)	400 m <sup>2</sup>
Patuakhali	Galachipa	Md. Sohrab Hossen Jomaddar	Brinjal (BARI Bt Begun-1)	09 Jan 2021	Harvested	18 m <sup>2</sup> (6 m×3 m)	216 m <sup>2</sup>
Bhola	Lalmohon	Nurul Islam Mia	Tomato (Super)	25 Nov 2020	Harvested	16.2 m <sup>2</sup> (6 m×2.7 m)	200 m <sup>2</sup>
	Char Fasson	Fazle Ali Biswas	Brinjal (BARI Bt Begun-1)	16 Jan 2021	Harvested	32 m <sup>2</sup> (8 m×4 m)	400 m <sup>2</sup>

The Photographic views of field experiments at Patuakhali, Barguna and Bhola Districts during 2020-21 Rabi crops season with large (180 L/min) solar pump for irrigating different crops are shown in Fig. 29.



a. Tomato at Barguna Sadar



b. Brinjal at Amtali



c. Brinjal at Galachipa



d. Brinjal at Char Fasson



e. Tomato at Lalmohon

**Fig.29: Field experiment at Patuakhali, Barguna and Bhola (2020-21) with large solar pump  
Field Experiments with mini solar pump during 2020-21**

Before the beginning of Rabi crops season, 2020-2021, BARI component developed a mini model of solar pump based SHS (Solar Home System) before the Rabi crops season of 2021. The pumps were installed in farmers' fields to irrigate crops of the Rabi crops season of 2020-21. So, field experiments were set up in all new sites. Vegetables (tomato, brinjal, chilli, and watermelon) were planted in the selected farmers' fields of Patuakhali, Barguna and Bhola districts under mini solar pump irrigation systems. The varieties, Manik and Super Bijli of tomato, BARI Bt Begun-1 of brinjal, Kanya and dragon of watermelon and BARI Marich-1 and Bombai of chilli were transplanted in all locations. Row to row and plant to plant distances of tomato, brinjal, chilli, were 100 cm and 80 cm, respectively. Those of water melon were 300 cm and 150 cm, respectively. The names of farmers with addresses, unit plot size, crop varieties, dates of planting and harvesting are given in Table 12 for 40 L/min solar pump in Table 12.

Experiments of tomato, brinjal, and chilli were laid out in RCB design with three treatments and four replications as follows:

T<sub>1</sub>= Drip irrigation system

T<sub>2</sub>= Alternate furrow irrigation system

T<sub>3</sub>= Farmers' practice i.e. every furrow irrigation (control)

Experiments of watermelon were conducted in RCB design with four replications and three treatments as follows:

T<sub>1</sub>= Drip irrigation system

T<sub>2</sub>= Ring basin irrigation system

T<sub>3</sub>= Farmers' practice

**Table 12: The names of farmers, their addresses and crop information for mini solar pump**

District	Upazila	Farmers Name	Unit plot size, m <sup>2</sup> (m×m)	Crops	Date of Planting	Date of harvesting
Barguna	Barguna Sadar	Md. Milon	17.76 (4.8 ×3.7)	Brinjal (BARI Bt Begun-1)	08 Jan 2021	March-April
		Md. Abdul Rabb	30 (10 ×2.7)	Watermelone (Dragon)	16 Jan 2021	April-May
	Amtali	Md. Delowar	7.02 (2.7 ×2.6)	Watermelone (Dragon)	10 Jan 2021	April-May
		Md. Abdur Razzak Mia	37.5 (15 ×2.5)	Watermelone (Dragon)	22 Jan 2021	April-May
Patuakhali	Galachipa	Md. Bablu Jomadder	18 (6 ×3)	Chilli (BARI Marich-1)	20 Jan 2021	March-May
		Md. Firoz Rari	50 (20 ×2.5)	Watermelone (Dragon)	25 Dec 2020	April-May
		Sukha Ranjan Vhat	200.16 (7.2 ×2.8)	Brinjal (Super Muhini)	25 Nov 2020	March-May
		Md. Monir Dhali	27 (10 ×2.7)	Watermelone (Kanya)	16 Jan 2021	April-May
		Md. Delower Hossain	7.02 (2.7 ×2.6)	Chilli (Bombai)	14 Jan 2021	March-May
	Kalapara	Md. Joynal Abedin	18 (6 ×3)	Brinjal (BARI Bt Begun-1)	31 Jan 2021	March-May
Bhola	Lalmohon	Md. Jasim Uddin	32 (8 ×4)	Tomato (Super Bijli)	21 Dec 2020	Feb-March
	Char Fasson	Md. Abdul Kadir	10.4 (2.6 ×4)	Tomato (Manik)	16 Jan 2021	Feb-March

The photographic views of field experiments at Patuakhali, Barguna and Bhola Districts during Rabi crops season of 2020-21 irrigation with mini solar pump for different crops are shown in Fig. 30, Fig. 31 and Fig. 32, respectively.



a. Barguna Sadar



c. Watermelon at Amtali, Barguna

**Fig. 30: Photographic view of field experiments at Barguna district during Rabi crops season of 2020-21 irrigation with mini solar pump**



a. Chilli at Charkajol, Galachipa



b. Watermelon at Boro Charkajol, Galachipa



c. Brinjal at Char Bishwas, Galachipa



d. Chilli at Panpotti, Galachipa, Patuakhali



e. Watermelon at Galachipa, Patuakhali



f. Brinjal at Sonatala, Kalapara, Patuakhali

**Fig. 31: Photographic view of field experiments at Patuakhali district during Rabi crops season of 2020-21 irrigation with mini solar pump**



**Fig. 32: Field experiments at Bhola district during Rabi crops season of 2020-21 irrigation with mini solar pump**

#### 10.4.2 BRRRI component

##### Selection of farmers and lands

Sites for installation of solar pumps were selected in areas where irrigation being done to rice crop using diesel engine operated pumps. Crop lands were selected such that the farmers could irrigate crops during irrigation period using portable solar pumps and after irrigation season, the portable solar PV systems could be used for running the home electric appliances. Six farmers selected from six upazilas were provided with six sets of portable solar pumps and solar household appliances. Portable solar panels were set on a suitable open space of the farmer's house in such a way that the panels could receive sufficient sunlight. The rechargeable battery, inverter, LED bulb, and mobile phone charger were set as per requirement of the farmer. On the basis of baseline survey, a group of 10 farmers were selected from each upazila to irrigate 2 ha of land for cultivation of Boro and Aman rice. Newly released BRRRI HYVs were demonstrated in farmers' fields. Names and addresses of the selected farmers allocated solar pump for demonstrations in irrigation and SHSs (Solar Home System) at different locations are given in Table 13.

**Table 13: Names and addresses of selected farmers for solar pump demonstrations**

District	Upazila	Farmer's profile
Barishal	Bakerganj	Name of farmer: Md. Kanchon Ali Howlader Fathers Name: Hafiz Uddin Howlader Mothers Name: Jamina Khatun Date of Birth: 10 Jun 1967 NID: 19670610794509946; Cell-01736499899 Address: Village: Boalia, Post- Office: Boalia-8280
	Uzirpur (Experimented location)	Name of farmer: Selim Sardar Cell-01770520801, 01310504101 Address: Village: West Joyosri Post- Office: West Joyosri, Uzirpur, Barishal
	Barishal Sadar	Bangladesh Rice Research Institute, Barishal Regional Station, Sagardi, Barishal.
Jhalakati	Nalcity	Name of farmer: Md. Ziaul Haque Howlader Fathers Name: Late Abdul Barek Howlader Mothers Name: Late Urful Nacha Date of Birth: 31 May 1975 NID: 4217315381835; Cell-01718832584 Address: Village: Dopdopia, Post- Office: Dopdopia-8420

District	Upazila	Farmer's profile
	Jhalakati Sadar	Name of farmer: Abdul Jalil Molla Fathers Name: Late Mokbul Uddin Molla Mothers Name: Late Moyna Date of Birth: 06 May 1940 NID: 4168849653; Cell-01735269365 Address: Village: Romjankathi, Post- Office: Dogolchira-8403
Pirojpur	Pirojpur Sadar	Name of farmer: Md. Ripon Shek Fathers Name: Md. Ashrab Ali Shek Mothers Name: Monowara Begum Date of Birth: 05 Apr 1982 NID: 9141799776; Cell- 01943559456, 01683332435 Address: Village: Duliary kodomtola, Post- Office: Kodomtola-8500
	Najirpur	Name of farmer: Robindronath Gain Fathers Name: Odhir Chandra Gain Mothers Name: Omola Gain Date of Birth: 05 Oct 1978 NID: 9551451223; Cell-01834005433 Address: Village: Shamontogati, Post- Office: Tarabunia-88540

### Monitoring salinity of canal water

Salinity of surface water (river and canal water) was measured in the non-saline and saline areas from January to June. Water salinity was measured at an interval of 15 days round the year in the selected locations. Each time, samples were collected at an interval of 6 hr. at three points (near the banks and middle of the canal) from 5–10 cm below the water surface. Water samples were collected in 500 ml plastic bottles. Before taking samples, the bottles were rinsed 2-3 times with river/canal water. Then the samples were collected and tested for salinity by an EC meter (Fig 33).



Fig. 33: Measuring canal water salinity by EC meter

### Setting the solar PV system for rice irrigation

Eight solar panels were connected in series to increase voltage with a single string. The capacitor of irrigation pump was removed and set to rewiring as per pump requirement. Then about 15 feet reinforced flexible pipe having a foot valve at the end of it was connected to the suction end of the pump and a 3-inch delivery pipe was attached to the pump outlet. Pump was fixed with a basement of mild steel to protect the pumping system from vibrating during water delivery. Then the pump was set near to a pond to test the pumping of water.



**Fig.34: Panel installation in the portable mounting structure**

#### **Field experiments with portable solar PV system**

During the first year of the study, almost all sub-project works were confined to on-station activities at BIRRI, Joydebpur. From the second year of the sub-project, field experiments were conducted in the selected farmers' fields where irrigation was being applied to Boro rice using LLPs and no solar irrigation system was available. The farmers used to cultivate rain-fed T. Aman during wet season. From each site, a group of 10 farmers were selected and from them, 2 ha of land were obtained for rice cultivation under each portable solar pump system. These farmers were provided with modern irrigation technologies and agronomic practices. Irrigation water was distributed through high quality firefighting hose pipe to reduce conveyance loss and to increase water use efficiency and water productivity during Boro season. High yielding or hybrid rice varieties were cultivated to get more yield and benefit. Standard cultural managements were followed to grow rice crops. Similarly, fertilizers were applied as per BIRRI recommendations. Data on portable solar panel performance (Solar radiation, voltage, current, power, etc.), solar pump performance (Water head, motor rpm, pump rpm, discharge, etc.), crop parameters (Crop type, variety, date of sowing, dates of intercultural operations, date of harvesting, yield etc.), soil parameters (Soil texture, number of irrigations, quantity of water applied) etc. were collected during the field experimentations.

## 10.5 Application of solar photovoltaic panel (both portable and non-portable) to operate household appliances for year-round uses during off irrigation period

### 10.5.1 BARI Component

#### Installation of solar home system in farmers' houses

The solar home system was installed in the houses of all the selected farmers. Most of the solar panels were installed on the rooftop of the house with a clear view of the sun. A battery with controller and circuit breaker was connected to the panel.

#### Installation of a water supply system

A water supply system was tested and installed in every house of the selected farmers having ponds near to their houses. A 500-liter overhead tank was used to store water for each house. The pond was used as the source of pumping water for household uses. The tank water was used for washing dishes, using in latrines, feeding cattle, bathing, washing hands and feet etc. The solar pump was also connected to a hand tube well if available in farmer's house. Solar pumps were also used for taking out water from one pond and discharge it to another for fish farming or aquaculture during off irrigation time.

### 10.5.2 BRRRI Component

#### Installation of on-grid solar home system

The solar home system was used as an on-grid system due to supply of single-phase AC current available in the selected areas except Nazirpur upazila of Pirojpur district. A single-phase grid tie inverter was used to supply AC current in the household uses. Such an *inverter* converts direct current (DC) into an alternating current (AC) suitable for injecting into an electrical power grid, normally 120 V RMS at 60 Hz. AC output power of the grid tie inverter was 3kW and the maximum efficiency was 97.2%. This inverter was compatible to the on-grid areas. A digital energy meter and a circuit breaker were connected to the load side of the users which could measure electricity production each day from solar panels (Fig 35). Seven panels out of 8 were used in the on-grid solar home system.

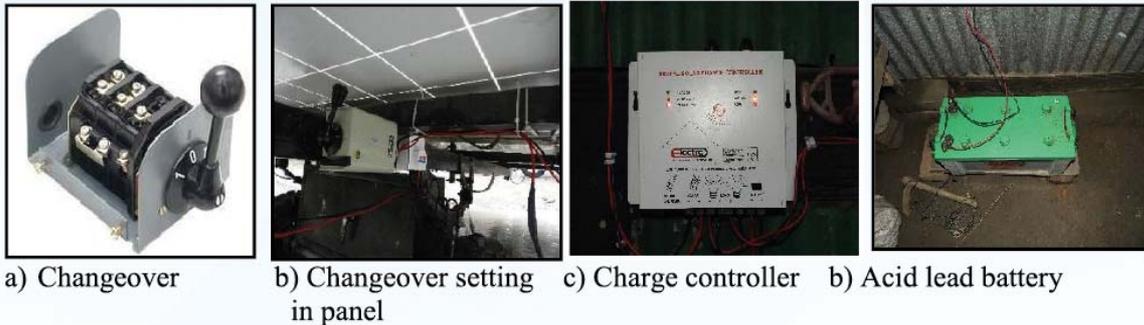


Fig. 35: Installation activities of on grid solar home system

#### Installation of off-grid solar home system

As mentioned earlier, eight panels were used for operating pump to irrigate rice in farmers' fields at each site. But out of 8 panels, only one was used for home applications for a single family when it was set in farmer's house during off-irrigation season. This panel produced 330 W delivering 24 Volts in off-grid condition. To minimize the cost, a 12 volt 100 AH acid lead battery was used. So, a special type of 10A solar charge controller was used that converted 24V to 12V suitable for operating an acid lead battery. A changeover was used to separate a single panel from the rest

seven panels. Thus, the remaining seven panels could be used in on-grid solar home system. In this system, with a single panel, two 5W LED tube lights, one DC 12V and 12W Table Fan and one 5W mobile charger were used in a farmer's house. Again, changeover consisted of a lever that comprised three options. Option '0' could be used to stop all the activities of the solar home system (Fig. 36a). Option '1' could be used to separate one solar panel from the remaining 7 panels and these 7 panels could be used as an on-grid solar home system to operate home appliances during day time on availability of grid connection in farmer's house. On the other hand, the separated one panel could be used as an off-grid solar PV system to operate home appliances at day-night by storing energy in a battery. Option '2' could be used to reconnect all the 8 panels together in series. Under this option, the irrigation pump or thresher could be operated when the solar PV system was fielded for rice irrigation.



**Fig. 36 Different devices of off grid solar home system**

#### Installation of a water supply system

A water supply system, an addition of multipurpose use of portable solar PV system, was tested as a pilot program in Sadar upazilas of Pirojpur and Jhalkati districts during the last year of the sub-project (2021). A 500-liter overhead tank was used to store water. A 10 feet high structure, made of MS angle bar was installed near the pond of the farmer's house. The pond was used as the source of pumping water for household uses. In household uses, this water was used for washing dishes, bathing, using in latrines, feeding cattle, washing hands and feet etc. Delivery pipe was reduced from 3-inch diameter at pump outlet to 2 inch and was connected to the overhead tank. Dynamic head was 15 feet (Suction head 5 feet + delivery head 10 feet). The overhead tank was connected to three supply lines. One for household uses, one for common services like bathing, washing utensils, hands & feet and the remaining one for sanitary uses (Fig 37a & b).



(a) Pirojpur Sadar upazila



(b) Jhalkati Sadar upazila

**Fig. 37: Solar energy operated water supply system**

### **Use of solar power operated BRR I thresher**

The connection mechanism of BRR I open drum thresher was the same as solar pump. Pump inverter was also used to operate the AC single phase solar thresher (Fig.38). But the motor of the thresher contained double capacitors- one is start capacitor and other is run capacitor. Both the capacitors were removed from the motor as the inverter had its inbuilt capacitor (Fig 38). Three core wire and a 15 A three pin plug were used to start the thresher.



**Fig. 38: Installation of BRR I open drum thresher in the portable solar panel**

## **10.6 Analyzing the technical and economic feasibility of solar pump for multiple uses**

### **10.6.1 Technical feasibility**

The designed solar PV system was first tested for technical feasibility in respect of panel efficiency to produce power from available sunlight, drawing water by solar pumps, expected output of the pumps at different suction lifts, suitability for irrigating field crops and the involvement of repair and maintenance costs. A comparison between solar pump and diesel pump was also made to assess the repair and maintenance of the systems. Further, farmers' feelings were also assessed as they were the principal users of the solar PV systems.

### **10.6.2 Economic feasibility**

#### **10.6.2.1 BARI Component**

Total cost of operation of solar pump, diesel engine-operated LLP and electric motor operated shallow tube well for crop production was calculated. The total cost for each of the pumping system was the sum of fixed cost and variable cost. Fixed cost was calculated as the sum of salvage value, capital consumption, shelter/taxes/insurance, repair and maintenance (1-10% of purchase price) and interest on investment.

Salvage Value (Sv) = 10% of Total Investment cost (Tic)

Where, Tic is the sum of purchase price of pump (Pp), purchase price of solar panel (Psp), installation cost (Ic), cables and accessories (c & a) and miscellaneous cost (Mc).

Capital Consumption =  $\{(Tic - Sv) * CRF\} + (Sv * i)$

Where, Tic = Total Investment cost  
Sv = Salvage value  
CRF = Capital Recovery Factor  
i = interest (10%)

$$CRF = \frac{i(1+i)^L}{(1+i)^L - 1}$$

Where, i = interest (10%)  
L = Economic life of system

Shelter/taxes/insurance = 5% of Total Investment cost (Tic)

Repair and maintenance for Solar PV = 1% of (Pp + Psp + c&a)

Where, Pp = purchase price of pump  
Psp = purchase price of solar panel  
c&a = cables and accessories

Repair and maintenance for LLP = 10% of (Pp + c&a)

Marginal Benefit Cost Ratio (MBCR) was calculated by the following equation

$$MBCR = \frac{\text{Gross Return}}{\text{Annual Operating Cost}}$$

Payback Period for solar PV pump ( $PBP_{solar}$ ) was calculated by the following equation

$$PBP_{solar} = \frac{Pp + Psp + c\&a}{Nr}$$

Where, Pp = purchase price of pump  
Psp = purchase price of solar panel  
c&a = cables and accessories  
Nr = Net return

Payback Period for Low Lift Pump LLP ( $PBP_{llp}$ ) was calculated by the following equation

$$PBP_{llp} = \frac{Pp + c\&a}{Nr}$$

Where, Pp = purchase price of pump  
c&a = cables and accessories  
Nr = Net return

Depreciation is often defined as the annual loss in value due to use, wear, tear, age, and technical obsolescence. Several methods or equations can be used to compute annual depreciation. Straight

line method was used in this study to calculate depreciation. The straight line method of calculating depreciation is widely used. The useful life of solar pump and diesel engine-operated pump was assumed to be 20 years and 5 years, respectively. Annual interest rate was considered 10 % of the capital price of the pump.

Net present value (NPV) was calculated by using the following equation

$$\text{NPV} = \text{PW of benefit at 10\% DF} - \text{PW of cost at 10\% DF}$$

Where, PW = Present worth  
DF = Discounted factor

The aim of this economic study is to compare the economic viability of PV water pumping systems with LLP and shallow tube well. To investigate investment prospects of PV water pumping applications, internal rate of return (IRR) is used as an indicator of sub-project profitability. Internal rate of return is defined as the interest rate at which present worth of the cash flows of a sub-project are zero. Internal rate of return higher than the market interest rate means profitable investment. internal rate of return (IRR) is expressed using the following equation.

$$\text{IRR} = \frac{\text{Cashflow}}{(1+r)^t} - \text{initial investment}$$

Where, IRR= The internal rate of return  
r= discount rate, and  
t=The number of time periods.

The sub-project cost was the sum of capital cost and operating cost of solar PV pumping system. The cash inflow of the sub-project comes from custom hire of irrigation service to the farmers. The pump hiring rate is considered equal for both diesel pump and solar pump.

#### **10.6.2.2 BRRI Component**

Assessment of costs and benefits of portable solar pump in the sub-project areas was done using information obtained from field experiments and secondary sources. Field experiments were conducted at 6 upazilas of 3 districts in the southern region of Bangladesh in the years 2019 and 2020. Primary data were collected from these field experiments. Secondary data collected from various sources were used in the analysis of economic feasibility. Annual operating costs and returns were calculated, and the sub-project financial profitability was determined. Four on-farm financial measurement techniques namely, benefit-cost ratio (BCR), net present value (NPV), internal rate of return (IRR), payback period (PBP) were used in the analysis. The economic performances of solar pumps to irrigate Boro rice, operate small agricultural machinery and run household appliances were subsequently compared. These were also compared with a locally used diesel pump.

#### **Economics of solar and diesel pumps**

The total cost of pump operation at farm level consists of fixed cost (FC) and variable cost (VC). Fixed costs included depreciation, interest on investment, shelter, taxes, insurance and housing costs. Variable costs included (for diesel pump) the costs of fuel, lubricant, operator's salary, labors, repair and maintenance and miscellaneous expenses whereas the variable costs for solar pump was the cost of operator's salary, labor cost and miscellaneous expenses. There was no repair and maintenance cost in solar pump operation. The repair and maintenance cost of solar

pump was much less and negligible. A comparison was made between solar and diesel operated pumps in respect of economic feasibility.

### Fixed costs

Fixed cost is defined as one, which does not change when level of output alters (i.e., it applies to a resource that is fixed in quantity). Fixed costs are expenses incurred regardless of whether the pump is operated or not including depreciation (D), interest on investment (I), shelter, taxes and insurance (STI). Fixed costs are fixed in total, but decline per unit of area, as the annual use of the machine is increased (Barnard and Nix, 1980). In the calculation of fixed cost, the following equation was used (Hunt, 2001).

Total fixed cost per year,  $FC_{yr} = D+I+STI$

Where,  $FC_{yr}$  = Total fixed cost, BDT  $yr^{-1}$ ; D = depreciation, BDT  $yr^{-1}$ ; I = interest on investment (bank interest rate on agricultural loans), BDT  $yr^{-1}$ ; STI = shelter, tax and insurance, BDT  $yr^{-1}$ ;

$$\text{Fixed cost per ha, } FC_{ha} = \frac{FC_{yr}}{A_{ha}}$$

Where,  $A_{ha}$  = Land area, ha (1 ha = 7.5 bigha).

**Depreciation, (D):** It is the measure of the amount by which value of the machine decreased with passage of time. In the calculation of fixed cost, sinking-fund depreciation was used and it was calculated by the following equation, (Hunt, 2001):

$$D = \left[ (p - s) \left\{ \frac{(1+i)^L - (1+i)^n}{(1+i)^L - 1} \right\} + s \right] - \left[ (p - s) \left\{ \frac{(1+i)^L - (1+i)^{n+1}}{(1+i)^L - 1} \right\} + s \right]$$

Where,

D = depreciation, BDT  $yr^{-1}$ ;

p = purchase price, BDT;

S = salvage value (10% of p), BDT;

L = Effective working life of machine, yr.;

n = age of the machine in years at the beginning of the year, yr.;

i = annual bank interest rate, decimal.

**Interest on investment, (I):** It is the interest generated from the capital money spent for buying the machine which could be used elsewhere to get the maximum return. The interest on investment in pump was included in fixed cost estimation. Interest on investment was the charge for the use of the money invested on the pump regardless of whether the money was borrowed or not. The interest rate was set to 14% as representing a current average rate for capital interest calculation in Bangladesh (Mottalib et al. 2019). The following equation was used for the calculation of interest on invest (Hunt, 2001)

$$I = \frac{P+S}{2} \times i$$

**Taxes, Shelter and Insurance (STI):** In the calculation, shelter, tax and insurance were considered for calculating fixed cost of the solar pump system (Hunt, 2001).

$$STI = 2.5\% \text{ of } P$$

### Variable cost

Variable costs were the expenses incurred as a result of pump operation and crop production (power costs, labor, and other inputs). Variable costs included hourly labor cost, fuel, oil, repair and maintenance cost and the production costs like seed cost, fertilizer cost, and the land use cost. Also the required working hour for each of the field operations was needed. The cost of operator/labor was calculated as the labor rate in BDT per day. The fuel and oil costs were estimated from consumption rate and multiplied by their respective prices. In calculation of variable cost the following equation was used (Hunt, 2001).

$$\text{Variable Cost for solar pump } VC_s = L_b + Mc$$

$$\text{Variable Cost for diesel pump } VC_d = F + O\&L + R\&M + Mc$$

$$\text{Variable cost for production of rice } VC_p = L_b + C_f + C_s + C_c + C_p + C_l + C_t$$

Where,

$L_b$  = Operator/labor cost

$C_f$  = Cost of fertilizer

$C_s$  = Cost of seed

$C_c$  = Cost of cultivation

$C_l$  = Land use cost

$C_p$  = Transplanting cost

$C_t$  = Threshing cost

$F$  = Fuel cost

$O\&L$  = Oil & lubricant cost

$R\&M$  = Repair and maintenance cost per year

$Mc$  = Miscellaneous cost, BDT.

### Annual cost of operation

Operating costs are recurring costs that are necessary to operate and maintain a pump during its useful life (White et al., 1989). Total cost of operations of solar pump and diesel pump was divided into fixed costs and variable costs. All calculated fixed costs and variable costs were converted into BDT per ha (1 ha = 7.5 bigha) and then summing up of fixed costs and variable costs, the operating cost was given in BDT per ha based on the average field data of solar pump and diesel pump operations.

$$\text{Annual cost (BDT ha}^{-1}\text{), } AC = FC + VC$$

where, AC = Annual cost, FC = Fixed cost and VC = Variable cost.

### Payment for replacement

Uniform annual payments to a fund are of such a size that by the end of the life of the pump, the funds and their interest have accumulated to an amount that can be used to purchase another pump. Payment for replacement was calculated by the following equation (Hunt, 2001).

$$PFR = (P - S) \times \frac{i}{(1+i)^l - 1}$$

Where, PFR = Payment for replacement per year

### Sub-project appraisal

For achieving the objectives of the study, the sub-project appraisal technique has been followed to find out the profitability of solar pump. Sub-project appraisal provides a comprehensive review of all aspects of the sub-project. It includes economic and financial analysis, analysis of economic

soundness of the sub-project, quantification and evaluation of costs and benefits and ensuring financial viability. This appraisal is based on three assumptions which are (1) All the devices are purchased with cash; (2) Operation technology is remaining unchanged throughout the sub-project life; (3) Prices of all inputs and outputs are remaining the same throughout the sub-project life and conversion rate of BDT was used for the year 2019. The methods most often used for evaluating a project are (Sarma, 2010):

- a) Benefit-cost ratio (BCR)
- b) Net present value (NVP) or Net present worth (NPW)
- c) Internal rate of return (IRR)
- d) Payback period

### **Benefit-cost ratio**

Benefit-cost ratio (B/C ratio) may be defined as the ratio of benefits to costs (expressed either in percent or annual worth). If the B/C ratio is greater than unity, then it will be economically accepted. It follows the systematic approach used in selecting between economic investments alternatives. The equation was used in the calculation of BCR (Gittinger, 1994).

$$BCR = \frac{\Sigma \text{Present worth of Benefits (PWB)}}{\Sigma \text{Present worth of Cost (PWC)}}$$

### **Net present value**

The NPV is a scientific method of calculating the present value of cash flows, both inflows and outflows of an investment proposal, using a discount rate and subtracting the present value of outflows to get the net present value. NPV was calculated by using the following formula:

$$NPV = PWB - PWC$$

Where, PWB = Present worth of benefits; and  
PWC = Present worth of costs.

### **Internal rate of return**

The IRR is called Discount Cash Flow (DCF) yield or DCF return on investment or effective rate of interest method or marginal efficiency of capital. The IRR is the value of discount factor when the NPV is zero. The IRR is also a relative measure which may be defined as the average earning power of the money invested in a project over the project life. It is considered to be the most useful measure of sub-project worth. It represents the average earning power of the money used in the sub-project over the sub-project life. The IRR is not affected by the rate of discount, while the NPV may change as a result of using different discount rates (George and Shorey, 1978; Miah and Hardaker, 1998). It is the maximum interest that a project can pay for the use of resources if the project is to recover its investment and operating cost and still break even. At this point, the BCR is equal to unity. This is usually found by trial and error, by interpolation and using following equation

$$IRR = [LIR + (HIR - LIR) \times \frac{NPV_{LIR}}{NPV_{HIR} - NPV_{LIR}}]$$

Where, LIR = lower interest rate and HIR = higher interest rate.

### **Payback period**

The payback refers to the time period within which the costs of investment can be covered by revenues. In other words, it is the length of time required for the stream of cash proceeds produced

by an investment to equal the initial expenditure incurred. This was computed by applying the following formula:

$$\text{Payback period} = \text{Investment (Initial total, BDT)} / \text{Net benefit (BDT/yr)}$$

## 11. Results and discussion

### 11.1 Baseline Survey

Baseline surveys were conducted in some southern districts of Bangladesh by both BARI and BRRI components before designing the solar PV system. The information of the survey works, especially, the socioeconomic conditions of the farmers like literacy, total land area, types of lands, cultivable land, irrigation modes, crops grown etc. helped in the design. Component wise information are given below.

#### 11.1.1 BARI Component

This component, as mentioned earlier, conducted their baseline surveys in Patuakhali, Barguna and Bhola districts. The selected upazilas were Kalapara and Galachipa of Patuakhali, Sadar and Amtali of Barguna and Charfashion and Lalmohan of Bhola districts.

#### Socio-economic profile of farmers

The socio-economic profile of farmers in the selected areas is shown in Table 14. Almost all types of agricultural operations were performed by male farmers and a few were done by female farmers. A maximum of 75 years old male farmer was interviewed in Barguna Sadar and a minimum of 22 years old male farmer was interviewed in Char Fasson upazila of Bhola district. Among the six upazilas, about 38.37 % farmers were around 31 to 40 years old, 24.53 % were 41 to 50, 16.98 % were 51 to 60, 11.32 % were 22 to 30, 7.55 % were 61 to 70 and rest 1.26 % were around 75 years old.

**Table 14: Socio-economic profile of farmers in the selected areas in Patuakhali, Barguna and Bhola districts**

Items	Patuakhali		Barguna		Bhola		Mean of all (180)	
	Kalapara (30)	Galachipa (30)	Sadar (30)	Amtali (30)	Char Fasson (30)	Lalmohon (30)		
Age of farmers (Years)	47	40	42	45	43	48	45	
Education	Illiterate (%)	0	8.70	0	0	10.35	12.41	5.24
	Primary (%)	100	82.60	92.30	89.65	79.3	24.14	78
	Secondary (%)	0	4.35	3.85	0	0	0	1.37
	Higher secondary (%)	0	4.35	3.85	6.90	3.45	0	3.09
	Degree and higher (%)	0	0	0	3.45	6.90	3.45	2.30
Total land area (decimal)	250	360	162	303	165	231	245	
Homestead area (decimal)	50	44	36	33	40	45	41	
Cultivable land (decimal)	175	266	141	240	129	149	183	
Area under vegetable (decimal)	45	48	42	38	54	62	48	
Area under watermelon (decimal)	85	47	23	38	56	45	49	

Almost all categories i.e. primary, secondary, higher secondary, degree and higher educated farmers were available in the surveyed areas. There was no illiterate farmer in Kalapara, Amtali

and Barguna Sadar upazilas. Average literacy in study areas was 94.76% which was much higher than the national literacy rate of 72.90% (Dhaka Tribune, 2018). Among six upazilas, almost all of the surveyed farmers had primary education. In Kalapara upazila of Patukhali district, the interviewed farmers had 100% primary education without any higher education. The maximum degree and higher qualified farmers were found from Char Fasson of Bhola district. However, the number was smaller but higher than any other surveyed upazila. On the other hand, educational background was found very poor in Lalmohon upazila. Most (72.41%) of them were illiterate. Out of 166 farmers surveyed in six upazilas, 75.90 % had primary education, 15.07 % had no education, 2.41% had secondary education, 3.61% had higher secondary and rest 3.01 % had degree and higher studies.

Average land holding and homestead land area in the study areas were found to be about 1.0 ha (2.45 acre) and 0.17 ha (41 decimal), respectively. The cultivated land area was about 75% (1.83 acre). The vegetable cultivation areas varied from 42-62 decimals and the average area was 48 decimals in all study areas. Among the surveyed areas, the highest vegetables production was found in Lalmohan upazila of Bhola district and the lowest was in Barguna Sadar upazila. Water melon was found a popular cash crop and was cultivated in all locations of the study areas.

### Land type

Land type in the selected locations in the study areas is shown in Table 3. Different types of lands i.e. high lands, medium high lands, medium low lands, low lands and very low lands were found in the study areas. All the high lands were used for production of different types of vegetables. Aman rice was found to grow in all types of lands. Boro rice cultivation was found in high land, and medium high land where irrigation facility and fresh water was available. Rabi crops such as mungbean, cowpea, grasspea, sunflower, etc. were found to grow generally under rainfed condition.

Table 15 reveals that in Kalapara upazila of Patuakhali district, most of the land is medium high land (99.6%). Only 133 ha of land (0.4%) is high land. There is no medium low land in this upazila. In Galachipa upazila, 83.1% land is medium high land and 16.2% land is under medium low land. Area of high land (0.7%) is also less in Galachipa upazila of Patuakhali district. Similar land types exist in Amtali upazila of Barguna district. But, in Sadar upazila of Barguna district, high land is higher (4.0%) than Amtali upazila (0.8%). In Bhola district, high lands are higher than those of Patuakhali and Barguna upazila. Medium high lands are above 55%. High land and medium high lands are suitable for vegetable production (Table 15).

**Table 15: Land types in the selected locations in the sub-project areas**

Locations		High land area		Medium high land area		Medium low land area		Low land area	
District	Upazila	ha	%	ha	%	ha	%	ha	%
Patuakhali	Kalapara	133	0.4	35266	99.6	0	0.0	0	0.0
	Galachipa	430	0.7	49983	83.1	9769	16.2	0	0.0
Barguna	Sadar	1047	4.0	25277	96.0	0	0.0	0	0.0
	Amtali	342	0.8	39887	89.6	4283	9.6	0	0.0
Bhola	Lalmohon	10700	21.4	27854	55.9	10296	20.7	1046	2.0
	Char Fasson	14322	18.6	44815	58.2	17248	22.4	6160	0.8

As regards to the primary objective of irrigation, the soil and crop of the sub-project areas are the main concerns. In the central coastal region, most of the soil is clay loam. The soil conditions of the sub-project areas in different upazilas are given in Table 16.

**Table 16: Soil texture of the sub-project areas**

Sub-project areas		Soil texture
Patuakhali	Kalapara	Clay loam
	Galachipa	Clay
Barguna	Barguna Sadar	Clay loam
	Amtali	Clay loam
Bhola	Lalmohon	Sandy loam
	Char Fasson	Loamy

**Crops and cropping patterns**

Major cropping patterns in the selected locations in Patuakhali, Barguna and Bhola districts are given in Table 17. As found from the table, farmers followed the cropping pattern, Rabi crops – Fallow - T.Aman in about 70% areas under Sadar upazila of Barguna district. But in Amtali upazila, 60% area was covered by Rabi crops -T. Aus - T. Aman cropping pattern. In both Sadar and Amtali upazila of Barguna district, 10% area was covered by vegetables (Vegetables-Fallow-T. Aman). In the study areas, Rabi crops included mungbean, cowpea, grass pea, maize, wheat, etc. and vegetables included cabbage, cauliflower, radish, hyacinth bean, yardlong bean, sweet gourd, bottle gourd, ash gourd, cucumber, ribbed gourd, teasel gourd, snake gourd, watermelon, potato, brinjal, tomato, chilli, red amaranth, sweet potato, spinach etc. Rabi crops –Fallow -T. Aman cropping pattern was practiced in most of the areas in Kalapara (70%) and Galachipa (60%) upazilas of Patuakhali district. In Patuakhali, Boro –Fallow -T. Aman cropping pattern was practiced in 25-30% areas. In Kalapara and Galachipa, vegetables-based cropping pattern (Vegetables-Fallow-T. Aman) was found to practice in 5% and 10% areas, respectively. Boro – Fallow -T. Aman cropping pattern was practiced in 55% and 60% cropped areas in Char Fasson and Lalmohon upazila of Bhola district. In these two upazilas, vegetables-based cropping pattern was 15%, which was a little higher than any other upazila.

**Table 17: Major cropping patterns in the selected locations in Patuakhali, Barguna and Bhola districts**

Locations		Cropping pattern	Area coverage (%)
Barguna	Sadar	Rabi crops-T. Aus- T. Aman	20
		Rabi crops -Fallow-T. Aman	70
		Vegetables-Fallow-T. Aman	10
	Amtali	Rabi crops -T. Aus- T. Aman	60
		Boro-Fallow-T. Aman	30
		Vegetables-Fallow-T. Aman	10
Patuakhali	Kalapara	Rabi crops -Fallow-T. Aman	70
		Boro-Fallow-T. Aman	25
		Vegetables-Fallow-T. Aman	5
	Galachipa	Rabi crops -Fallow-T. Aman	60
		Boro-Fallow-T. Aman	30
		Vegetables-Fallow-T. Aman	10
Bhola	Char Fasson	Boro-Fallow-T. Aman	55
		Rabi crops -T. Aus-T. Aman	30
		Vegetables-Fallow-T. Aman	15
	Lalmohon	Rabi crops -T. Aus-T. Aman	25
		Boro-Fallow-T. Aman	60
		Vegetables-Fallow-T. Aman	15

Different varieties of field crops were found to produce in different locations of the southern region of Bangladesh. Farmers mainly grow local Aus varieties like Abdul Hye, Kalisaittya, Sri Bailam etc. BRRI dhan 52, BRRI dhan23, BRRI dhan49 and BRRI dhan51 were grown successfully in Aman season. BRRI dhan53, BRRI dhan29, and BRRI dhan28 were found to be grown in Boro season. Aman was found to practice in all the surveyed locations as a rain fed crop. Area of Boro rice production was found different in different surveyed places. Except Barguna Sadar, Boro rice was found to be grown in all other surveyed places. Aus rice production was found only in Barguna district because Boro rice cultivation was more profitable than Aus. Among other cereal grains, maize was also found to be grown only in Galachipa of Patuakhali district. As a cheap and available source of protein, different types of pulses i.e. grass pea, mungbean, cowpea were found to be grown in almost all surveyed upazilas. Vegetables and spices were found to grown in all surveyed areas with more intensive cultivations in Char Fasson and Lalmohon upazilas of Bhola district. Water melon and sweet potato was also found to be grown in the surveyed places.

### Irrigation scenario

Irrigation status in the selected areas of Patuakhali, Barguna and Bhola districts is given in Table 18. Different types of diesel-powered pumps were found in the surveyed places. Solar pump was not found in operation due to the lack of knowledge in solar technology as well as available facilities. Average price of a 4.0 hp diesel operated low lift pump cost Taka 21258. The average fuel consumption was found 1.10 L/h with the maintenance price of Taka 2836 per machine per season. All the pumps were centrifugal type low lift pumps and used only for surface water irrigation. Plastic hose pipe was used for the conveyance of irrigation water to the crop fields from canals or ponds. Irrigation cost was found different in different upazilas. The average irrigation cost of Boro rice was found Tk.1033/- per bigha (.134 ha) (33 decimal) per season for the owner of the pump. But for the hirer of the irrigation pump for Boro rice production, the irrigation charge was found Taka 1680 per bigha (.134 ha) per season. Irrigation charge for Aus rice, vegetables and watermelon was found Taka 128 per hour in all the study places except Bhola district.

**Table 18: Irrigation status in the selected areas in Patuakhali, Barguna and Bhola districts**

Items		Patuakhali		Barguna		Bhola		Mean of all
		Kalapara	Galachipa	Sadar	Amtali	Char Fasson	Lalmohon	
Pump	LLP (%)	100	100	100	100	100	100	100
	Diesel (%)	100	100	100	100	100	100	100
	Power (hp)	6.5	7.3	5.33	4.5	8.32	10.50	7.08
	Owner (%)	19.23	34.48	11.54	17.39	17.25	10.35	18.37
	Hire (%)	80.77	65.52	88.46	82.61	82.75	89.65	81.63
	Price of pump (Tk.)	19700	22350	18333	10333	27000	29833	21258
	Fuel consumption (L/h)	1.03	1.21	0.872	0.792	1.22	1.5	1.10
	Operating time (h)	8.5	9.5	10	9	9.85	10.35	9.50
	Diesel price (Tk./L)	67	70	70	70	71	70	70
	Maintenance cost (Tk/season)	2400	3260	2333	1625	3600	3800	2836
Source of irrigation water	Canal (%)	85	73	90	65	87	74	79
	Pond (%)	15	27	10	35	13	26	21
Water surface available in dry season (m) from lands		3.04	2.90	1.59	1.15	1.48	1.27	1.91
Irrigation cost of Boro rice (Tk/Bigha/Season)	Pump owner's cost	970	870	-	1650	775	900	1033
	Hirer's cost	1400	1350	-	2000	1650	2000	1680

\*1 Bigha = 0.134 ha

Water sources with fresh water were found available in all upazilas. A minimum water depth of 1.91m was always available during dry season in all the water sources over the surveyed areas. Different types of local sluice gates were used during tidal waves to prevent the saline water intrusion into the fresh water. Some farmers also used pond water for irrigation in the crop fields.

### Solar power use in sub-project area

Status of solar power use in the selected areas of Patuakhali, Barguna and Bhola districts is given in Table 19. Solar power was found very popular by the people of all upazilas in solar home systems (SHS). The people installed the solar home system from some NGOs such as Grameen shakti, RDF, Reneta, BRAC, Roller and local service providers. All the solar panels were installed on the roof top of farmer's house, not on the land. The average price of a SHS (Solar Home System) package of 40 W<sub>p</sub> panel capacity with 3 DC light and 1 DC fan was found Taka 31670 five years ago. At present the price of 40 W<sub>p</sub> solar home system has been reduced to Taka 17000 (42.31% decrease). Now-a-days, all the solar home systems are supplied and installed by NGOs financed by the local government Kabikha project. There was no single solar pump in the selected areas. Here, diesel powered low lift pumps were used for irrigation. Almost, 100% farmers expressed their keen interest in solar pump irrigation and in other uses, such as, solar home system, operation of small farm machinery, household appliances, TV and mobile charging. On the other hand, electricity users were found only in Lalmohon upazila.

**Table 19: Status of solar power use in the selected areas in Patuakhali, Barguna and Bhola districts**

Items		Patuakhali		Barguna		Bhola		Mean of all
		Kalapara	Galachipa	Sadar	Amtali	Char Fasson	Lalmohon	
Purpose of using solar energy	Irrigation (%)	0	0	0	0	0	0	0
	SHS (%)	100	100	100	100	100	100	100
Location of solar panel	On roof (%)	100	100	100	100	100	100	100
	On land (%)	0	0	0	0	0	0	0
Panel capacity (Wp)		28.78	32.45	40.35	35.62	30.15	35.37	39.00
DC fan, Pieces/family		1	1	2	2	1	1	1
DC tube light, pieces		3	3	5	4	2	3	3
Price of the SHS package, Tk (5 years before)		26500	31500	36000	33000	30000	33000	31670
Present price of the SHS package, Tk (2018)		18000	18000	16000	15000	18000	17000	17000
SHS service providers		Grameen Shakti, RDF, Reneta, BRAC, Roller						

### 11.1.2 BRRI Component

BRRI component also conducted baseline survey in their study areas of Bakergonj and Uzirpur upazilas of Barishal district, Sadar and Nalcity upazilas of Jhalkati district and Sadar and Nazirpur upazilas of Pirojpur districts. Almost the same information as of BARI component were collected by BRRI component.

### Socio-economic profile of farmers

Almost all types of agricultural activities were performed by male farmers and only a few by female farmers. A total of 30 respondents from each upazila were interviewed through pre-tested questionnaire. The age range among the farmers was 25 to 65 years. Among six upazilas about

46.33 % farmers were found 25 to 40 years old, 30.0% were 41 to 50 years, 16.67 % were 51 to 60 years and rest 6.67 % were around 61 to 65 years old. Female farmers were mostly found engaged in post-harvest activities

**Table 20: Age, literacy, land area and crops cultivated by the farmers in the selected study areas**

Items	Barishal		Jhalkati		Pirojpur		Mean (180)	
	Bakerganj	Uzirpur	Sadar	Nalcity	Sadar	Nazirpur		
Respondents	30	30	30	30	30	30	30	
Age of farmers (Years)	45	40	43	42	47	48	44	
Education	Illiterate (%)	10.00	0.00	0.00	6.67	0.00	26.67	7.22
	Primary (%)	70.00	63.33	66.67	76.67	80.00	60.00	69.45
	Secondary (%)	13.33	20.00	16.67	13.33	10.00	10.00	13.89
	Higher Secondary (%)	6.67	13.33	10.00	3.33	6.67	3.33	7.22
	Degree and Higher (%)	0.00	3.33	6.67	0.00	3.33	0.00	2.22
Total land area (decimal)	1150	750	850	950	1658	1260	1103.0	
Cultivable land (decimal)	1050	710	775	900	1570	1140	1034.5	
Area under Boro (decimal)	746	450	650	550	1250	550	699.33	
Area under Aman (decimal)	1050	670	775	850	1510	850	950.83	
Area under non-rice (decimal)	150	175	125	250	100	450	208.33	

From Table 20 it is found that almost all categories i.e. primary, secondary, higher secondary, degree and higher educated farmers were available in the surveyed areas. There were a few illiterate farmers in Bakerganj, Nalcity and Nazirpur upazilas. Average literacy in the study area was found 92. 8% which was much higher than the national literacy rate of 72.90 % (Dhaka Tribune 2018). Among six upazilas, almost all of the surveyed farmers had primary education. The farmers of Pirojpur sadar upazila had the highest primary level education whereas the Nazirpur upazila of the same district had the lowest level of primary education. The degree and higher qualified farmers were found maximum in sadar upazila of Jhalkati district but the number was limited. On the other hand, educational background was poor in Nazirpur upazila with 26.67% illiterate. A total of 180 farmers were interviewed in the surveyed upazilas. Among them 69.45 % had primary education, 7.22 % were illiterate, 13.89 % had secondary, 7.22 % were qualified up to higher secondary and rest 2.22 % were degree and higher study holders (Table 20).

### Land type

From Table 21, it appears that most of the land (79.6%) in the sub-project areas falls under medium high and medium low lands in Bakergonj upazila of Barishal district. Similarly, 74% land of Uzirpur upazila of the same district is occupied by medium high and medium low lands. In both Bakergonj and Uzirpur upazias, the lowest land coverages were, respectively, 7.1% and 10%. Similar trend was found in sadar upazila of Pirojpur district with 88% land under medium high and medium low lands. But the maximum land coverage in Nazirpur upazila of Barishal district was found from medium high and low land areas (78.1%). In Jhalkati sadar upazila, 90% land falls under medium high and medium low lands. Similar topography was found in the lands of Nalcity upazila of Jhalkati district with 95.4% lands under medium high and medium low lands. This indicates that most of the lands in all the selected upazilas are suitable for agricultural crop productions.

**Table 21: Land types in the selected locations in the Sub-project areas**

Locations		High land area		Medium high land area		Medium low land area		Low land area	
District	upazila	ha	%	ha	%	ha	%	ha	%
Barishal	Bakerganj	2410	7.1	15675	46.2	11315	33.4	4510	13
	Uzirpur	1910	10	9250	49.5	4550	24.5	3010	16
Pirojpur	Sadar	3546	4.4	49199	59.5	23388	28.5	6281	7.6
	Nazirpur	680	4	3050	17.9	9890	58.1	3400	20
Jhalkati	Sadar	1077	6.8	4625	29.6	9438	60.4	497	3.2
	Nalcity	710	4.6	13550	88.6	1040	6.8	0	0

As regards to the primary objective of irrigation, the soil and crop of the sub-project areas are the main concerns. In the central coastal region, most of the soil is clay loam. The soil conditions of the sub-project areas in different upazilas are given in Table 22.

**Table 22: Soil condition of the sub-project areas**

Sub-project areas		Soil condition
Barishal	Bakerganj	clay-loam
	Uzirpur	clay-loam/ sandy loam
Jhalakati	Jhalakati sadar	Loam
	Nalcity	clay-loam
Pirojpur	Pirojpur sadar	clay-loam
	Najirpur	Sandy loam

### Crops and cropping pattern

Lands in the coastal regions usually get inundated due to tidal water. In the sub-project areas, lands do not get submerged in the Boro season. Soil moisture content remains high even in the month of January (Rabi crops season) and the water from the inundated lands recedes slowly. As a result, it is difficult to cultivate non-rice crops in the sub-project areas. Some farmers cultivate blackgram, mungbean, potato, jute, sesame, grass pea and mustard in the areas (Table 23).

**Table 23: Cropping patterns in the sub-project areas**

Sub-project area		Cropping pattern	Land coverage (%)
Barishal	Bakerganj	Aman-Boro-black gram	50
		Aman-Mung bean-Aus	25
		Aman-Sesame-Aus	25
	Uzirpur	Aman-Boro-Fallow	50
		Aman-Masterd-Jute	25
		Aman-potato-jute	25
Jhalkati	Jhalkati sadar	Aman-Boro-Fallow	55
		Aman-Boro-black gram	25
		Aman-Boro-pulse	20
	Nalcity	Aman-Boro-Fallow	100
Pirojpur	Pirojpur sadar	Aman-Boro-Fallow	90
		Aman-Boro-Aus	10
	Nazirpur	Aman-grass pea-jute	50
		Aman-boro-fallow	30
		Fish-Boro-fallow	20

The cropping intensity in the sub-project area varies from 200% to 300%. Cropping pattern differs depending on soil, crop, environment and facilities available in the areas. Existing cropping patterns of the sub-project areas along with their land coverage are given in Table 23.

It is seen that, Aman and Boro cultivation is in practice in the sub-project areas, but Aus cultivation is not a common practice. Some sub-project areas don't have Aus production at all. Also, the cultivation of local varieties of rice is significant, especially in Aman season. The varieties cultivated in the sub-project areas are given in Table 24.

**Table 24: Rice varieties cultivated in the sub-project areas**

Sub-project areas		Aus	Aman	Boro
Barishal	Bakerganj	BRRRI dhan 48, BRRRI dhan 27, BR 18	Local, BRRRI dhan 56	BRRRI dhan 47, BRRRI dhan 21, BRRRI dhan 28, Binadhan 10
	Uzirpur	-	BR-11, BRRRI dhan 23, BRRRI dhan 52, Local	Hybrid, BRRRI dhan 29, BRRRI dhan 29
Jhalakati	Sadar	-	BRRRI dhan 52, Local	BRRRI dhan 28, BRRRI dhan 29, BRRRI dhan 47
	Nalcity	-	Local, BR-8	BRRRI dhan 28, BRRRI dhan 29
Pirojpur	Sadar	BRRRI dhan 48, Local	Local	BRRRI dhan 28, Hybrid
	Najirpur	Vegetable, Wheat	BRRRI dhan 52, Hybrid, Local	BRRRI dhan 28, Hybrid

#### **Irrigation scenario**

Farmers in the sub-project areas depend on surface water for irrigation. This makes the use of low lift pump (LLP) convenient for the farmers. In the selected sub-project areas, irrigation in the Aman season is insignificant. Farmers irrigate in the Boro season. Most of them irrigate lands by hiring diesel powered pumps. Compared to the number of service providers, pump owners are small in number.

As revealed from Table 25, only LLPs were found to use in the selected upazilas and all of them were diesel operated. The pump horse power ranged from 3 to 6. The pumps of Jhalokati sadar upazila were of 3 hp. Those in Nalcity were of 6 hp and all other upazilas of 4 hp. Mostly, the pumps were used on hiring basis (90-99%) in the upazilas. Based on the power (hp) of the pumps, the prices varied from Tk.14000.00 to Tk.20000.00 per pump for 4 to 6 hp, respectively. A large variation in operating hours of the pumps per day was found ranging from 6 to 12 hours.

The repair and maintenance cost of pumps were found to vary from Tk.1300.00 to Tk.3000.00 with the highest (Tk.3000.00) in Bakerganj, Nazirpur and Jhalokati sadar and the lowest in Nalcity (Tk.1300.00). For these LLPs, about 92.44% water sources were canals and 7.56% were local ponds.

The highest irrigation cost was observed at Nalcity upazila of Jhalkati district, whereas, the lowest cost was found in Sadar upazila of Pirojpur district (Table 25). These estimates were made on the basis of pump hiring. When it was done on pump owning basis, the highest irrigation cost was found at Nazirpur upazila of Pirojpur district and the lowest at Nalcity of Jhalkati district (Table 25). These costs varied on the number of irrigations and some other variables.

**Table 25: Irrigation status in the selected areas in Patuakhali, Barguna and Bhola districts**

Items		Barishal		Pirojpur		Jhalkati		Mean of all
		Bakerganj	Uzirpur	Sadar	Nazirpur	Sadar	Nalcity	
Pump	LLP (%)	100	100	100	100	100	100	100
	Diesel (%)	100	100	100	100	100	100	100
	Power (hp)	4	4	4	4	3	6	6.7
	Owner (%)	3	5	5	10	5	1	4.83
	Hire (%)	97	95	95	90	95	99	95.17
	Price of pump (Tk.)	15000	14000	15000	14000	16000	20000	15666.7
	Fuel-use by engine(L/h)	1	1	0.5	0.5	0.75	1	0.792
	Operating time (h)	6	7	10	12	8	6	8.17
	Diesel price (Tk./L)	65	70	70	65	70	70	68.34
	R&M cost, Tk/season	3000	1500	2000	3000	3000	1300	2300
Source of irrigation water	Canal (%)	88.4	86.5	94.7	93.56	95.2	96.3	92.44
	Pond (%)	14.6	13.5	5.3	6.44	4.8	3.7	7.56
Water available in dry season (m)		1.5	2	1	1.25	1.25	1.5	1.42
Irrigation cost of Boro rice (Tk/Bigha /Season)*	Own cost	1150	1150	900	1200	1050	800	1041.7
	Hiring cost	1400	1200	1050	1500	1350	1550	1341.7

\*1 acre = 3 bighas

Almost all the sub-project areas had enough water for irrigation in the dry season (Boro season) ranging from 1.0 to 2.0 m depths in the canals. The exception was that Uzirpur of Barishal district faced slight water scarcity due to absence of available water depth in the canal during the dry season. Irrigation water in the sub-project areas was non-saline. The irrigation pump hiring system mainly involved hour basis or contract basis. Depending on them, the cost of irrigation varied to some extent. Table 26 shows the seasonal irrigation cost of Boro and Aman rice in the selected areas. In Aus season, farmers don't irrigate their crop fields.

**Table 26: Irrigation cost in Boro and Aman season**

Season	Ownership type	Irrigation cost (Tk/Bigha/season)					
		Barishal		Jhalkati		Pirojpur	
		Bakerganj	Uzirpur	Sadar	Nalcity	Sadar	Nazirpur
Boro	Pump owner	1155	1155	1056	806	938	1200
	Hourly basis	1389	-	-	-	1071	1514
	Contract basis/crop sharing	-	1206 or 1/8 of rice	1330	1/5 of rice	-	-
Aman	Pump owner	-	-	-	-	-	480
	Hourly basis	-	-	-	-	-	-
	Contract basis	-	-	-	-	-	-

\*1 Bigha = 0.134 ha

### Solar power use in sub-project area

Status of solar power uses in the selected areas of Barishal, Jhalkati and Pirojpur districts is given in Table 27. Solar power was found very popular by people of all upazilas as solar home system (SHS). Although the five of selected six upazilas had on-grid facility, they still use solar power for SHS due to frequent load shedding. The people installed the solar home systems from some NGOs like Grameen Shakti, Hilphul Phuzol, BRAC, Breeze and some local service providers. All the solar panels were installed in the roof top of farmers' houses. Only five years ago, the average price of a SHS package of 18 Wp panel capacity with 2 DC light and 1 DC fan was found Taka 20500. At present the price of the

same capacity solar home system has come down to Taka 13500.00 which is 34.15 % of the previous price. Almost 100 % farmers desired to adopt solar pumps for irrigation, operation of small farm machinery and household appliances (TV, DC Fan, LED Light and mobile phone chargers).

**Table 27: Status of solar power use in the selected areas in Barishal, Jhalkati and Pirojpur districts**

Items	Barishal		Jhalkati		Pirojpur		Mean
	Bakerganj	Ujirpur	Sadar	Nalcity	Sadar	Najirpur	
Irrigation purpose. (%)	0	0	0	0	0	0	0
Household purpose (%)	100	100	100	100	100	100	100
On roof panel setting (%)	100	100	100	100	100	100	100
On land panel setting %	0	0	0	0	0	0	0
Panel capacity (Wp)	17.5	22.5	12.5	13.3	10.53	35.5	18.6
DC fan per family, No.	1	1	1	1	1	2	1
DC tube-light per family	1	2	1	1	1	3	2
Price of SHS package, Tk. <sup>1</sup>	16300	20700	16500	16800	16200	35500	20500
Price of SHS package, Tk. <sup>2</sup>	13000	14000	12000	12000	12000	18000	13500
SHS service provider	Grameen Shakti, Hilphul Fuzul, RREL, BRAC						

<sup>1</sup> Price of panel- as in 2013. <sup>2</sup> Price of panel- as in 2018.

## 11.2 Up-scaling of solar pump for smallholder irrigation in the central coastal region of Bangladesh

BARI and BRRRI components designed their respective solar PV systems for the smallholders of the coastal region of Bangladesh. BARI developed a solar PV system suitable for upland crop irrigation and household appliances. BRRRI developed a system that suited for rice irrigation, thresher operation and household uses. BARI component designed two types of solar pumps for irrigation, 180L/min. (Large pump) and 40L/min. (Mini pump). The large pump was designed at the beginning of the sub-project and the mini pump was designed in 2020. So, the mini pump could be used only one season. The design procedure of the solar PV systems is discussed below:

### 11.2.1 BARI Component

#### Pump design

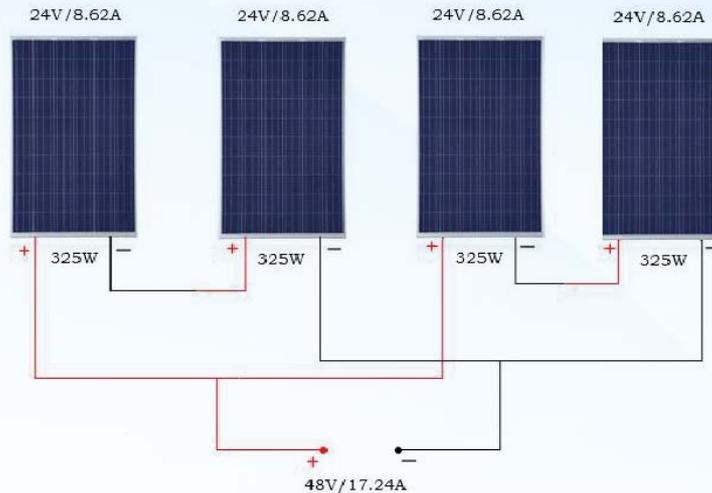
Two new solar pumps were fabricated at FMPE Division using available materials such as 51 mm centrifugal pump and 910W dc motor (Large model) and another one was made with 25mm centrifugal pump and 280W dc motor (Mini model). Both the pumps were directly coupled with the motor to reduce the power loss. The large solar pump can be operated by 1000 W<sub>p</sub> solar panel or more. The main features of the solar pumps are given in Table 28.

**Table 28: Main features of new solar pumps**

Main Features	Large Model	Mini model
Suitability	Surface water lifting	Surface water lifting
Maximum suction head	6.50 m	6.50 m
Capacity of solar panel	1300 W <sub>p</sub> or more	365 W <sub>p</sub> or more
Type of motor	DC, 48 V	DC, 24 V
Power of motor	910 W <sub>p</sub>	280 W <sub>p</sub>
Motor speed	3500 rpm	3500 rpm
Diameter of pipe (Suction and delivery)	51 mm	25 mm
Average discharge	180 L/min	40 L/min
The price of the pump with panel and fittings	Tk. 80,000.	Tk. 30,000.
Command Area, ha/season	1.80	0.40

### Solar panel arrangements

The panel arrangement of solar powered irrigation system is shown in Fig. 39. Total panel capacity of 4 panels was  $1300 W_p$  and supplying nominal voltage was 24 V that could produce 8.16A current at solar radiation of  $1000 W/m^2$ . Two sets of series connection were made to increase the voltage up to 48 V and then one set of parallel connection was made to increase the current up to 17.24 A at  $1000 W/m^2$ , so that the pump can operate well.



**Fig 39: Panel arrangement of solar powered irrigation system**

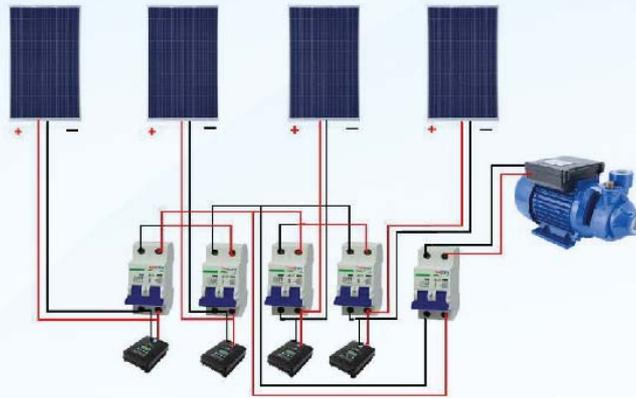
The solar panel generates 8.62A at  $1000 W/m^2$  with 24 V as nominal. The auto recut charge controller receives and diminishes the power and supplies it to recharge a 12 V battery. It disconnects the battery from solar panel while the battery becomes fully recharged thus it protects the battery from over charging and saves the whole system. A solar irrigation and solar home system model (Fig.40) has been developed through this solar pump sub-project at FMPE Division, BARI, Gazipur.



**Fig. 40: Solar home system model**

The solar irrigation pump and solar home system were finally designed. Total solar panel capacity was  $1300 W_p$ . Every single panel capacity was  $325 W_p$ . Total four pieces of solar panels were used. Each solar panel could generate 8.62A at  $1000 W/m^2$  solar radiation with 24V nominal voltage. Each panel was directly connected to a charge controller and the charge controller was connected to a 12V, 100 AH solar battery.

The capacity of motor of the solar pump was 910W. In order to minimize the losses and to combat lower solar radiation, solar panel capacity of 1.4 times the motor power (910W) was designed. For better performance and efficiency, a nominal voltage of 48V and a maximum current of 17.24A were required. Circuit breakers were used to make proper combination of series and parallel connections. At least  $300\text{W/m}^2$  solar radiation was needed to start the pump in early morning. The schematic diagram of the designed system of irrigation and home system is given in Fig 41. The panel capacity of  $1300\text{ W}_p$  was used to supply power to a single pump of 910W for irrigation and to four houses as solar home system.



**Fig. 41: Schematic diagram of the designed solar irrigation and home systems**

All six sets of solar pumps were installed in the selected locations (six). The installed system was slightly different from the designed system. In the installed system, four pieces of solar panels, a solar pump with flow meter, two circuit breakers, a charge controller, a solar battery and necessary equipment such as conductors, pipes etc. were supplied to all selected farmers in all the sites. Only one panel was found enough to supply required power to run the home appliances and still there was a scope for the use of rest three solar panels in other three different houses within the effective range. The schematic diagram of the installed system of solar irrigation and home system is shown in Fig 42.



**Fig. 42: Schematic diagram of the larger solar pump-based home system**

Twelve sets of mini solar pumps were installed in 12 selected locations of farmers' fields. One piece of solar panel, a solar pump with flow meter, one circuit breaker, a charge controller, a solar battery and necessary equipment such as conductors, pipes etc. were supplied to each of the selected farmers in all the sites. Only one panel was found enough to supply required power to run

the home appliances and the pump. The schematic diagram of the installed system of solar irrigation and home system is given in Fig 43.



**Fig. 43: Schematic diagram of mini solar pump-based home system**

A detailed home system is shown in Fig 44. The figure describes how a solar panel of  $325W_p$  or  $365W_p$  capacity provided service to a family. In the system a charge controller was used which received 24V from a single solar panel and converted it into 12V. Thus, the battery could be recharged safely. The solar charge controller was made with auto tracer technology i.e it could work both for a battery size of 12V or 24V in home system. The charge controller protected the solar battery from overcharging and provided service to the home appliances. The supplied battery was 12V, 100AH. Different types of solar home appliances such as light, fans, mobile charger, television etc. could be used safely.



**Fig. 44: Schematic diagram of installed solar home system**

#### **Solar pump based Solar Home System model displayed at Technology display fair at BARI**

The honorable Agriculture Minister visited the model at BARI technology display fair, 2019. The Chairman of BADC, Executive Chairman of BARC, Executive Director of KGF, Coordinator, Associate coordinator, Consultant and other guests also visited the model at BARI technology display fair, 2019 (Fig. 45). Before installation and development of this model, both in lab and field, sub-project design team visited the work place and suggested some improvements ( Fig. 46). The consultant visited us several times and gave us helpful directions.



Executive Chairman, BARC visited display fair



Stall visited by the Chairman, BADC



Visit by consultant, Associate coordinator and PI



Executive Director, KGF visited stall

**Fig. 45: Photographic views of BARI technology display fair 2019**



**Fig. 46: Design team visited photos**

## 11.2.2 BRRRI Component

### Pump design

Since BRRRI was going to irrigate Boro rice at farmer's field, they needed to apply much more water to crop than that of upland non-rice crops and so they required larger capacity pump. Thus, according to the requirement of power to run the pump, this component designed a pump of 656 L/min. (10.93 L/s) maximum discharge at the peak radiation of 954 W/m<sup>2</sup> to cover an irrigation area (command area) of 15 bighas (2 ha) of land.

### Solar panel arrangement

For BRRRI component designed pump, 8 numbers of solar panels of 325 Wp each were selected. This design was quite optimal for the area (2 ha) selected for irrigation. However, in off-grid areas, only one panel was sufficient to supply power to a household. The design for the system was also suitable for running the paddy thresher. The component used changeover to shift from 8 panels to a single panel operation and vice versa. Since for irrigation, the solar pump system of 8 panels was required to bring to crop field, it was made portable. This gave easy movement for the system. Further, due to folding system of the panels, the 8 panels could be accommodated only in half of the space normally required by 8 panels.

## 11.3 On station performance test of solar pump for irrigation and Solar Home System

### 11.3.1 BARI Component

#### Performance of the large solar pump

In Gazipur, at the FMPE pump test bed, the performance in respect of solar radiation, pump discharge, voltage produced and current of the DC solar pump was tested and the results are shown in Fig 47. A positive relationship was found among voltage, current, discharge and solar radiation. The average voltage, current, discharge and solar radiation were found 25.75V, 12.38 A, 180.00 L/min and 723.86 W/m<sup>2</sup>, respectively. The highest discharge was found 202.34 L/min at 1.30 pm from 886 W/m<sup>2</sup> solar radiation and at that time the voltage and current were also recorded as 30.35 V and 16.76 A, respectively. Motor speed (rpm) increased with the increase of voltage and the discharge also increased with the motor speed. This trend of voltage, speed and discharge was also applicable to the solar PV systems of other sites. The pump was coupled directly with the motor.

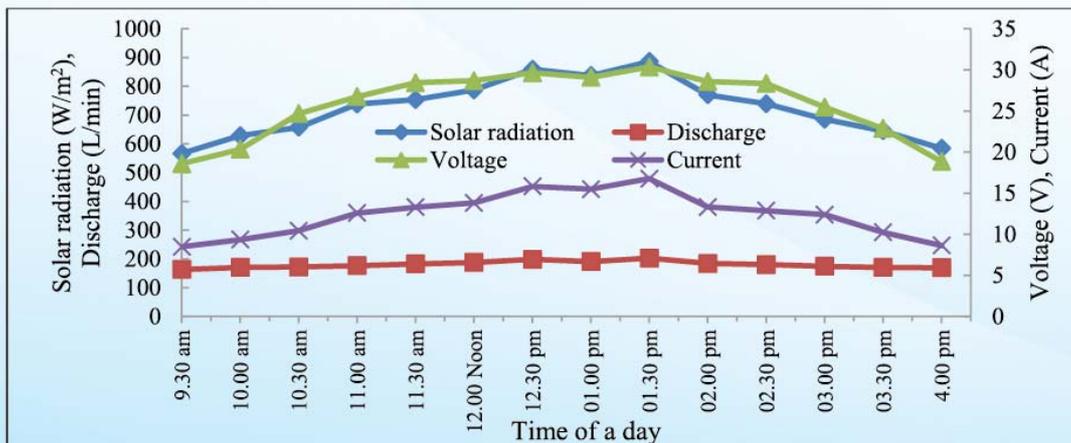
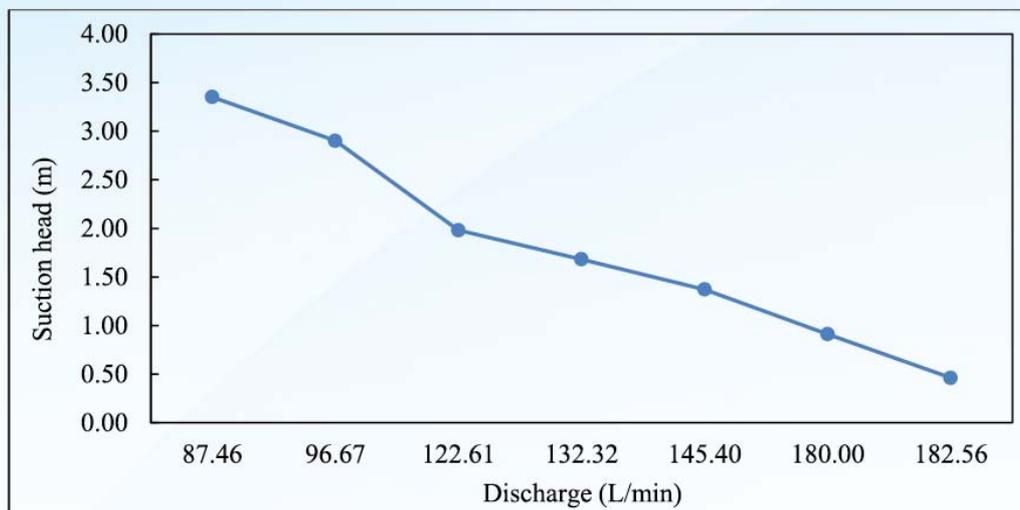


Fig. 47: Relationship among voltage, current, discharge and solar radiation at constant suction head (1.20 m, 18 February 2020, Gazipur)

The large (180 L/min) solar pump was also tested at different suction heads. The discharges of DC solar pump at different suction heads are shown in Fig. 48. At 0.46, 0.91, 1.37, 1.68, 1.98, 2.90 and 3.35 m suction heads the discharges were found 182.56, 180, 145.40, 132.32, 122.61, 96.67 and 87.46 L/min, respectively. The discharge decreased with the increase of suction heads. The highest and the lowest discharges were found 182.56 and 87.46 L/min. at 0.46 and 3.35 m suction heads, respectively.



**Fig. 48: Discharges of DC solar pump at different suction heads**

#### **On-station experimental results during 2018-2019**

##### **Weather data of field experimental period**

The weather parameters were recorded from the weather station near the experimental field. The different weather parameters during 2018-2019 are shown in Table 29. The maximum and the minimum temperatures were recorded in April (36.7°C) and December (7.9°C), respectively. The total rainfall was recorded 248 mm and effective rainfall was 232 mm during growing season of tomato crop (December-April) which was higher than any of the previous three year values. The temperature, sunshine hour, rainfall and reference evapotranspiration data were recorded the highest in the month of March and the lowest in the month of December. The Highest  $ET_0$  was obtained in the month of March (4.72 mm).

**Table 29: Monthly weather data at Gazipur during the crop growing period of 2018-2019**

Month	T <sub>max</sub>	T <sub>min</sub>	RH (%)	Wind speed (km/h)	Sunshine hour	Rainfall (mm)	ET <sub>0</sub> (mm)
December	28.6	7.9	81	123	5.9	11	2.28
January	30.0	9.6	74	157	6.5	-	2.75
February	31.0	11	72	236	6.9	88	3.69
March	34.7	11	71	262	7.4	117	4.72
April	36.7	17	80	229	6.5	120	4.65

##### **Yield and yield contributing parameters of tomato in 2018-19**

Yield and yield contributing parameters of tomato in different irrigation methods are shown in Table 30. The highest tomato yield was found from treatment T<sub>1</sub> (Drip irrigation at 3 days interval) followed by treatments T<sub>2</sub> (Drip irrigation at 5 days interval) and T<sub>3</sub> (Drip irrigation at 7

days interval) showing statistically significant. There were no significant differences among the treatments for number of fruits per plant, fruit length and fruit diameter. The lowest yield was found from T<sub>4</sub> (Furrow irrigation). Yield parameters among the treatments were found insignificant except unit fruit weight. Hartz and Hanson (2009) reported that drip irrigation enhanced better nutrient uptake in tomato and resulted in higher yield. Thus, the finding of Hartz and Hanson seems at par the findings of this experiment.

**Table 30: Yield and yield contributing parameters of tomato in different treatments at Gazipur during 2018-19**

Treatments	Number of fruit/ plants	Fruit length (cm)	Fruit diameter (cm)	Unit fruit weight (g)	Yield (t/ha)
T <sub>1</sub>	30.46	6.78	5.23	99.22	57.56
T <sub>2</sub>	29.10	6.70	5.16	96.26	56.41
T <sub>3</sub>	27.60	6.55	5.10	95.36	55.30
T <sub>4</sub>	27.33	6.42	5.06	92.32	52.38
CV%	8.31	9.54	8.43	6.68	4.45

#### **Yield and yield contributing parameters of brinjal in 2018-19**

Yield and yield contributing parameters of brinjal in different irrigation methods are shown in Table 31. The highest yield of brinjal was obtained from treatment T<sub>2</sub> (Drip irrigation at 5 days interval) followed by treatments T<sub>1</sub> (Drip irrigation at 3 days interval), T<sub>3</sub> (Drip irrigation at 7 days interval) and T<sub>4</sub> (Furrow irrigation) but there were no significant differences among the drip irrigation treatments. Yield parameters among the treatments were also found insignificant except fruit length. Fruit length enhanced higher yield of brinjal. The results are at par the findings of Hossain *et al.* (2014) who reported significantly higher yield of brinjal from drip irrigated plots (43.9 t/ha) compared to that of furrow irrigated plots (38.6 t/ha).

**Table 31: Yield and yield contributing parameters of brinjal in different treatments at Gazipur during 2018-19**

Treatments	Number of fruit/plants	Fruit length (cm)	Fruit diameter (cm)	Unit fruit weight (g)	Yield (t/ha)
T <sub>1</sub>	21.33	25.21	2.65	82.19	22.21
T <sub>2</sub>	22.40	25.49	2.66	83.78	22.71
T <sub>3</sub>	20.67	24.89	2.62	81.84	21.90
T <sub>4</sub>	19.93	22.48	2.56	80.67	20.02
CV%	7.63	5.83	4.62	8.61	6.08

#### **Seasonal water use by irrigation sequences in 2018-19**

Amount of water applied and water saving by different drip irrigation sequences over furrow irrigation of tomato and brinjal cultivation are given in Table 32. During the crop growing period (December, 2018- April, 2019), the highest amount of water was applied in furrow irrigation method (409 mm) compared to drip irrigation methods (190-205 mm) in tomato experiment. Among the drip irrigation treatments, irrigation at three days interval required the highest amount of water (205 mm) followed by five days (196 mm) and seven days (190 mm) intervals. Water saving by drip irrigation method over furrow irrigation method at three, five- and seven-days intervals were 49%, 52% and 54%, respectively. Therefore, drip irrigation saved about 52% water than furrow irrigation for tomato cultivation. Similar results were found for brinjal. In case of brinjal the growing period as well as irrigation requirement was higher than those of tomato. So, the higher amount of irrigation water was applied for drip and furrow irrigation methods. Hence,

about 45% water was saved from drip irrigation over furrow irrigation. This finding agrees well with the results presented by Hossain *et al.* (2014).

**Table 32: Water savings in different treatments of brinjal and tomato at Gazipur during 2018-19**

Treatments	Tomato		Brinjal	
	Applied water (mm)	Water saving over furrow irrigation (%)	Applied water (mm)	Water saving over furrow irrigation (%)
T <sub>1</sub>	205	49	254	43
T <sub>2</sub>	196	52	252	44
T <sub>3</sub>	190	54	233	48
T <sub>4</sub>	409	-	450	-

#### On station experiment results during 2019-2020

The weather parameters were recorded from the weather station set near to the experimental field. The different weather parameters during 2019-2020 are shown in the Table 33. During the growing season of tomato and brinjal (December 2019 to April 2020), the maximum temperature (36°C) was recorded in April and the minimum temperature (10.4°C) was recorded in the month of December. The total rainfall was recorded 180.4 mm and the effective rainfall was 163.91 mm during the growing season. The temperature, sunshine hour, rainfall and reference evapotranspiration data were recorded as the highest in the month of April and the lowest in the month of January. The highest ET<sub>0</sub> was obtained in the month of April (4.66 mm).

**Table 33: Monthly weather data during the crop growing period of Rabi crops 2019-2020**

Month	T <sub>max</sub> (°C)	T <sub>min</sub> (°C)	RH (%)	Wind speed (km/h)	Sunshine hour	Rainfall (mm)	ET <sub>0</sub> (mm)
December	31.0	10.4	87	128	5.4	-	2.03
January	28.0	9.3	85	169	4.9	29.0	2.09
February	29.5	9.5	77	185	6.6	1.0	3.19
March	34.0	13.5	78	225	6.4	28.4	4.25
April	36.0	17.0	81	243	7.2	122.0	4.66

Source: Weather Station, BARI, Gazipur

#### Yield and yield contributing parameters of tomato in 2019-20

Yield and yield contributing parameters of tomato in different irrigation sequences are shown in Table 34. There were 40 plants per 32 m<sup>2</sup> land i.e. plant population was 1.25 per m<sup>2</sup> for both tomato and brinjal. The highest tomato yield was found from treatment T<sub>2</sub> (Drip irrigation at 5 days interval) followed by treatments T<sub>1</sub> (Drip irrigation at 3 days interval) and T<sub>3</sub> (Drip irrigation at 7 days interval). The yield differences among the treatments were significant. There were no significant differences among the drip irrigation treatments. Significantly the lowest yield was found from T<sub>4</sub> (Furrow irrigation) than drip irrigations. There were no significant differences of number of fruits per plants. Other yield parameters of drip irrigated treatments were higher than furrow irrigation but among the drip irrigated treatments were insignificant. Hartz and Hanson (2009) reported that drip irrigation enhanced better nutrient uptake in tomato resulted higher yield and better quality.

**Table 34: Yield and yield contributing parameters of tomato in different treatments at Gazipur during 2019-20**

Treatments	Number of fresh fruit/ plant	Fruit length (cm)	Fruit diameter (cm)	Unit weight of fruit (g)	Yield (t/ha)
T <sub>1</sub>	39.16	6.21	4.45	88.01	63.96
T <sub>2</sub>	40.62	6.54	4.50	89.78	64.69
T <sub>3</sub>	38.65	6.19	4.41	86.26	61.48
T <sub>4</sub>	36.11	5.96	4.11	80.56	58.16
CV (%)	8.27	3.65	2.51	4.82	4.85

Note: T<sub>1</sub> = Drip irrigation at 3 days interval, T<sub>2</sub> = Drip irrigation at 5 days interval, T<sub>3</sub> = Drip irrigation at 7 days interval and T<sub>4</sub> = Furrow irrigation.

**Yield and yield contributing parameters of tomato in 2019-20**

Yield and yield contributing parameters of brinjal in different irrigation methods are shown in Table 35. There were no significant differences of yield and yield contributing parameters among the drip irrigated treatments. The highest yield of brinjal was obtained from treatment T<sub>2</sub> (Drip irrigation at 5 days interval) and T<sub>3</sub> (Drip irrigation at 7 days interval) followed by treatments T<sub>1</sub> (Drip irrigation at 3 days interval), than T<sub>4</sub> (Furrow irrigation) but there were no significant differences among the drip irrigation treatments. Unit weight of fruit of all treatments was statistically alike. Significantly the lowest yield and yield parameters were obtained from furrow irrigated plot. Hossain *et al.* (2014) reported significantly higher yield of brinjal from drip irrigated plots (43.9 t/ha) compared to the furrow irrigated plots (38.6 t/ha).

**Table 35: Yield and yield contributing parameters of brinjal in different treatments at Gazipur during 2019-20**

Treatments	Number of fresh fruit/ plant	Fruit length (cm)	Fruit diameter (cm)	Unit weight of fruit (g)	Yield (t/ha)
T <sub>1</sub>	22.25	27.37	2.75	94.88	24.77
T <sub>2</sub>	23.93	27.72	2.81	95.81	25.19
T <sub>3</sub>	23.266	28.35	2.84	96.24	25.56
T <sub>4</sub>	20.10	25.07	2.67	90.26	21.39
CV (%)	7.43	5.94	2.18	5.00	7.83

Amount of water applied and water saving by different intervals of drip irrigation over furrow irrigation of tomato and brinjal cultivation are given in Table 36. During the crop growing period (December, 2019- April, 2020), the highest amount of water was applied for tomato in furrow irrigation method (453 mm) compared to drip irrigation method. Among the drip irrigation intervals, irrigation at three days interval required the highest amount of water followed by five days and seven days intervals. Water saving by drip irrigation method over furrow irrigation method for tomato at three, five and seven days intervals were 51%, 52% and 54%, respectively. Therefore, drip irrigation saved about 51% than furrow irrigation for tomato cultivation. Similar results were found for brinjal. In case, of brinjal the growing period as well as irrigation requirement of brinjal was higher than those of tomato. So, the higher amounts of irrigation water were applied for drip and furrow irrigation methods. Hence, Water saving by drip irrigation method over furrow irrigation method for tomato at three, five and seven-days intervals were 33%, 34% and 38%, respectively. Therefore, about 35% of water saving from drip irrigation was found over furrow irrigation. This year less irrigation water required for brinjal because 122 mm rainfall occurred in April 2020. These finding are agreed well with the results presented by Hossain *et al.* (2014).

**Table 36: Amount of water applied and water saving in different treatments of tomato and brinjal at Gazipur during 2019-20**

Treatments	Tomato		Brinjal	
	Amount of irrigation water applied (mm)	Water saving compared to furrow Irrigation (%)	Amount of irrigation water applied (mm)	Water saving compared to furrow Irrigation (%)
T <sub>1</sub>	220	51	354	33
T <sub>2</sub>	215	52	351	34
T <sub>3</sub>	205	54	325	38
T <sub>4</sub>	453	-	527	-

**On-station experimental results during 2020-21**

**Yield and yield contributing parameters of tomato in 2020-21**

Yield and yield contributing parameters of tomato in different irrigation methods are shown in Table 37. Highest tomato yield was obtained from treatment T<sub>1</sub> (Drip irrigation) followed by treatments T<sub>2</sub> (Alternate furrow irrigation) and T<sub>3</sub> (Furrow irrigation) and it was significantly different from other treatments. The lowest yield was found from T<sub>3</sub> (Furrow irrigation). Yield parameters among the treatments were found insignificant from except unit fruit weight.

**Table 37: Yield and yield contributing parameters of tomato in different treatments at Gazipur during 2020-21**

Treatment	Plant Length, cm	No. of Fruits /plant	Unit weight gm/fruit	Fruit length, cm	Fruit Dia cm	Yield ton/ha
Drip	103.33	41.59	108.2	5.28	5.28	63.29
AFI	100.36	41.11	95.57	4.99	4.99	57.21
FP	98.13	39.53	92.96	4.86	4.86	52.86
CV	4.85	3.38	11.95	5.53	5.53	5.66
LSD	8.45	2.38	20.31	0.48	0.48	5.65

Note: AFI=alternate furrow irrigation, FP= Farmers practice (every furrow irrigation)

**Seasonal water use by irrigation sequences in 2020-21**

Water applied by different irrigation methods by solar pump for irrigation in tomato is shown in Table 38. It is observed from the table that about double amount of water was required in farmers' practice i.e. furrow irrigation than drip method. Irrigation water savings in tomato by alternate furrow method and drip method over farmers' practice were 49.63%, and 35.21% respectively. So, drip irrigation method was found the best water saving technology for tomato cultivation followed by alternate furrow irrigation method.

**Table 38: Water savings in different treatments of tomato in 2020-21**

Treatments	Tomato	
	Applied water (mm)	Water saving over furrow irrigation (%)
Drip	206	49.63
AFI	265	35.21
FP	409	-

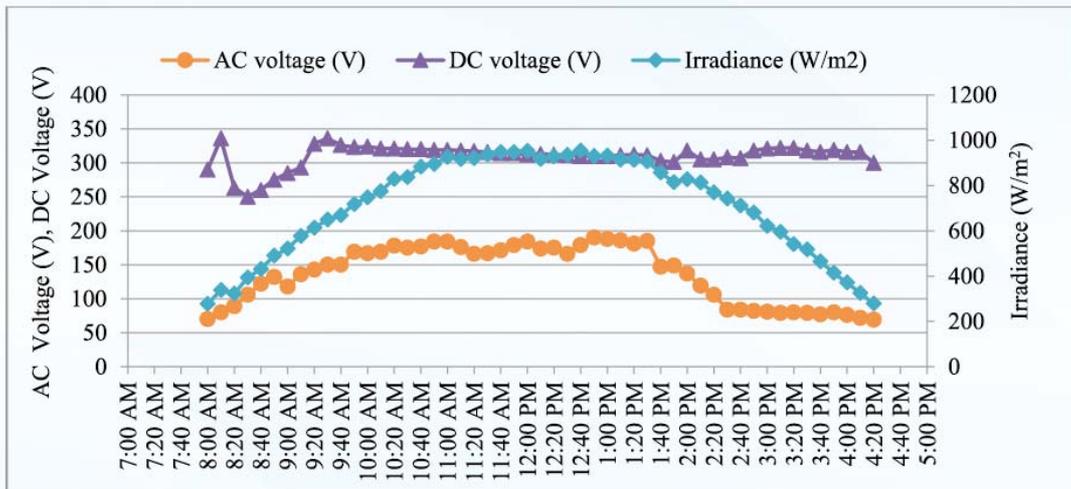
### 11.3.1 BRRRI Component

#### On station test of portable solar pump

Since BRRRI had no on-station crop experiment at Joydebpur during the sub-project years, no crop experiment data and results are presented here. The designed solar PV system was tested only for its technical performance at Joydebpur. The tests results are discussed here.

#### AC and DC voltage outputs of PV panels

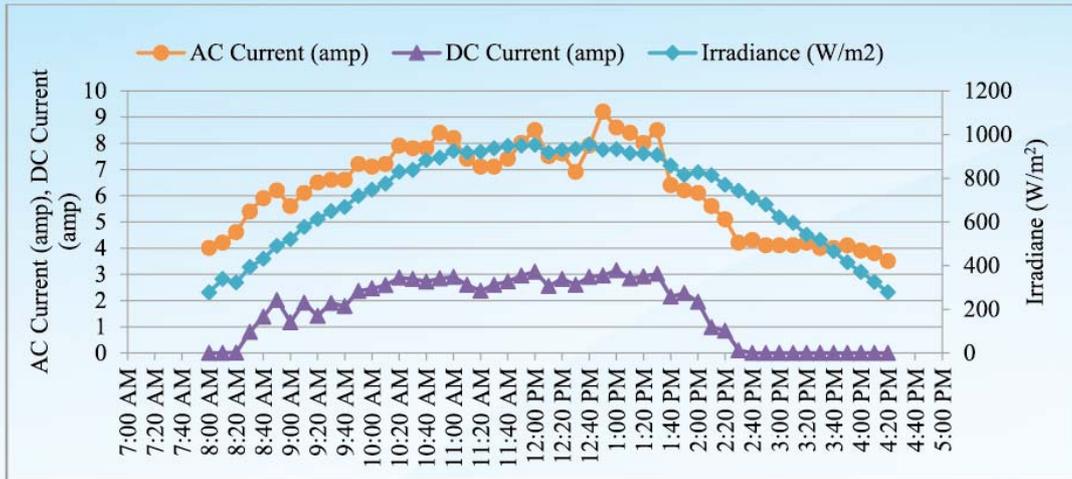
The variation of AC and DC voltages (V) against solar intensity ( $\text{W/m}^2$ ) is presented in Fig.49. The change of AC voltage ranged from 69 volts to 190 volts, whilst DC voltage ranged from 0 volt to 336 volts. However, the variation of AC voltage with respect to the variation of solar intensity was unsmooth to some extent compared to almost constant distribution of DC voltage. During data recording, DC voltage was found to attain the highest value of 336 volts at 8:10 am and 9:30 am, whilst AC voltage attained its peak (190 volt) at 12:50 pm, 10 minutes after the irradiance peak (at 12:40 pm).



**Fig. 49: Variation of AC voltage and DC voltage with respect to irradiance throughout the day**

#### Variation of AC and DC current output of PV panels

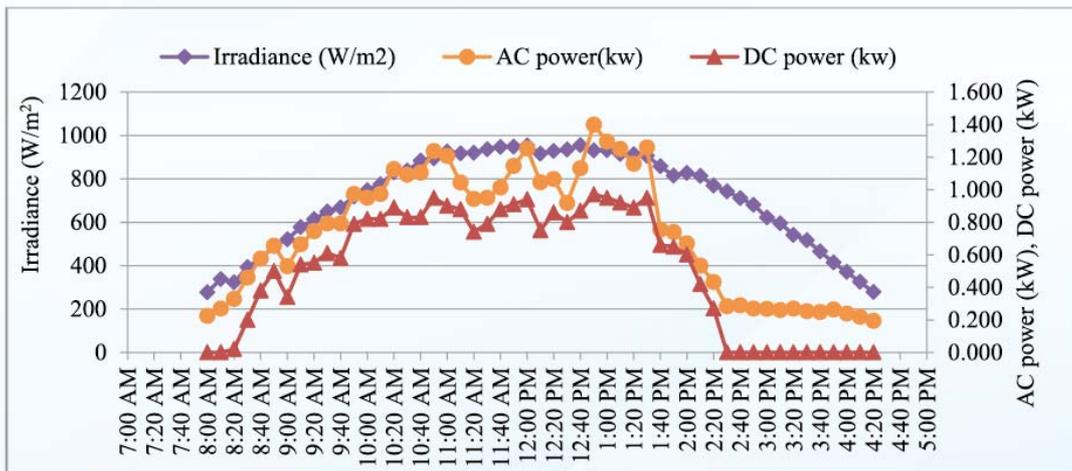
The variation of AC current and DC current (A) regarding irradiance ( $\text{W/m}^2$ ) is shown in Fig.50. It is seen from the figure that the variation of AC current, ranging from 3.5 A to 9.2 A seems more vivid compared to DC current, which has the values from 0.0 A to 3.15 A. AC current peaked at 12:50 pm with a value of 9.2 A. On the other hand, DC current peaked at 1:00 pm with a value of 3.15 A. However, solar intensity peaked at 12:40 pm with a value of  $954 \text{ W/m}^2$ .



**Fig. 50: Variation of AC current and DC current with respect to irradiance throughout the day**

**Variation of AC and DC power output with irradiance**

The variation of AC power and DC power (kW) with respect to solar intensity (W/m<sup>2</sup>) is shown in Fig. 51.

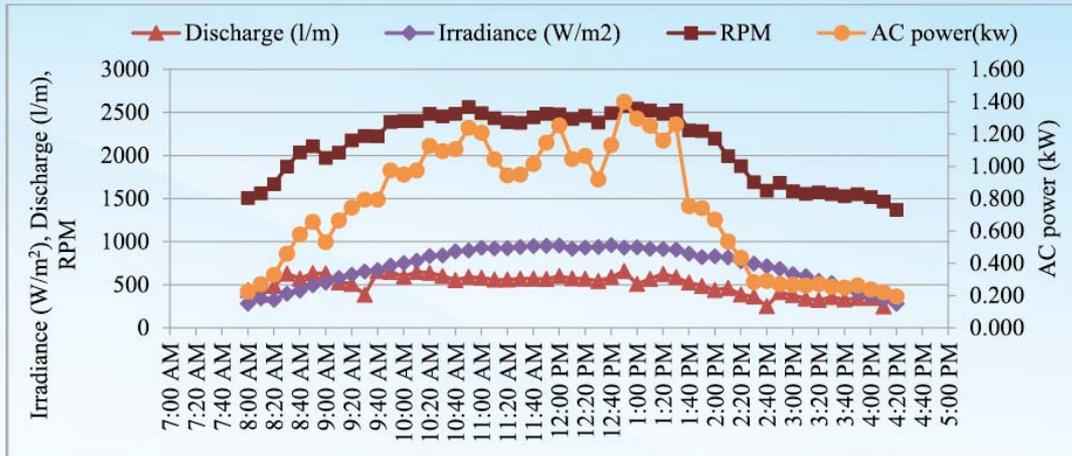


**Fig. 51: Variation of AC power and DC power with respect to irradiance throughout the day**

As seen from figure 27, the changing patterns of both AC and DC power outputs were almost identical. Both AC and DC power increased with the increase of solar intensity and peaked at the same time (1.398 kW and 0.97 kW respectively). This was observed 10 minutes from the peak of solar intensity (954 W/m<sup>2</sup>). Again, both the powers recessed with the recession of solar intensity. Though the solar intensity recessed gradually, the power droppings (AC and DC) were drastic. From Fig.27, it is evident that, AC power output (ranging from 0.193 kW to 1.398 kW) was greater than DC power output (ranging from 0 kW to 0.97 kW) with the same solar intensity input.

**Variation of discharge with solar intensity**

Though the variation of discharge (l/min) with solar intensity was the main focus, other governing factors like AC power output and RPM were also related to discharge (Fig.52).

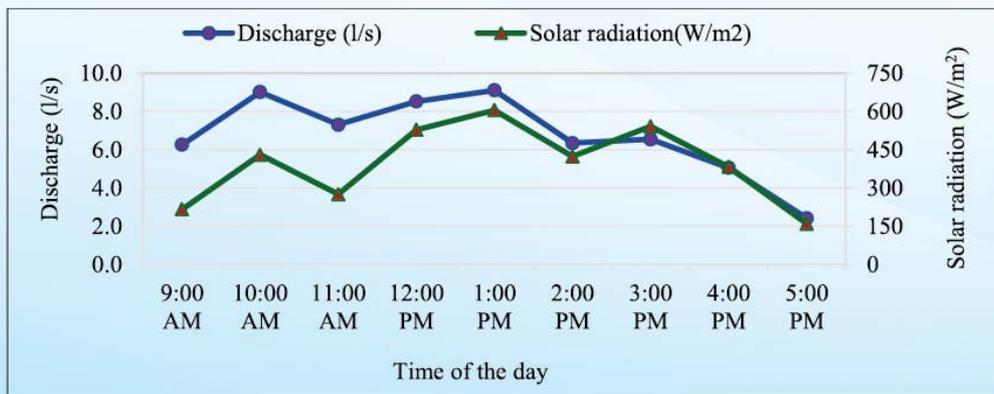


**Fig. 52: Variation of discharge and RPM with respect to irradiance and AC power Output throughout the day**

The variation of discharge against solar intensity was noticeable. However, the changing pattern was not completely similar. The variation of discharge was dependent on both solar intensity and AC power output. Also, the pattern found in discharge distribution was verified by the pattern of RPM, as the variation in these two parameters was found almost identical because of their linearly proportional relationship. According to discharge distribution (Fig.52), the peak discharge, 656 l/min was found at 12:50 pm, while the peak solar intensity, 954 W/m<sup>2</sup> was found 10 minutes earlier at 12:40 pm. However, if looked at the AC power output distribution, the peak (1.398 kW) was found at 12:50 pm, the same time when discharge peaked. The peak RPM was found at 12:50 pm too, as 2572. The average discharge was found to be 505.06 l/min throughout the whole day.

**Relationship between discharge and irradiance**

Single phase AC solar pump was designed for use in farmers’ fields. The flow rates of the pump were recorded for different months. Discharge rates (l/s) in the month of September, October and November were recorded in 2018 in the pump testing bed. Variation of discharge with irradiance was noticeable. An example of discharge and irradiance variation throughout a particular day (10th September 2018) is given in Fig. 53. This Figure shows that the discharge increases as the solar radiation increases. The highest discharge (9.10 l/s) was recorded in between 12:00 pm and 1:00 pm, when the irradiance was 605 W/m<sup>2</sup>. The suction lift was kept constant at 4.38 feet and the average discharge was 6.76 l/s.



**Fig. 53: Variation of discharge of solar pump with solar radiation at different times of the day**

### Relationship between discharge and suction lift

Relationship between discharge and suction lift represents pump characteristics. However, the relationship was derived at constant pump speed (RPM). As the source of power of solar pump was irradiance, which was dynamic and varied a lot throughout the day, the pump didn't operate at a constant speed. This drawback made it difficult to generate discharge-suction lift curve. To back this shortcoming up, discharge in likely equal speed was taken to generate discharge-suction lift curve. Figure 54 shows the discharge-suction lift curve. It can be seen from the Figure 54 that, the relationship stands as negatively correlated and the equation is second-degree polynomial.

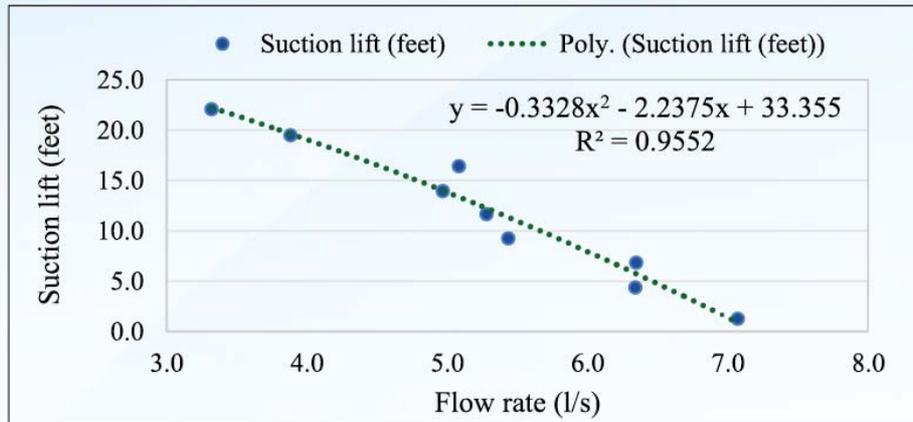


Fig. 54: Relationship between suction lift and flow rate

### Relationship between discharge and delivery head

Relationship between discharge and delivery head represents pump characteristics and this relationship was derived at constant pump speed (RPM). As the source of solar pump was irradiance which is dynamic and varies a lot throughout the day, the pump did not operate at a constant speed. This drawback made it difficult to generate discharge-delivery head curve. To back this shortcoming, discharge in likely equal speed was taken to generate discharge-delivery-head curve. Figure 55 shows the discharge-delivery-head curve. It can be seen from the Figure 55 that, the relationship stands as inversely proportional and the equation is a second degree polynomial.

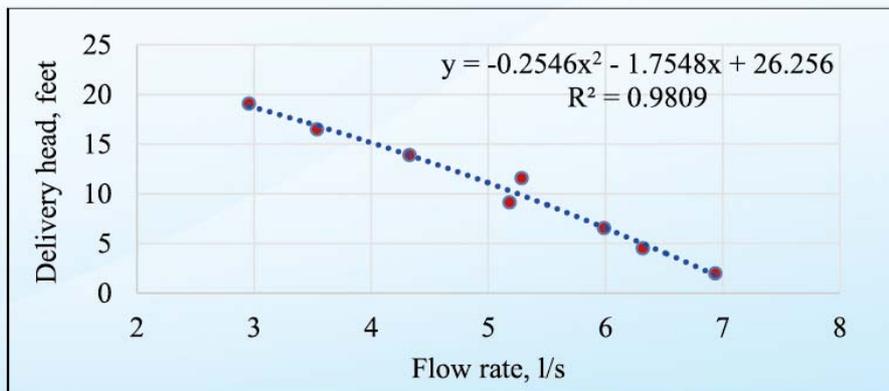


Fig.55: Relationship between delivery head and flow rate of solar pump

### Relationship between discharge and irradiance

Discharge rate (l/s) at different delivery heads in the month of October and November were observed in 2018. Variation of discharge against irradiance was noticeable. Figure 56 shows that the discharge increased as the solar radiation increased. The highest discharge (9.07 l/s) was recorded in between 12:00 pm and 1:00 pm, when the irradiance was 646 W/m<sup>2</sup>. The delivery head was 2 feet and average discharge was 7.89 l/s. Figure 56 represents the irradiance and discharge distribution on 24th October, 2018. Discharge changed with the irradiance and peaked between 12:00 am and 1:00 pm, while irradiance peaked for 622 W/m<sup>2</sup> at 12:00 pm. The highest value of discharge was recorded 9.54 l/s with an average discharge of 6.94 l/s.

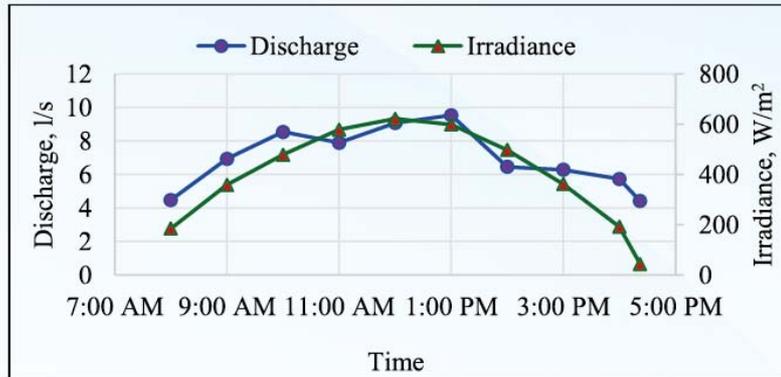


Fig. 56: Variation of discharge with solar radiation at different times of the day

### Development of a relationship between flow rate and irradiance

The experimental data on solar radiation and the corresponding pump discharges were obtained from the pumping system located at BRRI, Gazipur, for developing a model to simulate the flow rate by using only the solar radiation data. The energy output from PV panels was found to vary with the incident solar irradiance. Output of the PV panels was used as the input for the pump. The flow rates from the solar pump were measured by a flow meter at different solar irradiance intensities, keeping the suction and delivery heads constant (2.0 m). The daily average of hourly solar irradiances and flow rates showed a non-linear 2<sup>nd</sup> degree polynomial relationship as shown in Fig.57 with good co-efficient of determination ( $R^2 = 0.9838$ ). It should be mentioned that the equation is valid for 2.0 m head and a particular set of solar panels and pump.

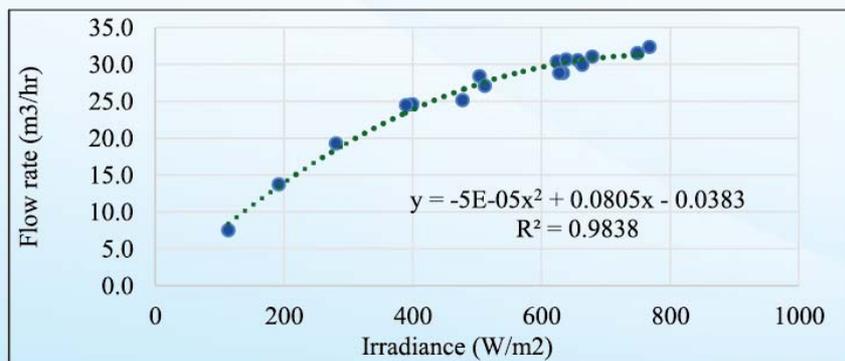


Fig. 57: Measured flow rate (Q<sub>m</sub>) versus incident solar radiation relationship

The proposed model is given by the relationship-

$$y = -5E-05x^2 + 0.0805x - 0.0383 \dots\dots\dots (1)$$
$$R^2 = 0.9838$$

Where, y= Measured flow rate,  $Q_m$  ( $m^3/hr$ ) and x= Solar irradiance ( $W/m^2$ )

The figure 57 shows that the flow rate increased with the increase of irradiance up to certain value of irradiance. When this specific irradiance level was reached, there was no further effect of increase of irradiance on flow rate. Obviously, this was the limitation of the pump performance at the specified head (2.0 m). It was also observed that the minimum irradiance required to start the pump was  $114 W/m^2$ . At an irradiance level of  $114 W/m^2$ , the discharge from the pump was  $7.5 m^3/hr$ . When irradiance level increased to  $200 W/m^2$ , the discharge from the pump was recorded to be  $13.7 m^3/hr$  and at  $400 W/m^2$ , the discharge was recorded as  $24.6 m^3/hr$ . At an irradiance of  $600 W/m^2$ , the discharge from pump was recorded to be  $30.4 m^3/hr$ . Further increase of irradiance level ( $700W/m^2$ ), the pump discharge became almost constant ( $31.1 m^3/hr$ ). During the hot days, the discharge from pump was low and lower power output was obtained (Munir *et al.*2012) Sometimes, it was found that some solar pumps had temperature sensors to regulate flow rate and it stopped the pump when it was over heated.

**Performance of BIRRI open drum thresher**

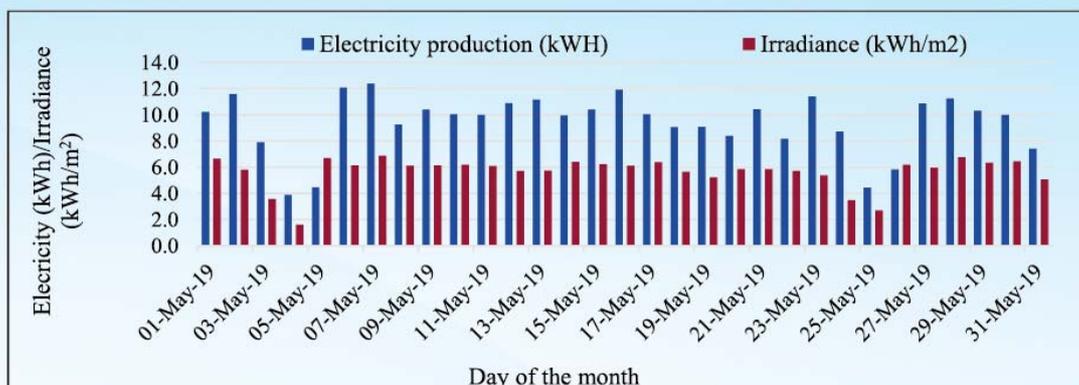
The BIRRI open drum thresher was tested during day time from 11.00 am to 12.00 am at BIRRI threshing floor in 2018-19. The capacity of this solar power operated paddy thresher was recorded 250-350 kg/hour. It required two labors to operate the thresher. Threshing quality of the paddy was good. Embryos of the paddy were not affected or damaged. Fig. 58 shows the solar power operated BIRRI Open drum thresher.



**Fig. 58: Solar power operated BIRRI Open drum thresher**

**Performance evaluation of on grid solar home system at BIRRI, Gazipur**

After harvesting of Boro rice in 2018 from the IWM experimental field, BIRRI, portable panel was transferred from the field to IWM Division. Data in respect of daily electricity production from solar panel were recorded. Analytical data in the month of May 2019 are shown in the graphical form (Fig. 59). The maximum daily electricity production was 12.4 kWh on 7 May 2019 when irradiance was  $6.9 kWh/m^2$  and that the minimum production was 3.9 kWh on 4 May 2019 when irradiance was  $1.6 kWh/m^2$ . Average daily electricity production from on grid solar home system was 9.4 kWh when the average irradiance was  $5.6 kWh/m^2$ . The average daily electricity production is, universally, dependent on the intensity of the daily solar radiation. Thus, it was found to vary in different months.



**Fig. 59: Daily electricity production by on-grid solar home system at BRRI, Gazipur**

## 11.4 Field trials and demonstrations of solar pump systems for surface water irrigation in high value crops and rice

### 11.4.1 BARI component

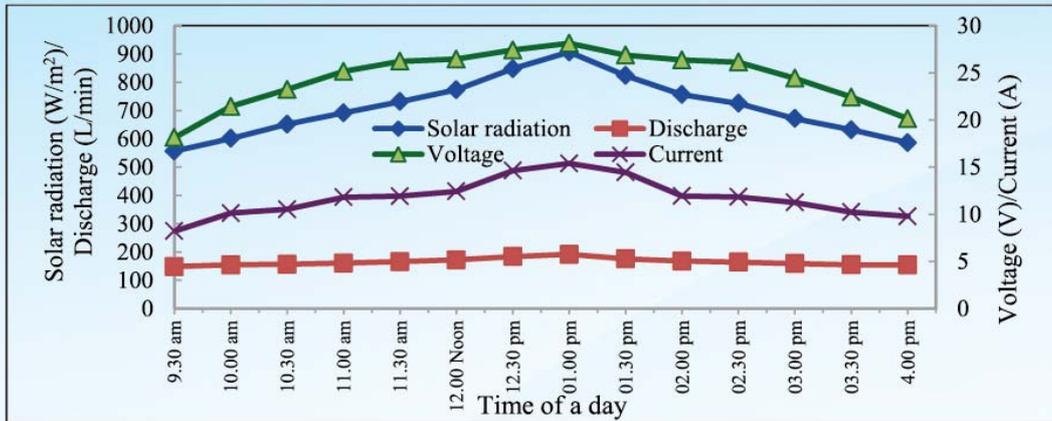
#### Test performances of solar PV systems in farmer's field

##### Large Solar Pump (910 W)

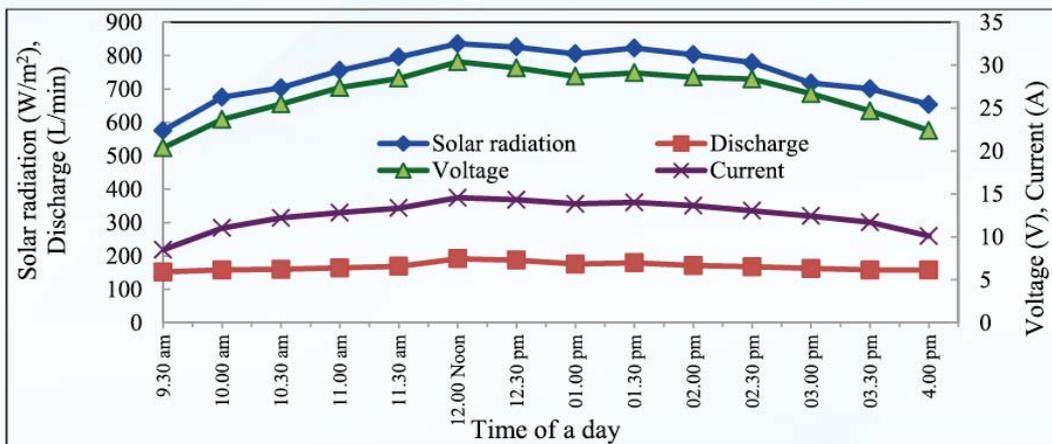
Average and maximum values of parameters recorded from solar panel tests at different sites were shown in Table 39. As it is revealed from Table 39 that the tested parameters, voltage, current, solar radiation, and pump discharge were found to vary from site to site. The maximum and the minimum voltages varied from 24 to 33.56V and so on. It has to be mentioned that the coupling between pump and motor was direct in all sites. This reduced power transmission loss to a large extent. Relationship among voltage, current, discharge and solar radiation were shown in Fig. 60-65.

**Table 39: Average values of parameters recorded from solar panel tested at different sites**

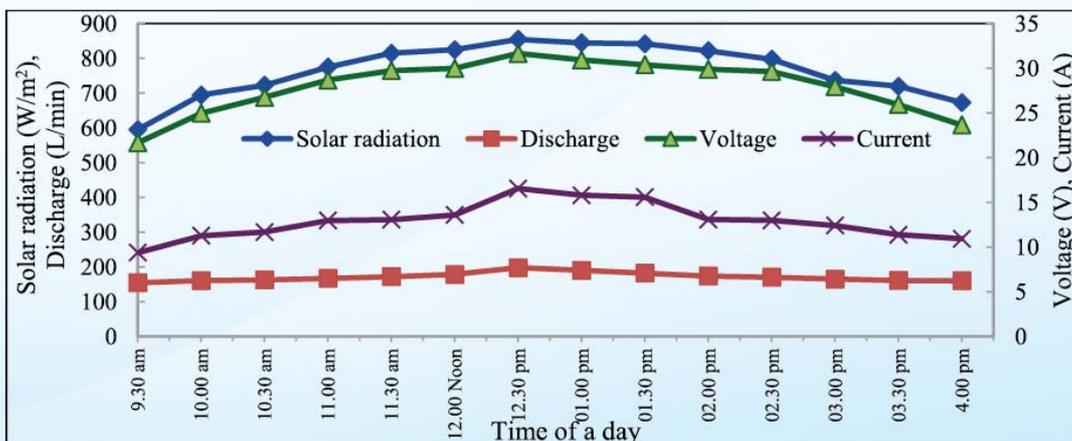
District	Upazila	Name of farmer	Voltage, V	Current, A	Solar Rad. W/m <sup>2</sup>	Discharge, L/min.
Patuakhali	Galachipa	Md. Sohrab Hossen	24.92	11.86	895.61	162.27
	Kalapara	Zillur Rahman Bashir	28.00	12.91	765.7	171.35
Barguna	Barguna Sadar	Md. Sajahan Mia	24.48	11.76	711.57	165.39
	Amtali	Nur Alam	26.73	12.55	746.71	168.62
Bhola	Char Fasson	Fazle Ali Biswas	26.25	12.24	740.71	166.54
	Lalmohon	Nurul Islam Mia	28.94	14.01	827.50	173.20



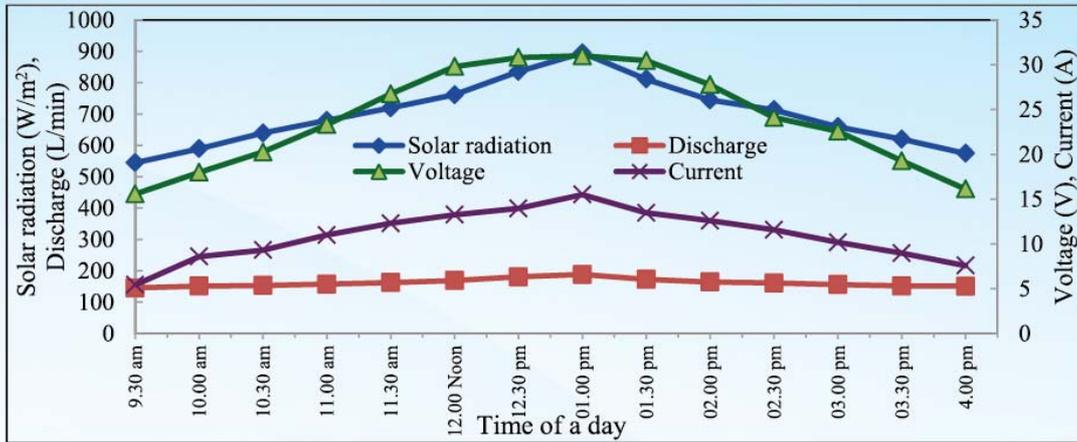
**Fig. 60: Relationship among voltage, current, discharge and solar radiation at the suction head of 1.22 m on 26 February 2020 at Barguna Sadar, Barguna**



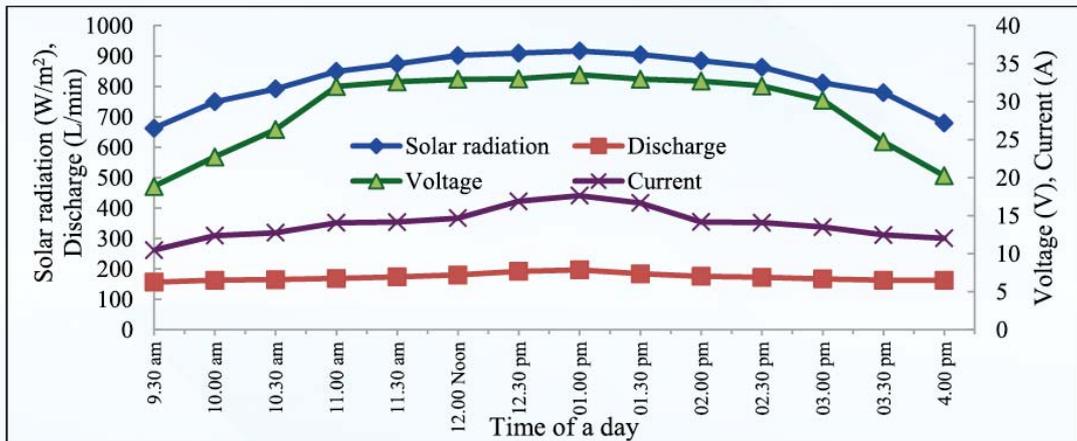
**Fig. 61: Relationship among voltage, current, discharge and solar radiation at the suction head of 1.25 m on 27 February 2020 at Amtali, Barguna**



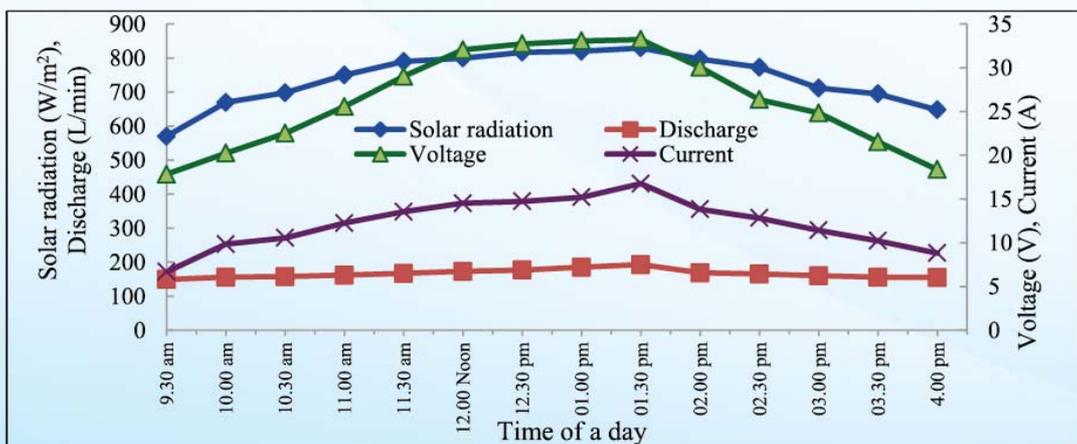
**Fig. 62: Relationship among voltage, current, discharge and solar radiation at the suction head of 1.23 m on 05 March 2020, Kalapara, Patuakhali**



**Fig. 63: Relationship among voltage, current, discharge and solar radiation at the suction head of 1.21 m on 03 March 2020 at Galachipa, Patuakhali**



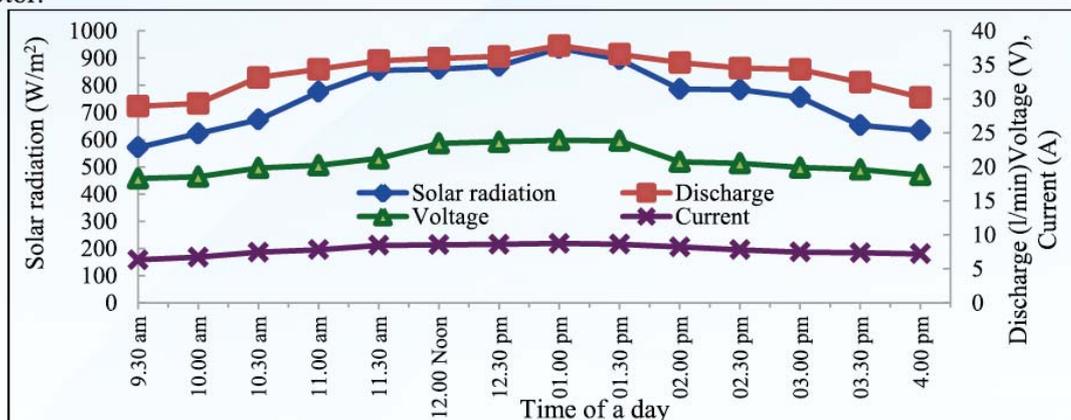
**Fig. 64: Relationship among voltage, current, discharge and solar radiation at the suction head of 1.20 m on 07 March 2020 at Lalmohon, Bhola**



**Fig. 65: Relationship among voltage, current, discharge and solar radiation at the suction head of 1.15 m on 10 March 2020 at Char Fasson, Bhola**

### Performance of Mini Solar Pump (280W)

In FMPE pump test bed, BARI, Gazipur, the performance in respect of solar radiation, pump discharge, voltage produced and current of the mini solar pump was tested during 2020-21. Relationship among voltage, current, discharge and solar radiation at constant suction head 1.20 m are shown in Fig 66. A positive relationship was found among voltage, current, discharge and solar radiation. The average voltage, current, discharge and solar radiation were found 20.93V, 7.83 A, 35.00 L/min and 762 W/m<sup>2</sup>, respectively. The highest discharge was found 37.85 L/min at 1.00 pm from 937 W/m<sup>2</sup> solar radiation and at the voltage and current were also recorded as 23.94 V and 8.74 A, respectively. Motor speed (rpm) increased with the increase of voltage and the discharge also increased with the motor speed. This trend of voltage, speed and discharge was also applicable to the solar PV systems of other sites. The pump was coupled directly with the dc motor.

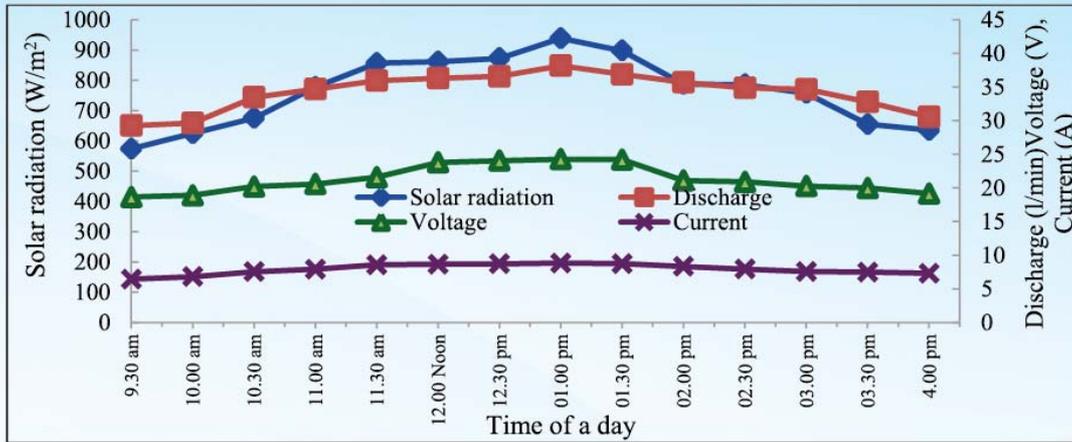


**Fig 66: Relationship among voltage, current, discharge and solar radiation at constant suction head of 1.20 m on 13 August 2020 in Gazipur**

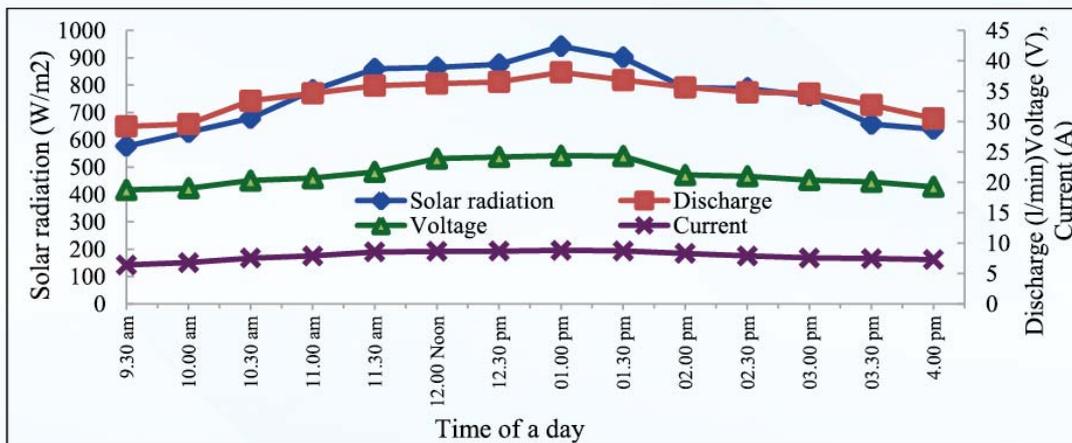
Average values of parameters recorded from solar panel tests at different sites are presented in Table 40. As revealed from table that the tested parameters, voltage, current, solar radiation, and pump discharge were found to vary from site to site. The maximum and the minimum voltages varied from 21.28 to 25.19V and so on. It has to be mentioned that the coupling between pump and motor was direct in all sites. This reduced power transmission loss to a large extent. Relationship among voltage, current, discharge and solar radiation were shown in Figs. 67-78.

**Table 40: Average values of parameters recorded from solar panel tests at different sites**

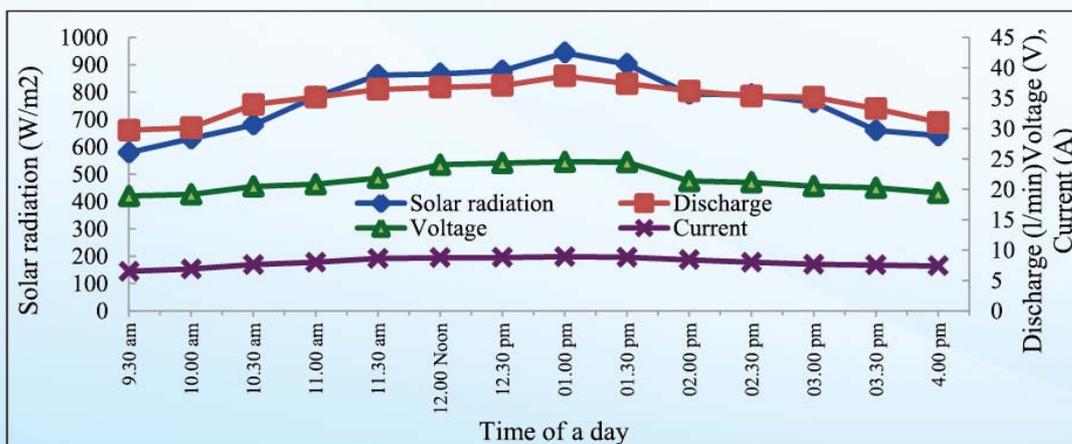
District	Upazila	Farmers Name	Voltage, V	Current, A	Solar Rad., W/m <sup>2</sup>	Discharge, L/min.
Barguna	Barguna Sadar	Md. Milon	21.28	7.93	764.64	34.27
		Md. Abdur Rab	21.39	7.91	767.64	34.22
	Amtali	Md. Delowar	21.36	7.88	766.64	34.21
		Md. Abdur Razzak Mia	21.55	8.01	769.64	34.76
Patuakhali	Galachipa	Md. Bablu Jomadder	22.12	8.54	777.38	35.35
		Md. Firoz Rari	22.02	8.64	775.54	35.29
		Sukha Ranjan Vhat	22.18	8.68	779.27	35.44
		Md. Monir dhali	22.06	8.36	776.35	35.10
		Md. Delowar Hossain	22.1	8.34	774.42	35.15
	Kalapara	Md. Joynal Abedin	21.68	8.04	772.25	34.86
Bhola	Lalmohon	Md. Jasim uddin	21.85	8.23	777.32	35.06
	Char Fasson	Md. Abdul Kadir	21.79	8.14	774.86	34.90



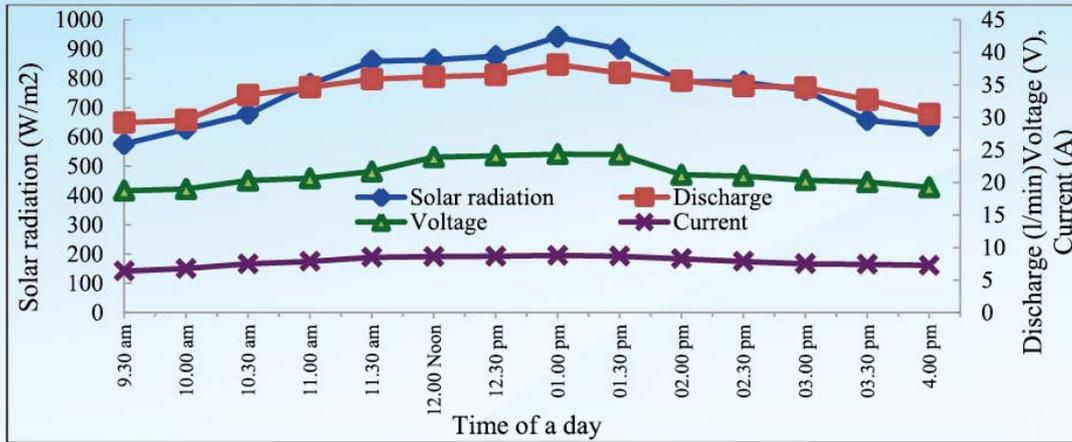
**Fig. 67: Relationship among voltage, current, discharge and solar radiation at the suction head of 1.19 m on 16 January 2021 at Gazi Mahmud, Barguna Sadar, Barguna**



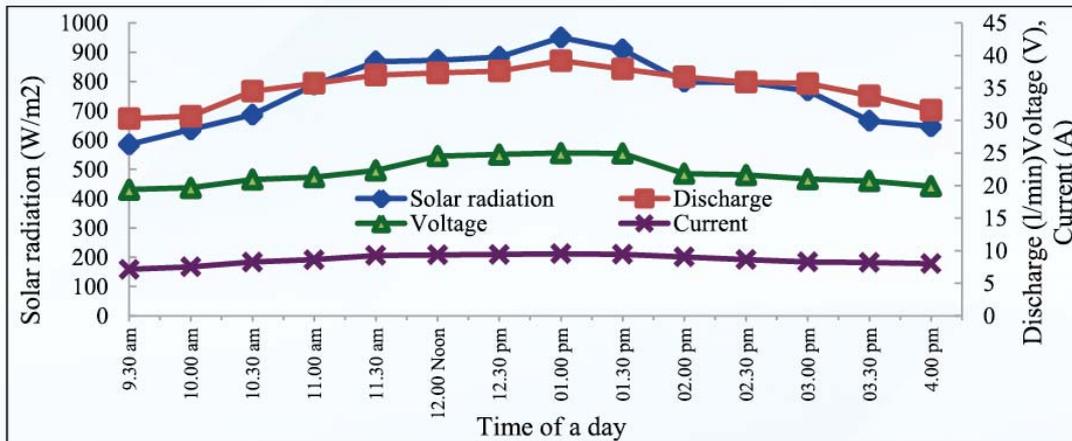
**Fig. 68: Relationship among voltage, current, discharge and solar radiation at the suction head of 1.22 m on 18 January 2021 at Kot Baria, Barguna Sadar, Barguna**



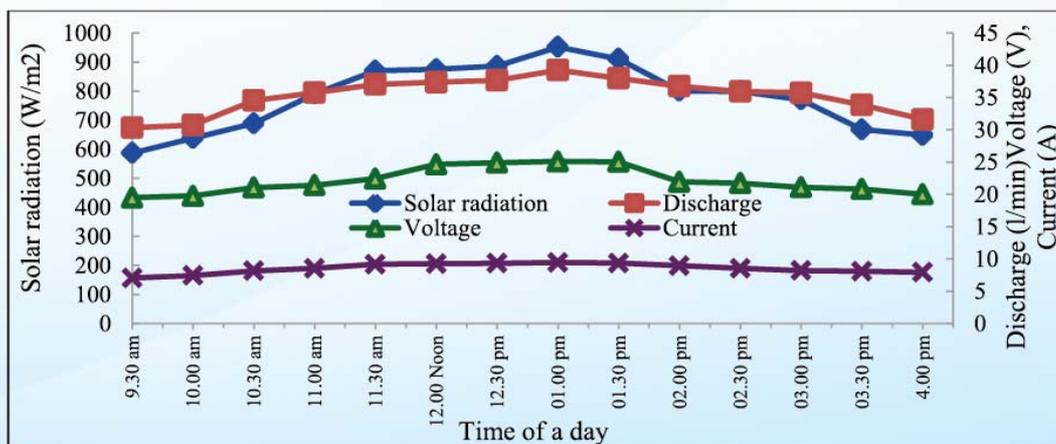
**Fig. 69: Relationship among voltage, current, discharge and solar radiation at the suction head of 1.24 m on 19 January 2021 at North Ghotkhali, Amtali, Barguna**



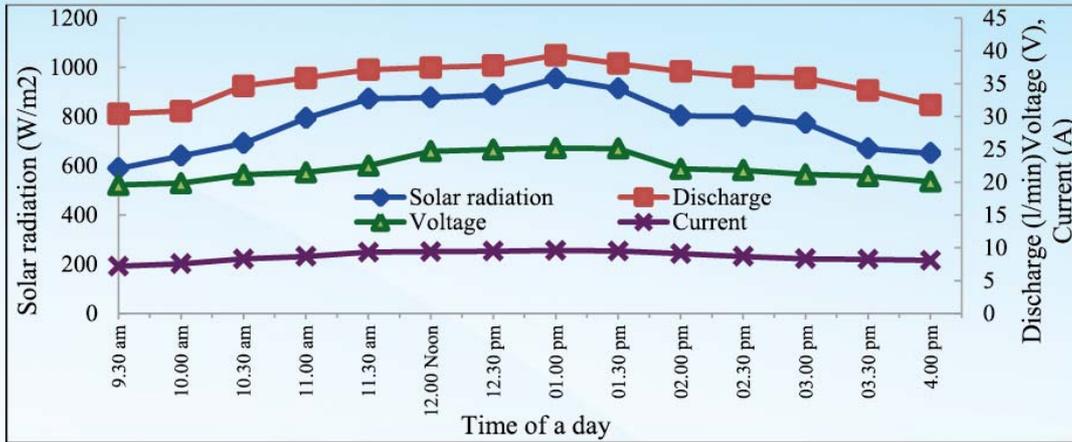
**Fig. 70: Relationship among voltage, current, discharge and solar radiation at the suction head of 1.23 m on 22 January 2021 at Purba Chunakhali, Amtali, Barguna**



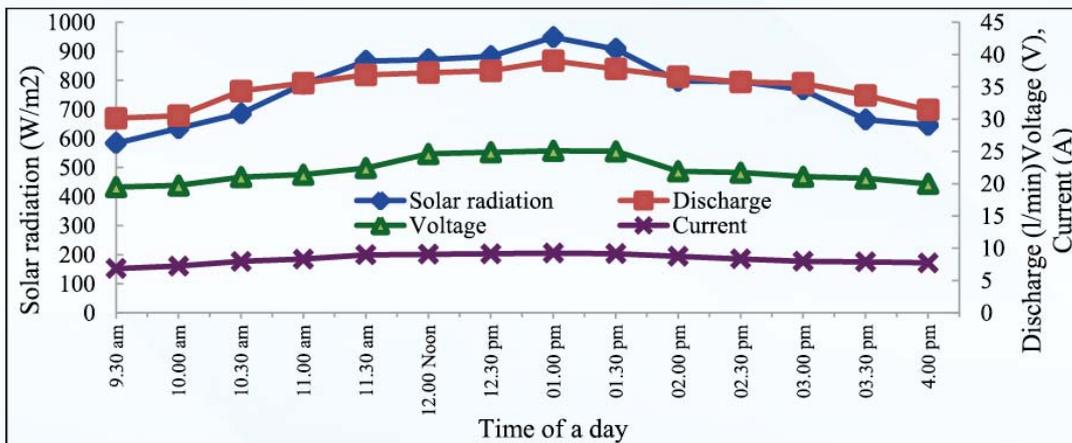
**Fig. 71: Relationship among voltage, current, discharge and solar radiation at the suction head of 1.30 m on 25 January 2021 at Boro Charkajol, Galachipa, Patuakhali**



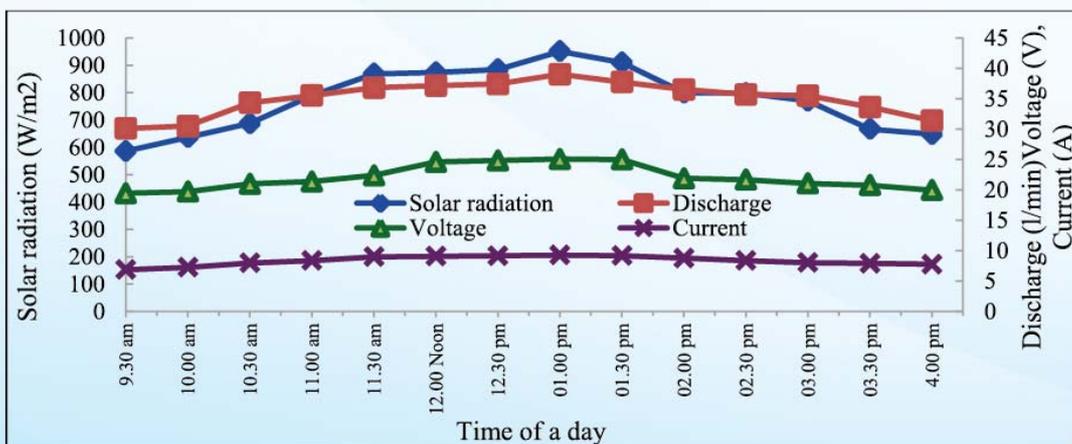
**Fig. 72: Relationship among voltage, current, discharge and solar radiation at the suction head of 1.28 m on 25 January 2021 at South Charbiswas, Galachipa, Patuakhali**



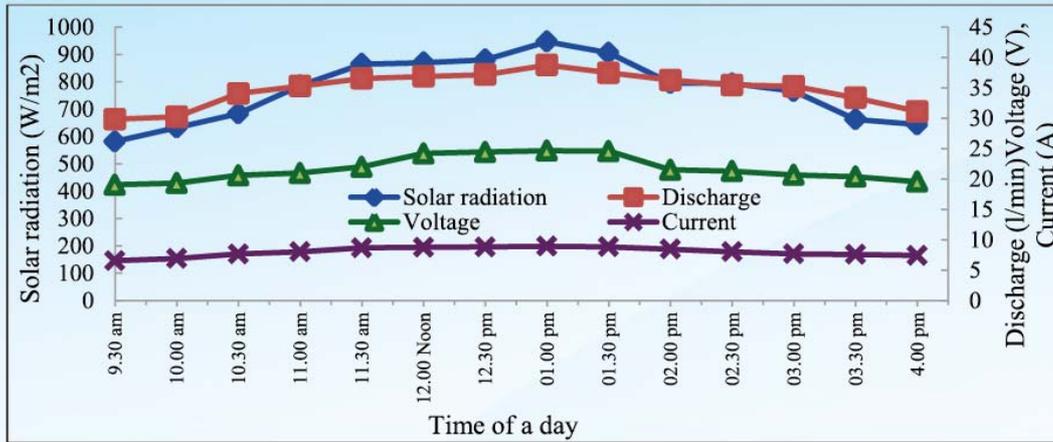
**Fig. 73: Relationship among voltage, current, discharge and solar radiation at the suction head of 1.30 m on 26 January 2021 at Soto Shiba, Galachipa, Patuakhali**



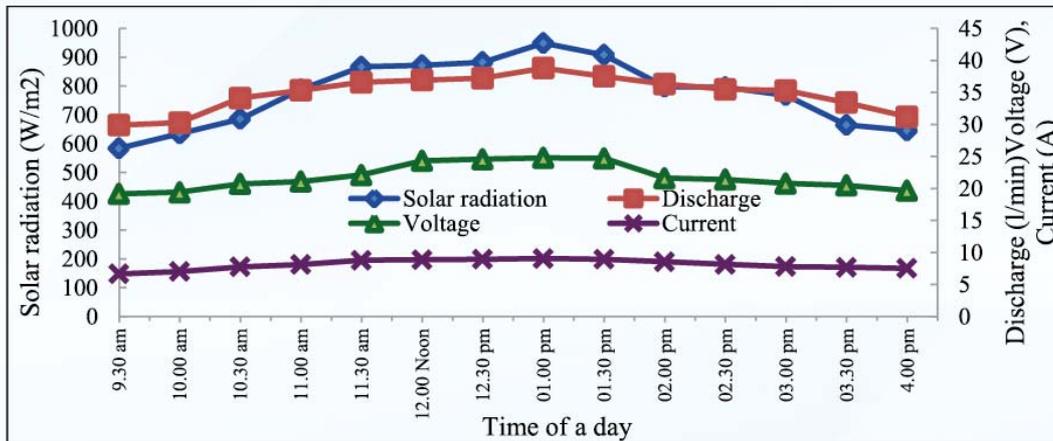
**Fig. 74: Relationship among voltage, current, discharge and solar radiation at the suction head of 1.31 m on 26 January 2021 at Panpotti, Galachipa, Patuakhali**



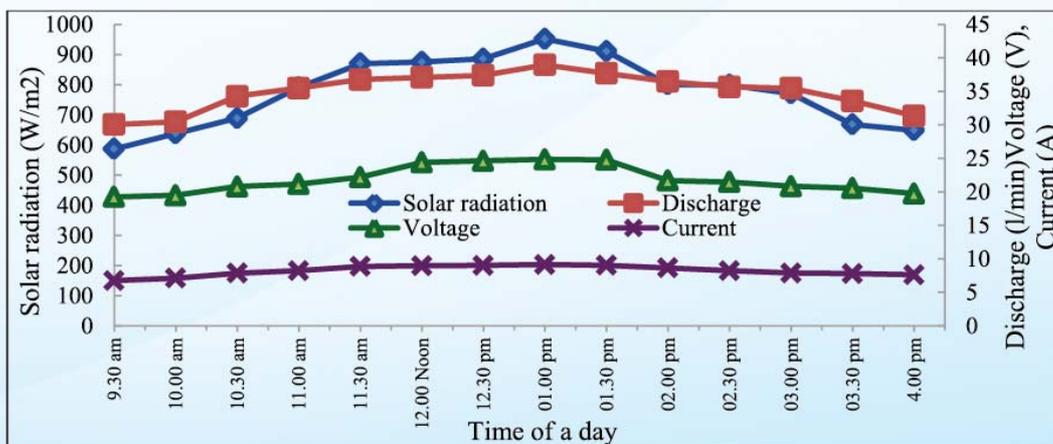
**Fig. 75: Relationship among voltage, current, discharge and solar radiation at the suction head of 1.31 m on 26 January 2021 at Char Badai, Galachipa, Patuakhali**



**Fig. 76: Relationship among voltage, current, discharge and solar radiation at the suction head of 1.23 m on 05 February 2021 at Sonatala, Kalapara, Patuakhali**



**Fig. 77: Relationship among voltage, current, discharge and solar radiation at the suction head of 1.18 m tested on 26 December 2020 at Matabbar Bari, Bhola**



**Fig. 78: Relationship among voltage, current, discharge and solar radiation at the suction head of 1.17 m tested on 28 December 2020, Lalmohon, Bhola**

## Experiments at farmers' fields during 2019-2020

### Crop: Tomato

Yield and yield contributing parameters of tomato at Barguna Sadar upazila of Barguna district are shown in Table 41. There were 40 plants per 32 m<sup>2</sup> land i.e. plant population was 1.25 per m<sup>2</sup> at all locations. The highest yield was found from drip irrigation than alternate furrow irrigation (AFI) and farmers practice or every furrow irrigation (FP) treatments and was significantly different. But AFI and FP were statistically similar. There was no significant difference in yield contributing parameters among the treatments except the number of fruits per plant. The highest number of fruits of drip irrigation contributed the highest yield. At Amtali, Barguna, the highest yield was obtained from drip irrigation but it was statistically alike with other treatments (Table 42). Similar trend of results of tomato were found for Galachipa of Patuakhali district (Table 43) and Lalmohon of Bhola district (Table 44).

**Table 41: Yield and yield contributing characters of tomato at Barguna Sadar, Barguna**

Treatment	Plant height (cm)	No. of Fruits /plant	Unit weight (g/fruit)	Fruit length (cm)	Fruit diameter (cm)	Yield (t/ha)
Drip	80.48	37.93	84.97	6.52	6.41	76.31
AFI	78.19	31.67	82.16	6.02	6.17	58.93
FP	74.14	31.16	83.06	6.22	6.28	60.77
HSD	NS	5.26	7.63	NS	NS	12.48
CV (%)	4.36	7.21	4.56	4.61	5.16	8.80

**Table 42: Yield and yield contributing characters of tomato at Amtali, Barguna**

Treatment	Plant height (cm)	No. of Fruits /plant	Unit weight (g/fruit)	Fruit length (cm)	Fruit diameter (cm)	Yield (t/ha)
Drip	113.43	55.93	49.32	4.63	5.11	75.81
AFI	104.64	48.92	47.51	4.35	4.98	63.93
FP	105.59	50.41	45.16	4.29	4.98	65.27
HSD	8.60	5.22	NS	0.33	NS	11.37
CV (%)	3.67	4.65	6.35	3.46	2.34	7.66

**Table 43: Yield and yield contributing characters of tomato at Golachipa, Patuakhali**

Treatment	Plant height (cm)	No. of Fruits /plant	Unit weight (g/fruit)	Fruit length (cm)	Fruit diameter (cm)	Yield (t/ha)
Drip	99.66	51.50	60.86	4.81	5.61	56.31
AFI	97.37	50.93	45.05	4.75	5.15	49.92
FP	95.82	50.42	44.20	4.68	5.03	50.67
HSD	NS	NS	6.40	NS	0.58	5.69
CV (%)	2.57	5.67	5.90	2.14	5.04	5.01

**Table 44: Yield and yield contributing characters of tomato at Lalmohon, Bhola**

Treatment	Plant height (cm)	No. of Fruits /plant	Unit weight (g/fruit)	Fruit length (cm)	Fruit diameter (cm)	Yield (t/ha)
Drip	100.14	60.67	51.33	4.88	4.52	67.01
AFI	98.35	60.10	41.99	4.82	4.53	50.21
FP	95.29	59.59	42.94	4.75	4.45	54.73
HSD	NS	NS	7.63	NS	NS	5.69
CV (%)	2.57	5.67	5.90	2.14	5.04	5.01

### Crop: Brinjal

Yield and yield contributing parameters of brinjal at Barguna Sadar upazila of Barguna district are given in Table 45. There were 40 plants per 32 m<sup>2</sup> land i.e. plant population was 1.25 per m<sup>2</sup> at all locations for brinjal. The highest yield of brinjal was obtained from drip irrigation than AFI and FP methods. But it was statistically similar with FP. There were no significant differences in yield contributing parameters among the treatments except fruit diameter. Significantly the highest fruit diameter of drip irrigation enhanced the highest yield. Similar results of brinjal were found for Amtali, Barguan (Table 46), Kalapara (Table 47) and Galachipa (Table 48) upazila of Patuakhali district and Char Fasson upazial of Bhola (Table 49). In Lalmohon upazila of Bhola district, significantly the highest yield was found from drip and FP than AFI as shown in Table 50. But drip irrigation method and farmers' practice were statistically insignificant. Hence number of fruits per plant contributed higher yield in drip irrigation treatment as well as farmers practice.

**Table 45: Yield and yield contributing characters of brinjal at Barguna Sadar, Barguna**

Treatment	Plant height (cm)	No. of Fruits /plant	Unit weight (g/fruit)	Fruit length (cm)	Fruit diameter (cm)	Yield (t/ha)
Drip	101.32	45.75	74.23	12.99	7.86	34.71
AFI	98.96	40.50	66.47	12.24	7.23	27.99
FP	99.83	41.75	69.39	12.66	7.47	32.63
HSD	NS	NS	NS	NS	0.54	5.99
CV (%)	2.64	8.41	5.73	4.32	3.33	8.68

**Table 46: Yield and yield contributing characters of brinjal at Amtali, Barguna**

Treatment	Plant height (cm)	No. of Fruits /plant	Unit weight (g/fruit)	Fruit length (cm)	Fruit diameter (cm)	Yield (t/ha)
Drip	97.57	42.75	70.58	12.61	7.46	31.36
AFI	96.46	37.50	64.32	11.86	6.83	28.89
FP	97.33	38.75	65.74	12.28	7.07	29.78
HSD	NS	2.58	NS	NS	0.46	2.06
CV (%)	3.12	3.00	5.46	4.45	2.96	3.16

**Table 47: Yield and yield contributing characters of brinjal at Kalapara, Patuakhali**

Treatment	Plant height (cm)	No. of Fruits /plant	Unit weight (g/fruit)	Fruit length (cm)	Fruit diameter (cm)	Yield (t/ha)
Drip	97.52	41.75	71.39	12.63	7.49	32.03
AFI	95.91	36.50	65.13	11.88	6.86	25.31
FP	96.78	37.75	66.55	12.30	7.10	29.95
HSD	NS	2.58	NS	NS	0.46	5.99
CV (%)	3.23	3.08	5.39	4.45	2.94	9.48

**Table 48: Yield and yield contributing characters of brinjal at Golachipa, Patuakhali**

Treatment	Plant height (cm)	No. of Fruits /plant	Unit weight (g/fruit)	Fruit length (cm)	Fruit diameter (cm)	Yield (t/ha)
Drip	96.01	40.75	70.78	12.59	7.44	31.51
AFI	94.40	35.50	65.02	11.84	7.00	24.56
FP	95.27	36.75	66.44	12.26	7.11	29.17
HSD	NS	2.14	NS	NS	NS	5.81
CV (%)	2.80	2.62	5.79	4.46	4.62	9.42

**Table 49: Yield and yield contributing characters of brinjal at Lalmohon, Bhola**

Treatment	Plant height (cm)	No. of Fruits /plant	Unit weight (g/fruit)	Fruit length (cm)	Fruit diameter (cm)	Yield (t/ha)
Drip	99.41	52.75	76.98	13.58	8.47	31.23
AFI	97.62	37.25	64.91	13.10	7.66	21.60
FP	97.67	43.75	66.25	13.55	8.25	28.84
HSD	NS	11.46	NS	NS	NS	4.36
CV (%)	5.69	11.85	20.08	5.51	5.52	7.38

**Table 50: Yield and yield contributing characters of brinjal at Char Fasson, Bhola**

Treatment	Plant height (cm)	No. of Fruits /plant	Unit weight (g/fruit)	Fruit length (cm)	Fruit diameter (cm)	Yield (t/ha)
Drip	100.69	35.50	79.57	10.87	7.80	28.53
AFI	97.71	32.00	67.48	10.48	7.00	21.81
FP	98.71	33.25	72.95	10.54	7.40	26.45
HSD	NS	NS	7.15	NS	NS	5.69
CV (%)	2.06	7.77	4.49	2.96	8.47	10.24

Water applied by different irrigation methods by solar pump for irrigation in tomato is shown in Table 51. It is observed from the table that about double amount of water was required in farmers' practice than drip method. Irrigation water savings in tomato by alternate furrow method and drip method over farmers' practice in different locations of southern region were, 31-35% and 46-47%, respectively. So, drip irrigation method was found the best water saving technology for tomato cultivation followed by alternate furrow irrigation method.

**Table 51: Amount of water applied and water savings in tomato in different treatments at different locations during 2019-20**

Treatments	Barguna Sadar		Amtali		Golachipa		Lalmohon	
	Irrigation applied (mm)	Water saving (%)						
Drip	213	47.79	217	47.84	205	46.75	235	47.31
AFI	268	34.31	275	33.89	264	31.43	292	34.53
FP	408		416		385		446	

Water applied by different irrigation methods by solar pump for irrigation in brinjal is given in Table 52. Irrigation water savings in brinjal by alternate furrow method and drip method over farmers' practice in different locations southern region were 34-36% and 47-49%, respectively. So, drip irrigation method was found the best water saving technology for irrigation in brinjal followed by alternate furrow irrigation method.

Cyclone Amphan damaged some crops in the all sub-project sites except Lalmohon, Bhola. Brinjal and tomato at Lalmohon was harvested just before the cyclone Amphan. Tomatoes were harvested before the cyclone Amphan in all experimental fields of all locations due to the end of the tomato season. But brinjal and watermelon were affected by cyclone Amphan in all locations except Lamohon Bhola. Average damages of brinjal due to cyclone Amphan were 25% at Barguna Sadar, 40% at Amtali, 25% at Kalapara and 20% at Galachipa and 10% at Char Fasson upazila. About 20% water melon were damaged in Kalapara of Patuakhali district. Photographic views of experimental field during cyclone Amphan are given in Fig. 79.

**Table 52: Amount of water applied and water savings in brinjal in different treatments at different locations during 2019-20**

Treatments	Barguna Sadar		Amtali		Golachipa		Kalapara		Char Fasson		Lalmohon	
	Irrigation applied (mm)	Water saving (%)										
Drip	242	47.96	246	47.88	237	47.57	238	48.48	252	48.78	248	48.76
AFI	298	35.91	310	34.32	294	34.96	305	33.98	324	34.15	322	33.47
FP	465		472		452		462		492		484	



**Fig. 79: Photographic views of experimental field after the Cyclone Amphan in the sub-project area**

#### Experiments at farmers' fields during 2020-21

##### Irrigation to tomato by solar pump

Yield and yield contributing parameters of tomato at different sub-project locations are shown in Tables 53-55. Significantly higher yield was obtained from drip irrigation over any of the alternate furrow irrigation and all furrow irrigation (farmers practice). But alternate furrow irrigation (AFI) and furrow irrigation (FP) were statistically similar.

**Table 53: Yield and yield contributing characters of tomato at Barguna Sadar, Barguna**

Treatment	Plant height (cm)	No. of fruits /plant	Unit weight (g/fruit)	Fruit length (cm)	Fruit diameter (cm)	Yield (t/ha)
Drip	154.98	39.82	89.05	5.23	5.23	35.01
AFI	136.22	34.02	82.06	4.72	4.50	29.60
FP	131.44	27.42	77.18	4.43	4.06	25.09
CV (%)	7.25	3.12	5.8	7.45	11.82	12.11
LSD	17.69	1.82	8.31	0.61	0.94	6.26

Note: AFI=alternate furrow irrigation, FP= Farmers practice (every furrow irrigation)

**Table 54: Yield and yield contributing characters of tomato at Lalmohon, Bhola**

Treatment	Plant height (cm)	No. of fruits /plant	Unit weight (g/fruit)	Fruit length (cm)	Fruit diameter (cm)	Yield (t/ha)
Drip	149.61	42.90	92.32	5.30	5.28	40.70
AFI	130.85	37.09	85.33	4.79	4.55	35.29
FP	126.07	30.50	80.45	4.50	4.15	30.78
CV (%)	7.54	6.89	5.58	7.35	11.69	10.18
LSD	17.69	4.39	8.31	0.62	0.94	6.26

**Table 55: Yield and yield contributing characters of tomato at Matabbarbari, Char Fasson, Bhola**

Treatment	Plant height (cm)	No. of fruits /plant	Unit weight (g/fruit)	Fruit length (cm)	Fruit diameter (cm)	Yield (t/ha)
Drip	82.75	41.72	88.33	6.89	6.59	44.29
AFI	80.45	35.46	86.42	6.6	6.47	38.41
FP	76.40	34.94	85.52	6.4	6.35	37.69
CV (%)	4.23	6.48	4.38	4.33	5.01	7.13
LSD	5.84	4.19	6.57	0.49	0.56	4.95

Water applied by different irrigation methods by solar pump for irrigation in tomato is shown in Table 56. It is observed from the table that about double amount of water was required in farmers' practice than drip method. Irrigation water savings in tomato by alternate furrow method and drip method over farmers' practice in different locations of the southern region were, 28-32% and 47-49%, respectively. So, drip irrigation method was found the best water saving technology for tomato cultivation followed by alternate furrow irrigation method.

**Table 56: Amount of water applied and water savings in tomato in different treatments at different locations**

Treatments	Barguna Sadar, Barguna		Lalmohon, Bhola		Char Fasson, Bhola	
	Irrigation applied (mm)	Water saving (%)	Irrigation applied (mm)	Water saving (%)	Irrigation applied (mm)	Water saving (%)
Drip	225	48.28	235	48.69	247	48.11
AFI	294	32.41	325	29.04	342	28.15
FP	435	-	458	-	476	-

#### Irrigation to brinjal by solar pump

Yield and yield contributing parameters of brinjal at different sub-project locations are shown in Tables 57-61. The highest yield of brinjal was obtained from drip irrigation but the drip, AFI and FP methods produced statistically similar yields.

**Table 57: Yield and yield contributing characters of brinjal at Galachipa, Patuakhali**

Treatment	Plant height (cm)	No. of fruits /plant	Unit weight (g/fruit)	Fruit length (cm)	Fruit diameter (cm)	Yield (t/ha)
Drip	77.91	41.68	89.7	9.32	2.26	47.71
AFI	75.96	37.08	87.77	9.07	2.16	44.62
FP	74.25	35.90	80.25	8.06	1.91	44.04
CV (%)	13.58	2.96	6.96	12.89	10.89	9.85
LSD	17.87	1.96	10.35	1.96	0.39	7.75

**Table 58: Yield and yield contributing characters of brinjal at Amtali, Barguna**

Treatment	Plant height (cm)	No. of fruits /plant	Unit weight (g/fruit)	Fruit length (cm)	Fruit diameter (cm)	Yield (t/ha)
Drip	81	40.75	88.98	12.89	3.49	47.49
AFI	79.05	36.75	82.39	12.64	3.39	44.4
FP	77.34	35.50	79.15	11.63	3.14	43.82
CV (%)	13.05	3.16	4.94	9.18	6.89	9.89
LSD	17.87	2.05	7.15	1.96	0.39	7.74

**Table 59: Yield and yield contributing characters of brinjal at Barguna Sadar, Barguna**

Treatment	Plant height (cm)	No. of fruits /plant	Unit weight (g/fruit)	Fruit length (cm)	Fruit diameter (cm)	Yield (t/ha)
Drip	75.93	40.35	95.55	10.90	2.5	38.88
AFI	73.98	35.75	93.62	10.65	2.4	35.81
FP	72.27	34.57	86.1	9.64	2.15	35.27
CV (%)	13.94	3.07	6.52	5.59	9.78	8.36
LSD	17.87	1.96	10.35	1.00	0.39	5.3

**Table 60: Yield and yield contributing characters of brinjal at Kalapara, Patuakhali**

Treatment	Plant height (cm)	No. of fruits /plant	Unit weight (g/fruit)	Fruit length (cm)	Fruit diameter (cm)	Yield (t/ha)
Drip	74.78	51.61	83.58	14.37	7.96	45.1
AFI	73.17	47.85	76.99	13.62	7.74	42.01
FP	72.61	43.7	73.75	12.75	7.16	41.43
CV (%)	8.03	10.06	5.29	5.23	5.88	10.44
LSD	10.22	8.31	7.15	1.22	0.77	7.74

**Table 61: Yield and yield contributing characters of brinjal at Char Fasson, Bhola**

Treatment	Plant height (cm)	No. of fruits /plant	Unit weight (g/fruit)	Fruit length (cm)	Fruit diameter (cm)	Yield (t/ha)
Drip	72.04	49.43	82.40	14.19	7.17	42.35
AFI	70.43	45.67	75.81	13.44	6.95	39.26
FP	69.87	41.52	72.57	12.57	6.37	38.68
CV (%)	8.34	4.34	5.37	6.82	6.56	11.16
LSD	10.22	3.42	7.15	1.58	0.77	7.74

Water applied by different irrigation methods using solar pump for irrigation in brinjal is given in Table 62. Irrigation water savings in brinjal by alternate furrow method and drip method over farmers' practice in different locations of the southern region were 27-29% and 48-51%, respectively. So, drip irrigation method was found the best water saving technology for irrigation in brinjal followed by alternate furrow irrigation method.

**Table 62: Amount of water applied and water savings in brinjal in different treatments at different locations**

Treatments	Galachipa, Patuakhali		Amtali, Barguna		Barguna Sadar Barguna		Kalapara, Patuakhali		Char Fasson, Bhola	
	Irrigation applied (mm)	Water saving (%)								
Drip	287	48.93	276	48.12	270	50.64	297	49.14	283	48.82
AFI	406	27.76	386	27.44	397	27.42	425	27.23	402	27.31
FP	562	-	532	-	547	-	584	-	553	-

**Irrigation to watermelon by solar pump**

Yield and yield contributing parameters of watermelon at different sub-project locations are shown in Tables 63-67. Significantly higher yield of watermelon was obtained from drip irrigation over RBI (Ring basin irrigation) or FP (Farmer's practice) method. But RBI was statistically similar with FP. In Kotbari of Barguna Sadar the highest yield (32.08 t/ha) was obtained from drip method, but there was no statistical difference in yield of watermelon among the treatments.

**Table 63: Yield and yield contributing characters of watermelon at Boro Char Kajol, Galachipa, Patuakhali**

Treatment	Vine Length (cm)	No. of Fruits /plant	Unit weight (g/fruit)	Fruit length (cm)	Fruit dia (cm)	Yield (t/ha)
Drip	494.81	1.75	10925.00	56.62	27.33	44.59
RBI	468.31	1.25	9962.50	47.79	23.47	40.33
FP	404.95	1.00	8551.25	40.59	21.28	38.70
CV (%)	7.22	7.95	7.04	4.42	6.35	4.81
LSD	57.02	0.64	1196.28	3.7	2.64	3.43

**Table 64: Yield and yield contributing characters of watermelon at Char Badai, Galachipa, Patuakhali**

Treatment	Vine Length (cm)	No. of Fruits /plant	Unit weight (g/fruit)	Fruit length (cm)	Fruit dia (cm)	Yield (t/ha)
Drip	450.22	2.75	10475.00	55.71	55.82	47.24
RBI	423.72	2.00	9262.50	46.88	46.99	42.98
FP	360.36	1.50	7751.25	39.68	39.79	41.35
CV (%)	8.01	2.62	5.95	4.5	4.49	4.51
LSD	57.02	0.81	943.65	3.7	3.7	3.43

**Table 65: Yield and yield contributing characters of watermelon at Amtali, Barguna**

Treatment	Vine Length (cm)	No. of Fruits /plant	Unit weight (g/fruit)	Fruit length (cm)	Fruit dia (cm)	Yield (t/ha)
Drip	495.58	2.75	11550.00	57.60	29.22	49.14
RBI	469.09	2.25	9587.50	48.77	25.36	44.88
FP	405.72	1.75	7576.25	41.57	23.17	43.25
CV (%)	7.21	14.81	10.24	4.33	5.88	4.33
LSD	57.01	0.57	1696.57	3.7	2.64	3.43

**Table 66: Yield and yield contributing characters of watermelon at Chunakhali, Amtali, Barguna**

Treatment	Vine Length (cm)	No. of Fruits /plant	Unit weight (g/fruit)	Fruit length (cm)	Fruit dia (cm)	Yield (t/ha)
Drip	486.798	2.75	10350.00	52.13	24.84	42.36
RBI	460.303	2.25	8387.50	43.30	20.98	38.10
FP	396.938	2	6376.25	36.10	18.79	36.47
CV (%)	7.35	2.42	11.71	4.87	7.08	5.08
LSD	57.01	0.86	1696.57	3.7	2.64	3.43

**Table 67: Yield and yield contributing characters of watermelon at Kotbaria, Barguna Sadar, Barguna**

Treatment	Vine Length (cm)	No. of Fruits /plant	Unit weight (g/fruit)	Fruit length (cm)	Fruit dia (cm)	Yield (t/ha)
Drip	400.74	2.25	9233.75	38.49	21.09	32.08
RBI	391.14	2	8575.50	37.11	19.09	29.83
FP	388.39	1.5	8242.50	35.45	18.46	27.51
CV (%)	3.9	5.85	5.45	4.35	1.29	12.15
LSD	26.57	1.18	819.96	2.79	0.43	6.26

Water applied by different irrigation methods using solar pump for irrigation in watermelon is given in Table 68. Irrigation water savings in watermelon by ring basin method and drip method over farmers' practice in different locations of the southern region were 30-34% and 52-55%, respectively. So, drip irrigation method was found the best water saving technology for irrigation in watermelon followed by alternate furrow irrigation method.

**Table 68: Amount of water applied and water savings in watermelon in different treatments at different locations**

Treatments	Boro Char Kajol, Galachipa, Patuakhali		Char Badai, Galachipa, Patuakhali		Ghatkhali, Amtali, Barguna		Chunakhali, Amtali, Barguna		Kotbaria, Barguna Sadar, Barguna	
	Irrigation applied (mm)	Water saving (%)	Irrigation applied (mm)	Water saving (%)	Irrigation applied (mm)	Water saving (%)	Irrigation applied (mm)	Water saving (%)	Irrigation applied (mm)	Water saving (%)
Drip	315	53.40	318	52.11	322	53.06	328	53.93	338	54.08
RBI	473	30.03	463	30.27	452	34.11	486	31.74	489	33.56
FP	676	-	664	-	686	-	712	-	736	-

#### **Irrigation to chilli by solar pump**

Yield and yield contributing parameters of chilli at different sub-project locations are presented in Tables 69-70. Among the three water application methods, the highest yield of chilli was obtained from drip irrigation but it was not statistically significant from other treatments. This indicates that in respect of yield all are similar or in other words, response of chilli to drip irrigation is nothing different from other application methods.

**Table 69: Yield and yield contributing characters of chilli at Panpotti, Galachipa, Patuakhali**

Treatment	Plant height (cm)	No. of fruits /plant	Unit weight of fruit (g)	Fruit length (cm)	Fruit dia (cm)	Yield (t/ha)
Drip	26.68	449.45	1.67	5.66	2.62	12.5
AFI	25.51	439.1	1.65	5.52	2.59	12.4
FP	24.16	435.86	1.55	5.45	2.57	12.21
CV	4.02	4.41	5.51	4.41	7.54	5.75
LSD	1.77	33.68	0.15	0.42	0.34	1.23

**Table 70: Yield and yield contributing characters of chilli at Char Biswas, Galachipa, Patuakhali**

Treatment	Plant height (cm)	No. of fruits /plant	Unit weight of fruit (g)	Fruit length (cm)	Fruit dia (cm)	Yield (t/ha)
Drip	29.67	451.25	1.27	5.66	2.62	10.47
AFI	28.50	442.00	1.26	5.52	2.59	10.42
FP	27.15	438.50	1.16	5.44	2.56	10.22
CV (%)	6.00	1.16	7.25	4.41	7.54	6.22
LSD	2.95	8.92	0.15	0.42	0.34	1.12

The quantity of water applied and water savings among the treatments under solar pump system in chilli is shown in Table 71. It is observed from the table that about double amount of water was required in farmers' practice than drip method. Irrigation water savings in chilli by alternate furrow method and drip method over farmers' practice in different locations of southern region were, 30-36% and 60-61%, respectively. Thus, having producing similar yields of chilli drip irrigation saved the water most and so drip irrigation method was judged the best water saving technology for chilli cultivation followed by alternate furrow irrigation method.

**Table 71: Amount of water applied and water savings in chilli in different treatments at different locations**

Treatments	South Char Biswas, Galachipa, Patuakhali		Panpotti, Galachipa, Patuakhali	
	Irrigation applied (mm)	Water saving (%)	Irrigation applied (mm)	Water saving (%)
Drip	98	61.26	96	60.66
AFI	162	35.97	170	30.33
FP	253	-	244	-

#### 11.4.2 BRRI component

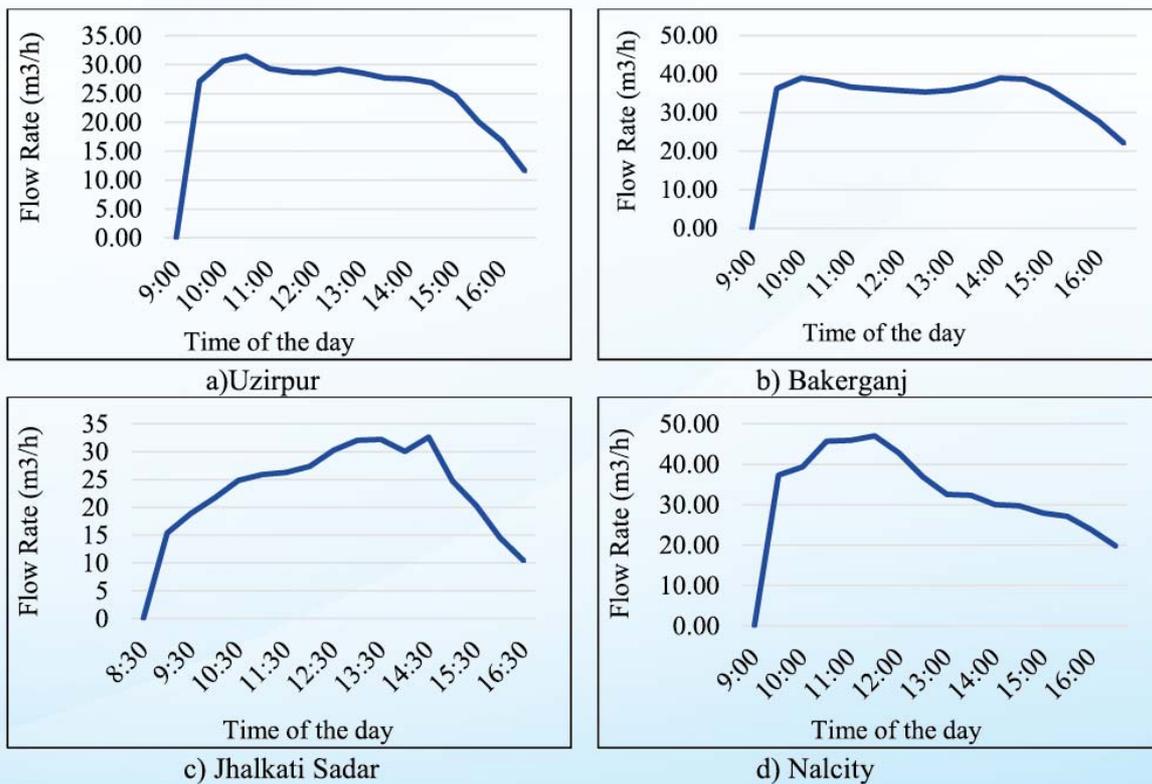
##### Experiments in farmers' fields and data collection

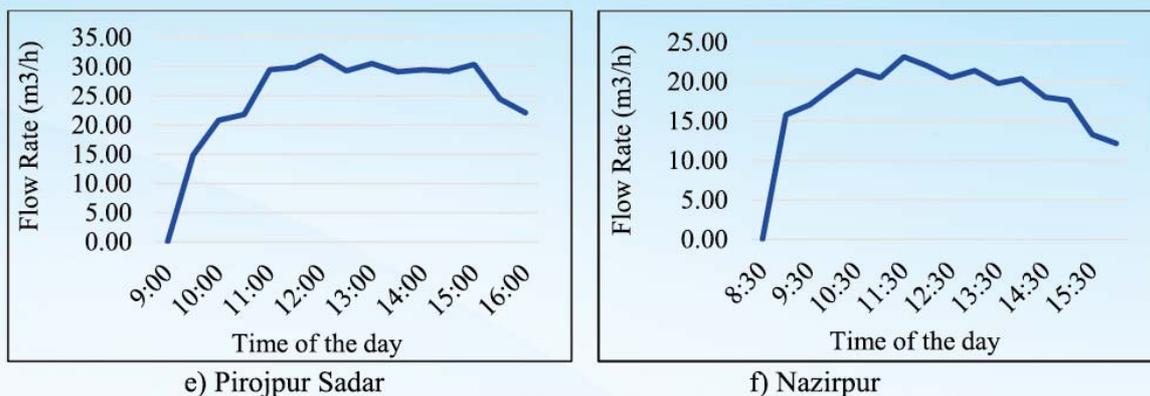
The field research was conducted aiming to observe the technical and economic feasibility of solar PV systems for irrigation and home applications. In this respect, performance of solar panels, pumps and home appliances were tested in the selected farmers' crop fields and houses. Pump performances in respect of head, discharge and irradiance for rice irrigation, household water supply and threshing were evaluated with the supply of power from solar panels. Further, power was supplied from panels to run home appliances like bulbs, table fans, mobile chargers etc.

### Field test and crop demonstrations

BRRRI developed HYV rice varieties were demonstrated in the selected farmers' fields during Boro and Aman seasons. Both inbred and hybrid rice varieties were selected as per farmers' choice. No irrigation was required during Aman season. Portable solar panels were brought back home after the end of rice irrigation in Boro season. The system was then used for supplying power to home appliances. The solar pump system was kept in the field for 3-4 months for land preparation and subsequent irrigations to rice crop.

The performances of solar pumps were tested at different pumping heads in the selected locations of Barishal region. Figure 80 presents the flow rate of the solar pumps at different times of the day in the selected locations. The discharge data were recorded with an interval of half an hour during the operating time. Figure 80 shows that the discharge increased with the increase of solar radiation. It was zero at the start of the day (at 8-9 a.m.) and increased with the increase of solar radiation attaining the maximum value at mid-day. After that it decreased gradually showing lower values towards the evening. All pumps generated flow rate above 30 m<sup>3</sup>/h except that at Nazirpur upazila. Although all the solar pumps were of the same brand, the variations of the dynamic heads and the intensity of the solar radiation caused the variation of the flow rates. The incident solar radiation varied not only at different times of the day but also on different days of the testing periods. Highest maximum flow rate (46.98 m<sup>3</sup>/h) was observed at Nalcity upazila of Jhalkati district (Fig. 80 d) and the lowest minimum (23.14 m<sup>3</sup>/h) at Nazirpur upazila of Pirojpur district (Fig. 80 f). The pump flow rate versus time graphs are shown with a time interval of one hour.





**Fig.80: Flow rate (m<sup>3</sup>/h) of the solar pumps under different times of the day at selected upazila of Barishal region**

### Land preparation of Boro rice

Usually the Boro season is pushed back in the southern region of the country as the T. Aman harvest takes longer duration. Thus, during the Boro season of 2020-21, solar pumps were taken in the field at the start of January. However, the land preparation time was not the same in every upazila. Figure 81 shows the land preparation scenario of Bakerganj upazila, Barishal. During data collection, it was observed that land preparation started from 8:00 am to 9:30 am and ended from 16.30 pm to 17:00 pm depending on the availability of solar radiation. From the field data it is seen that the daily highest land preparation was covered by BRRRI portable solar pump in Bakerganj and Nalcity upazilas and the lowest was found in Nazirpur and Jhalkati Sadar upazilas (Table 72). Using the solar pump, the daily average quantity of land prepared for seedling transplantation was 0.33ha. During this time, the average pump discharge was recorded 6.36 l/s when the average solar radiation was 542 W/m<sup>2</sup> (Table 72).

**Table 72: Daily area coverage by the solar pumps during land preparation in Boro 2020-21**

Location	Starting Time	Closing Time	Average Irradiation (W/m <sup>2</sup> )	Average Discharge (l/s)	Area coverage (ha/day)
Uzirpur	8:00 AM	16:30 PM	414	5.22	0.32
Bakerganj	9:00 AM	16:30 PM	652	9.55	0.40
Jhalkati Sadar	9:30 AM	16:30 PM	502	6.89	0.27
Nalcity	9:00 AM	16:30 PM	584	7.16	0.40
Pirojpur sadar	8:30 AM	17:00 PM	632	4.21	0.35
Nazirpur	8:00 AM	16:00 PM	471	5.16	0.27
<b>Average</b>			<b>542</b>	<b>6.36</b>	<b>0.33</b>

As the targeted area at each site was 2 ha of land, it took around 6 hours by the pump to cover this area. However, the time differed slightly depending upon the intensity of solar radiation. Even, in a few areas, the entire 2 ha could not be covered due to continuous foggy weather. Firefighting (canvas) hose pipes were used to keep the conveyance loss of water to a minimum quantity. Farmers used diesel operated LLP as supplemental source of irrigation water during land preparation. This is a limitation of the solar pump.



**Fig. 81: Land preparation activities by using solar pump in Barshal region**

#### **Daily irrigation coverage by the solar pumps**

After crop establishment, the daily water requirement of Boro cultivation was lower than that required for land preparation. Data in respect of irrigation were recorded to find the daily area coverage after transplantation in different locations. Table 73 shows the daily irrigation coverage by the solar pumps after establishment of Boro rice. Farmers of the selected locations usually started applying water to fields between 8:30 and 9:00 am and stopped irrigation between 16:00 and 16:30 pm. Sometimes they started earlier depending on the availability of sunshine. The farmers started to transplant their seedlings in the first week of February. Figure 82 shows some activities regarding irrigation in the rice field.



**Fig. 82: Field irrigation activities after transplanting by using solar pump in Barishal region**

As the farmers started seedling transplantation in the first week of February, the growth duration of Boro rice was found comparatively shorter than that of the other regions of the country. This occurred due to higher temperature and solar radiation during the growing period of Boro rice. During this growth period of Boro rice, average solar radiation prevailed about 6-7 W/m<sup>2</sup> in this region. The daily average operating time of the solar pump was 7.42 hrs. (Table 73). It is also seen from the Table 73 that the daily highest irrigated area (0.6 ha) was obtained at Nalcity and the lowest at Bakerganj (0.32ha). The region average daily irrigated area was 0.47 ha. The irrigation interval of the solar pump varied from 4 to 7 days to cover the desired command area depending on the flow rate and texture of the soil of the respective locations (Table 73).

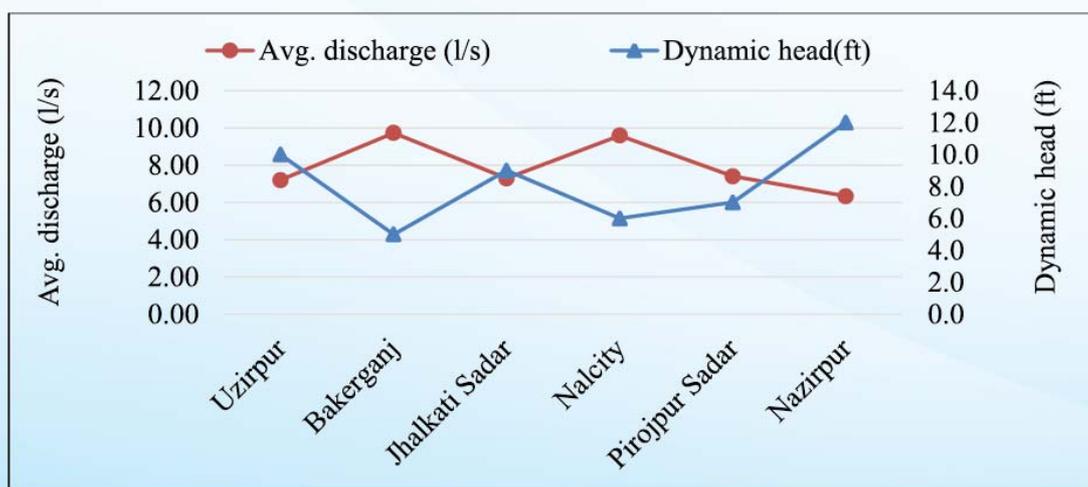
**Table 73: Daily irrigation coverage by the solar pumps after crop establishment during Boro Season of 2020-21**

Location	Starts Time (AM)	Close Time (PM)	Operating time/day (hr)	Avg. flow rate (l/s)	Total flow (l)	Area irrigated (ha)	Irrig. interval (days)
Uzirpur	9:00	16:30	7.5	7.20	194400	0.47	4.00
Bakerganj	9:00	16:30	7.5	9.73	262710	0.54	7.00
Jhalkati Sadar	9:00	16:30	7.5	7.29	196830	0.54	5.00
Nalcity	9:00	16:30	7.5	9.59	258930	0.60	4.00
Pirojpur Sadar	9:00	16:00	7.0	7.40	186480	0.37	4.00
Nazirpur	8:30	16:00	7.5	6.33	170910	0.32	4.00
<b>Region average</b>			<b>7.42</b>	<b>7.92</b>	<b>211710</b>	<b>0.47</b>	<b>4.67</b>

The highest irrigation interval was 7 days at Bakerganj followed by Jhalkati Sadar (5 days) and the lowest, 4 days at Uzirpur, Nalcity, Pirojpur Sadar and Nazirpur. The region average irrigation interval was 4.67 days. So after transplanting, solar pump covered the desired command area (2 ha/location) properly. High quality firefighting (Canvas) hose pipes were supplied to the farmers to minimize the conveyance loss. Also, AWD method was applied in the experimental fields. Based on AWD technique, 4-5 cm irrigation water was applied in the fields per irrigation. It was found that the solar pumps at different sites produced sufficient discharges from January to May with the available solar radiations and the flow rates were sufficient for irrigating Boro lands.

#### Discharge and dynamic head relationship of BRRI solar pump

Experiments were conducted in all six locations during the middle of March, 2021 after Boro crop establishment to form a relationship between dynamic head and discharge of the solar pump. Fig. 83 shows that the highest dynamic head (12 ft) was found at Nazirpur upazila of Pirojpur district and the respective average discharge was 6.33 l/s. On the other hand, the lowest dynamic head (5ft) was observed at Bakerganj upazila of Barishal district and the respective average discharge was 9.73 l/s. The characteristic of solar pump was found to match with the theoretical characteristics of pump where the discharge increased as the head decreased and vice versa (Fig. 83).

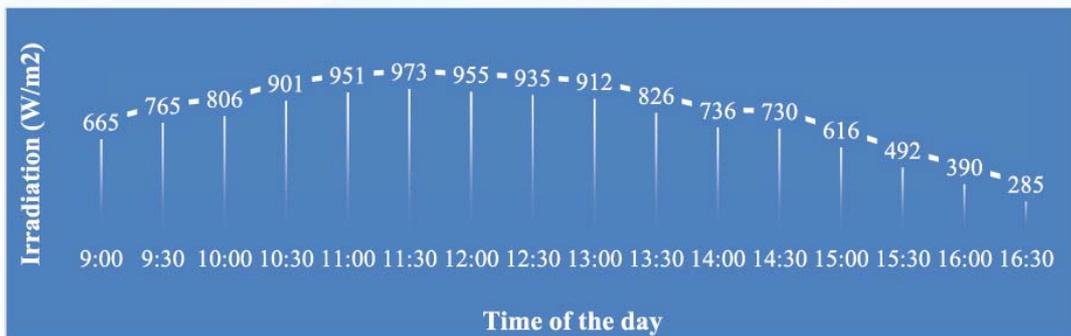


**Fig. 83: Relationship between average discharge and dynamic head at the selected locations of BRRI solar pump**

### Spatial simulation of flow rate using solar radiation

Solar radiation, often called the solar resource or just sunlight, is a general term for the electromagnetic radiation emitted by the sun. Solar radiation can be captured and turned into useful forms of energy, such as heat and electricity, using a variety of technologies. Solar irradiation is the amount of sun energy per unit of area, i.e.,  $\text{MJ}/\text{m}^2$  and Solar irradiance is the rate of solar energy received on an earth surface or is the solar power incident per unit area on the earth's surface. Solar irradiance has the unit of energy per unit of time per unit of surface area, i.e.,  $(\text{MJ}/\text{T})/\text{m}^2$  or  $\text{W}/\text{m}^2$ . It is the most important parameter for a PV system. The amount of the solar irradiance for a specific location is important in the optimization of a PV system (Markvart and Castaner, 2003). Different parts of the world have different solar irradiance levels.

Integrating extraterrestrial radiation over a specific time, usually an hour or half an hour, half hourly radiation was obtained. Solar radiation at different times of a day is shown in Fig.84. The test was carried out on 16 March 2021 at Nalcity upazila from morning till evening. Solar radiation was measured by irradiance meter. The data shown are the radiation values for a PV panel surface fixed at a tilt angle equal to the latitude of the location ( $22.6283^\circ\text{N}$ ,  $90.2688^\circ\text{E}$ ).



**Fig. 84: Relationship between solar irradiance and time of day**

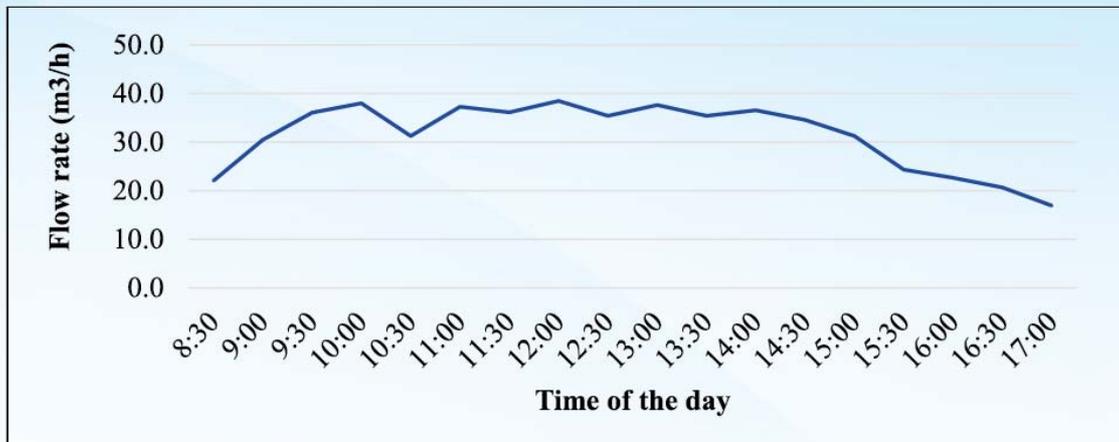
Figure 84 depicts the highest amount of solar radiation obtained at 11:30 pm when irradiance was 973 watts. The solar radiation increased from morning to 11:30 pm and then it started to decrease.

### Flow rate Calculation

The flow rate of the solar pump was calculated at 30-minute intervals by using a flow meter in the field. The corresponding irradiance was recorded simultaneously on the same day at Sadar upazila of Pirojpur district. Similarly, the volume of water pumped, time and irradiance from 8.30 am to 5.00 pm were recorded. By integrating the measured half hourly volume of water, the flow rate was calculated by dividing this volume by the recorded time (half an hour). The test was done from morning to evening and got the pump flow rates at different times of the day.

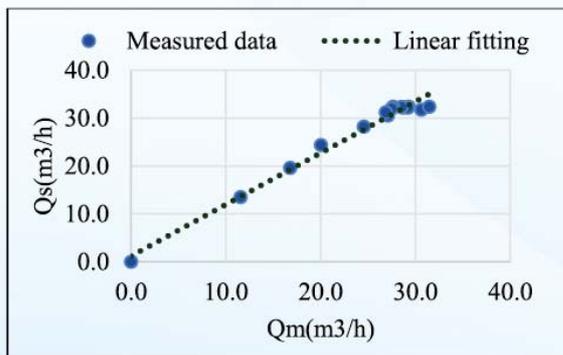
From Figure 85 it is seen that the highest flow rate was  $38.05 \text{ m}^3/\text{h}$  at 12:00 pm when the irradiance was  $1005 \text{ W}/\text{m}^2$ . The highest irradiance ( $1035 \text{ W}/\text{m}^2$ ) was obtained at 12:30 pm. But the flow rate decreased suddenly and the pump stopped at 12:30 pm when irradiance was more than  $1005 \text{ W}/\text{m}^2$ . According to Sumathey *et al.* (1997), the efficiency of PV system was increased with the increase of ambient temperature up to  $30^\circ\text{C}$  and then decreased with increase of temperature. An ideal condition reveals that the maximum irradiance should not exceed  $1000 \text{ W}/\text{m}^2$  and the ambient temperature near or equal to  $30^\circ\text{C}$ . Beyond this level of irradiance, the solar pumps coupled with motors do not function properly. A temperature sensor was used to control the solar pump to protect it from overheating during over irradiance (over  $1000 \text{ W}/\text{m}^2$ ). So the maximum discharge can be obtained at the ideal condition with irradiance level,  $1000 \text{ W}/\text{m}^2$ . This is the limitation of the solar pump. The pumping of water (discharge) was started from morning, then it

reached the peak at 12:00 pm and then it again started decreasing. All sequential data of pump flow rates and solar radiation were collected from six upazilas during field demonstration of solar pumps.

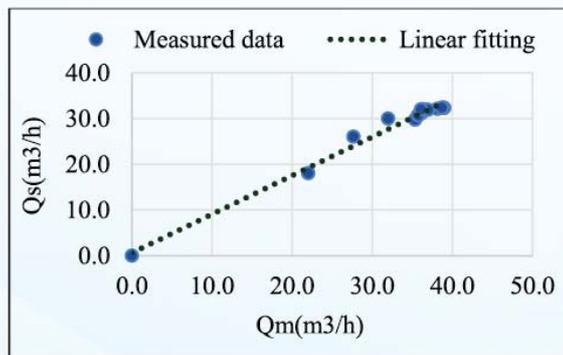


**Fig. 85: Flow rate (m<sup>3</sup>/h) versus time of the day**

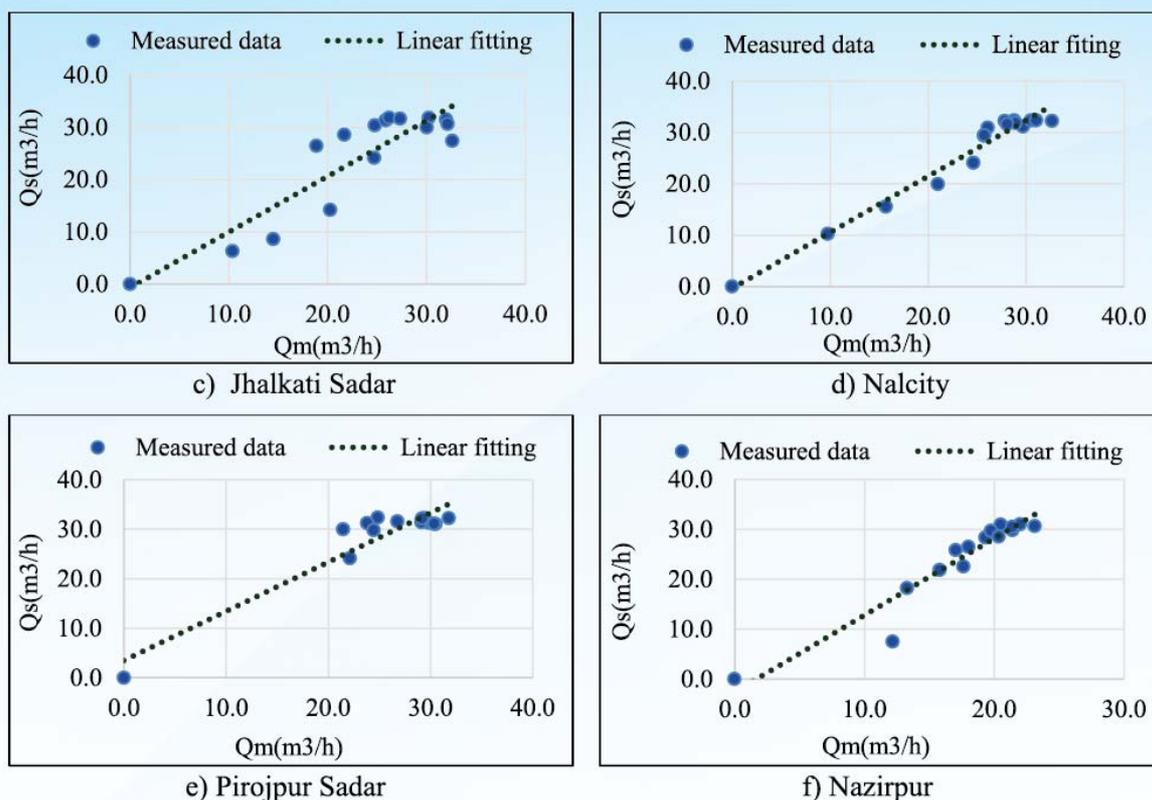
Knowing the hourly solar radiation data, the flow rate  $Q$  could be simulated from the generated relationship between irradiance and flow rate for the selected locations of Barishal region keeping the water head, panel configuration and pump characteristics intact. Fig. 86 (a, b, c, d, e and f) show the comparison between the simulated flow rate  $Q_s$  (Equation 1, Section 11.2.5) and the measured (experimental) data of flow rate  $Q_m$  for Uzirpur, Bakerganj, Jhalkati Sadar, Nalcity, Pirojpur Sadar and Nazirpur upazila, respectively. Good correlations were obtained between the simulated and experimental flow rates. The site wise relationships between  $Q_m$  and  $Q_s$  were developed and the equations and level of correlations are given in Table 74.



a) Uzirpur



b) Bakerganj



**Fig. 86: Simulated flow rate  $Q_s$  vs. measured flow rate  $Q_m$  for the selected upazilas**

**Table 74: Linear correlation between simulated and experimental water flow rate**

Location	$Q_s = f(Q_m)$	Correlation coefficient, $R^2$
Uzirpur	$Q_s = 1.075 Q_m + 1.1947$	0.9818
Bakerganj	$Q_s = 0.8448 Q_m + 0.583$	0.9827
Jhalkati Sadar	$Q_s = 1.0666 Q_m - 0.7277$	0.8084
Nalcity	$Q_s = 1.0911 Q_m - 0.3694$	0.9656
Pirojpur Sadar	$Q_s = 0.9937 Q_m + 3.4467$	0.8849
Nazirpur	$Q_s = 1.536 Q_m - 2.5898$	0.9111

#### Performance of BRRRI solar open drum thresher

After harvesting Boro and Aman rice, farmers used solar power operated BRRRI open drum thresher for paddy threshing in their house yards. The efficiency of the thresher varied from location to location due to the intensity of the solar radiation as well as efficiency of labours. During Boro season, farmers used their solar thresher in the month of May to June. On the other hand, during Aman season, they used it between the months of December and January. So, solar intensity and operating time were different in two seasons. The analyzed data of Boro season are shown in Table 75. The highest threshing capacity (309 kg/hr) was found at Pirojpur Sadar and that the lowest at Jhalkati Sadar (260 kg/hr). Considering the average yield of rice in Boro season to be 6 t/ha at all the sub-project locations, the time required to thresh paddy of 1 bigha (0.134 ha) of land was found about 3 to 3.8 days (Table 75). From the same table it is found that the region average threshing capacity was 280 kg/hr. With this threshing capacity, 1727 Kg of paddy could be threshed per day. So, the region average required time to thresh paddy of 1 bigha (0.134 ha)

land was 3.5 days (Table 75) depending on the intensity of the solar radiation. Some threshing activities have been shown in Figure 87.

**Table 75: Performance of BRRI solar open drum thresher in the sub-project locations**

Upazila	Operating duration (hr)	Operators used	Threshed paddy (kg)	Thresher capacity (kg/hr)	Threshing time of 1 bigha (0.134 ha) of land (day)
Bakerganj	6.0	2	1680	280	3.6
Uzirpur	6.0	2	1740	290	3.4
Jhalkati Sadar	6.0	2	1560	260	3.8
Nalcity	6.0	2	1620	270	3.7
Pirojpur Sadar	6.5	2	2010	309	3.0
Nazirpur	6.5	2	1750	269	3.4
<b>Region average</b>			<b>1727</b>	<b>280</b>	<b>3.5</b>



**Fig. 87: Boro rice threshing by using BRRI solar open drum thresher**

#### **Boro irrigation under solar pump in sub-project area**

In Bangladesh, about 96 percent of the yearly rainfall occurs during the month of April to October, leaving the remaining five months of the year essentially dry. Drought conditions prevail over most of the country during the months from November to April, when potential evapotranspiration exceeds rainfall substantially. Boro rice is grown during this dry period of the year and it is a water hunger crop. Thus, the crop cannot sustain during this period with rainfall alone and thus irrigation becomes essential. On the other hand, the monsoon rainfall is sufficient to cultivate T. Aman rice without any irrigation in Barishal region.

#### **Boro crop cultivation in different sub-project sites under solar pump**

BRRI released HYV and hybrid rice varieties were used in the sub-project sites. To ensure expected production, regular field monitoring, data collection and farmer interactions were done. Date of seedbed preparation, transplanting and crop cutting were found to vary for different rice varieties. The varieties were introduced as per the preference of the selected farmers. Table 76 shows the different rice varieties and crop establishment parameters of 3 years of Boro demonstrations in the selected locations. Seedbed preparation and transplanting dates were different in the sub-project areas due to variations in resource availability. It was observed from the 3 years of Boro demonstrations that BRRI dhan74 known as a zinc enriched high yielding variety (HYV) gave the stable and sustainable yield at all the locations except Sadar upazila of Pirojpur district. Farmers of Pirojpur Sadar upazila had the choice to cultivate BRRI hybrid dhan 3 and BRRI hybrid dhan5. Farmers of Barishal region usually prefer to eat bold grained rice. BRRI dhan74 being a bold grained rice variety, it is gaining popularity day by day in region. From crop and solar PV system demonstrations, the farmers were trained about agronomic practices

including crop irrigation and its management. Alternate wet and drying (AWD) method of irrigation was demonstrated to the farmers to increase the water use efficiency. Figure 88 shows some activities during Boro crop establishment in different locations of the selected districts.

**Table 76: Date of transplanting and yield of Boro varieties in the sub-project locations**

Year	Variety	Date of seeding	Date of transplanting	Date of harvesting	Yield (t/ha)
<b>Location: Bakerganj</b>					
2018-2019	BRRRI dhan74	08.01.19	05.03.19	20.05.19	5.40
2019-2020	BRRRI dhan74	02.01.20	12.02.20	14.05.20	6.74
2020-2021	BRRRI dhan74	02.01.21	07.02.21	18.05.21	7.10
<b>Location: Uzirpur</b>					
2018-2019	BRRRI dhan28	12.01.19	16.02.19	08.05.19	6.50
	BRRRI dhan74	14.01.19	17.02.19	09.05.19	6.80
2019-2020	BRRRI dhan74	26.01.20	25.02.20	10.05.20	7.95
2020-2021	BRRRI dhan74	10.12.20	14.01.21	10.05.20	7.50
<b>Location: Nalcity</b>					
2018-2019	BRRRI dhan67	17.12.18	10.02.19	12.05.19	5.90
	BRRRI dhan74				4.90
2019-2020	BRRRI dhan74	25.12.19	15.02.20	15.05.20	6.25
2020-2021	BRRRI dhan89	25.12.20	18.02.21	22.05.21	6.90
<b>Location: Jhalkati Sadar</b>					
2018-2019	BRRRI dhan67	16.01.19	23.02.19	12.05.19	8.60
2019-2020	BRRRI dhan74	02.12.19	03.02.20	11.05.20	6.84
2020-2021	BRRRI dhan74	05.12.20	18.01.21	26.04.21	6.00
<b>Location: Pirojpur Sadar</b>					
2018-2019	BRRRI hybrid dhan2	17.12.18 to 02.01.19	15.01.19 to 12.02.19	14.05.19	6.60
	BRRRI hybrid dhan 3				8.00
	BRRRI hybrid dhan5				8.30
	BRRRI dhan67				6.70
2019-2020	BRRRI hybrid dhan 3	13.12.20	05.01.20	16.05.20	7.87
	BRRRI hybrid dhan 5		08.01.20		7.39
2020-2021	BRRRI hybrid dhan 3	05.12.20	15.01.21	12.05.20	7.90
	BRRRI hybrid dhan 5				8.25
<b>Location: Nazirpur</b>					
2018-2019	BRRRI dhan28	10.12.18 to 25.12.18	10.01.19 to 25.01.19	09.05.19	7.00
	BRRRI dhan64				7.50
	BRRRI dhan67				6.50
	BRRRI dhan74				7.70
2019-2020	BRRRI hybrid dhan 3	07.01.20	13.02.20	11.05.20	8.14
	BRRRI hybrid dhan 5		15.02.20		6.74
2020-2021	BRRRI dhan74	02.12.20	23.01.21	29.04.21	6.25



**Fig. 88: Some activities during Boro crop establishment in different locations of the selected Barishal region**

As seen from Table 77, the water productivity calculated based on total water applied ranges from 43.75 to 81.37 kg/ha-cm over the years and locations. The maximum water productivity was obtained from BIRRI hybrid dhan 5 during 2015-19 at Pirojpur Sadar, while the lowest water productivity was found from BIRRI dhan 74 during the same year at Nalcity. The quantity of applied water did not vary too much with a range of 105 to 123 cm over the years. The table also reveals that the variety of rice played an important role in controlling the water productivity. The findings of water productivity are mostly similar to that (65 kg/ha-cm) obtained by Hossain and others (2016).

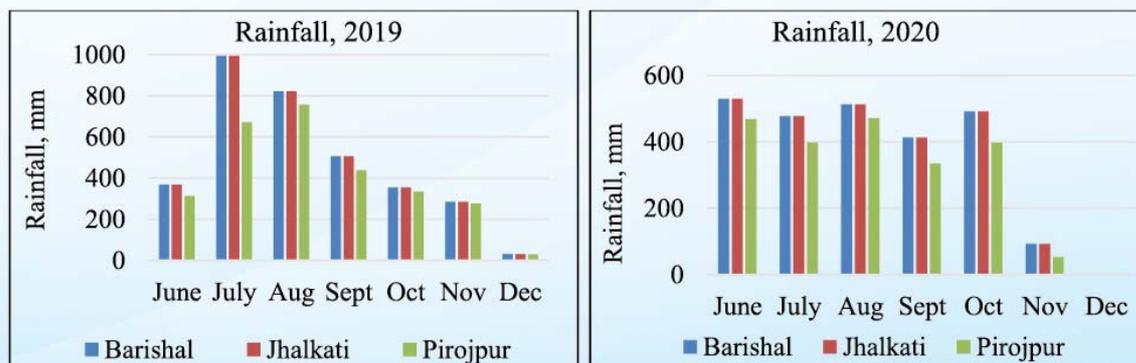
**Table 77: Water productivity of Boro varieties in the sub-project locations**

Year	Variety	Total water applied (cm)	Yield (t/ha)	Water productivity (Kg/ha-cm)
<b>Location: Bakerganj</b>				
2018-2019	BIRRI dhan74	105	5.40	51.43
2019-2020	BIRRI dhan74	110	6.74	61.27
2020-2021	BIRRI dhan74	109	7.10	65.14
<b>Location: Uzirpur</b>				
2018-2019	BIRRI dhan28	106	6.50	61.32
	BIRRI dhan74		6.80	64.15
2019-2020	BIRRI dhan74	107	7.95	74.30
2020-2021	BIRRI dhan74	109	7.50	68.81
<b>Location: Nalcity</b>				
2018-2019	BIRRI dhan67	112	5.90	52.68
	BIRRI dhan74		4.90	43.75
2019-2020	BIRRI dhan74	106	6.25	58.96
2020-2021	BIRRI dhan89	123	6.90	56.10

Year	Variety	Total water applied (cm)	Yield (t/ha)	Water productivity (Kg/ha-cm)
<b>Location: Jhalkati Sadar</b>				
2018-2019	BRRi dhan67	113	8.60	76.11
2019-2020	BRRi dhan74	108	6.84	63.33
2020-2021	BRRi dhan74	116	6.00	51.72
<b>Location: Pirojpur Sadar</b>				
2018-2019	BRRi hybrid dhan2	102	6.60	64.71
	BRRi hybrid dhan3		8.00	78.43
	BRRi hybrid dhan 5		8.30	81.37
	BRRi dhan67		6.70	65.69
2019-2020	BRRi hybrid dhan3	110	7.87	71.55
	BRRi hybrid dhan 5		7.39	67.18
2020-2021	BRRi hybrid dhan3	108	7.90	73.15
	BRRi hybrid dhan 5		8.25	76.39
<b>Location: Nazirpur</b>				
2018-2019	BRRi dhan28	115	7.00	60.87
	BRRi dhan64		7.50	65.22
	BRRi dhan67		6.50	56.52
	BRRi dhan74		7.70	66.96
2019-2020	BRRi hybrid dhan3	118	8.14	68.98
	BRRi hybrid dhan 5		6.74	57.12
2020-2021	BRRi dhan74	110	6.25	56.82

#### Aman cultivation in sub-project area during wet season

The selected locations are under non-saline tidal ecosystem of Barishal region. It is also affected by daily tide and monsoon tide. But among them, Nazirpur upazila of Pirojpur district is not affected by daily tide and monsoon tide. During 2019 and 2020, rainfall exceeded the normal quantity over the growing period of T. Aman (Fig.89) in Barishal region. So, there was no irrigation requirement during growing period. The major environmental problem from crop production in the tidal wetlands was the inundation of land by tides.



**Fig. 89: Rainfall during T. Aman 2019 and 2020 in Barishal region**

It occurred twice daily over a period of 5 to 8 months (April to November) of the year with the highest peak being normal in August (Panauallah *et al.*, 1993). The tidal water depth during normal transplanting time of T. Aman usually remains high. On the other hand, the modern varieties are short statured and does not fit in such situation. So, BRRi dhan76 and BRRi dhan52 were found

suitable as these varieties are much taller than any other modern T. Aman varieties and also produce yield greater than 4.0 t/ha (Table 78). So, farmers had their choice to cultivate BRRi dhan52 and BRRi dhan76 in tidal ecosystem of Barishal region. But, in Nazirpur, the sites remain out of tidal ecosystem and the farmers chose to cultivate BRRi Hybrid dhan4, BRRi hybrid dhan6 and BRRi dhan52 for higher yields. Some pictorial views of T. Aman are shown in Fig. 90.

**Table 78: Date of transplanting and yield of Aman varieties in the sub-project locations**

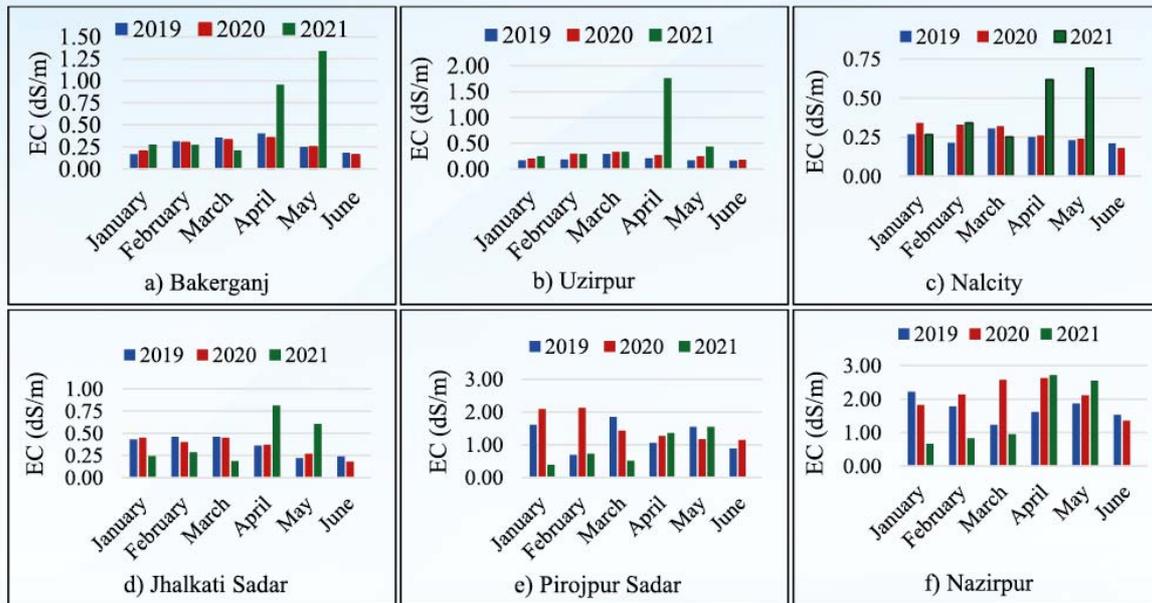
Year/Yield parameters	Variety	Date of seeding	Date of transplanting	Date of harvesting	Yield (t/ha)
<b>Location: Bakerganj</b>					
2019	BR 23	01.07.19	22.08.19	15.12.19	4.37
2020	BRRi dhan 52	15.06.20	12.08.20	19.12.20	4.50
<b>Location: Uzirpur</b>					
2019	BRRi dhan76	05.07.19	23.08.19	27.11.219	4.14
2020	BRRi dhan 52	05.07.20	10.09.20	10.11.20	4.25
<b>Location: Nalcity</b>					
2019	BRRi dhan76	26.06.19	13.08.19	03.12.19	4.03
2020	BRRi dhan 72	25.06.20	15.08.20	23.12.20	4.50
<b>Location: Jhalkati Sadar</b>					
2019	BRRi dhan76	28.06.19	22.08.19	15.12.19	4.49
2020	BRRi dhan 52	02.07.20	14.09.20	23.12.20	4.50
<b>Location: Pirojpur Sadar</b>					
2019	BRRi dhan76	10.07.19	25.08.19	08.12.19	4.26
2020	BRRi dhan 52	12.07.20	09.09.20	13.12.20	5.00
<b>Location: Nazirpur</b>					
2019	BRRi Hybrid dhan4	12.07.19	12.08.19	18.11.19	5.87
	BRRi hybrid dhan6	12.07.19	12.08.19	18.11.19	5.52
2020	BRRi dhan 52	15.06.20	18.07.20	02.11.20	4.95



**Fig. 90: Some activities during Aman crop establishment in different locations**

### Canal water salinity in the sub-project areas

In order to ensure quality irrigation water, salinity content of the sub-project areas was measured. Six canals were selected adjacent to the fields from which the respective fields were irrigated to collect EC data from January to June. The data were collected from six inch below the water surface and this process was repeated three times in the same canal from three different places to ensure acceptable average value. The EC data of 3 years of six different locations are presented in Figure 91.



**Fig. 91: Salinity dynamics of canal water in consecutive 3 years of the sub-project sites**

From the graphs (Fig.91), Nazirpur and Pirojpur Sadar are found to show higher EC values implying more salinity in those areas. Highest value was recorded in Nazirpur, 2.71 dS/m in the month of April 2021. In the same month, the maximum daytime temperature ranged from a low of 3.9 degrees Celsius to a high of 6.8 degrees Celsius. So, river water salinity increased in most of the southern rivers of Bangladesh in 2021. Figure 91 shows that EC is greater than 1 dS/m in Pirojpur Sadar and Nazirpur upazila of Pirojpur district. EC of other four locations were found much lower than 1 dS/m except Uzirpur upazila in April 2021. EC of some locations also increased in the month of May due to higher temperature and the effect of Cyclone “Yaas”. Boro rice usually attains the growing stage of hard dough to maturity here in April to May and thus, in this stage, salinity does not affect the yield of rice. Rice is most sensitive to salinity at the 3-leaf growth stage and panicle initiation stage (Zeng et al., 2001). Rice yield starts to decrease when irrigation water salinity is greater than 1 dS/m (Zeng et al., 2001). Fig. 91 shows that salinity level of irrigation water in all the locations remained below 1 dS/m during the above mentioned stages. The salinity values recorded in the sites were below hazardous levels and the crops were not affected at all by salinity. Some variations of data throughout the time were observed most likely due to the influence of tidal flow and rainfall in the selected canals. In short, the canals contained good quality of water for irrigation in respect of water salinity.

## 11.5 Application of solar photovoltaic panel (both portable and non-portable) to operate household appliances round the year during off irrigation period

### 11.5.1 BARI Component

Solar pumps and household appliances were installed successfully in the selected locations. The pictorial views of installed solar pumps and SHSs are shown in Fig. 92.



a. Solar pump installation at Galachipa, Patuakhali



b. Solar pump installation at Kalapara, Patuakhali



c. Solar pump installation at Barguna, Sadar, Barguna



d. Solar pump installation at Amtali, Barguna



e. Solar pump installation at Char Fasson



f. Solar pump installation at Lalmohon, Bhola



g. Solar pump installation at FMPE pump test bed, BARI, Gazipur

**Fig 92: Solar pump installation in all sub-project locations.**

Mini-Solar pumps and household appliances were installed successfully in the selected locations. The pictorial views of installed solar pumps and SHSs are shown in Fig. 93.



a. Solar pump installation at Barguna Sadar, Barguna



b. Solar pump installation at Barguna Sadar, Barguna



c. Solar pump installation at Amtali, Barguna



d. Solar pump installation at Amtali, Barguna



e. Solar pump installation at Galachipa, Patuakhali



f. Solar pump installation at Galachipa, Patuakhali



g. Solar pump installation at Charkajol, Galachipa, Patuakhali



h. Solar pump installation at Charkajol, Galachipa, Patuakhali



i. Solar pump installation at Charkajol, Galachipa, Patuakhali



j. Solar pump installation at Pakhimara, Kalapara, Patuakhali



k. Solar pump installation at Lalmohon, Bhola



l. Solar pump installation at Char Fasson, Bhjola

**Fig. 93: Mini solar pump and SHS installation at different sub-project sites**

### Performance of Large Solar Pump (910W) Based SHS (Solar Home System)

The results of field tests of solar home systems (DC mode) at different locations are given in Table 79-84. The performance of solar home systems was found quite satisfactory.

**Table 79: Field performance of SHS at Galachipa, Patuakhali**

Item	PV (W)	Battery (W)		Name of appliances	Numbers/ quantity	Power per appliance (W)/services	Total Load (W)/ quantity	Remarks
		AH	Volt					
SHS	325	100	12	Light	4	7	28	Working well
				Fan	2	12	24	
				Mobile phone	1	8	8	
Water supply	1300			Sanitation and drip irrigation	500 L tank	Yard tap	1	Improved sanitation and hand wash
						Basin tap	1	
						Toilet tap	1	
						Bath tap	2	

**Table 80: Field performance of SHS at Kalapara, Patuakhali**

Item	PV (W)	Battery (W)		Name of appliances	Numbers/ quantity	Power per appliance (W)/services	Total Load (W)/ quantity	Remarks
		AH	Volt					
SHS	325	100	12	Light	5	7	35	Working well
				Fan	2	12	24	
				Mobile phone	2	8	16	
Water supply	1300			Sanitation and drip irrigation	500 L tank	Basin tap	1	Improved sanitation and hand wash
						Toilet tap	1	
						Bath tap	2	

**Table 81: Field performance of SHS at Amtali, Barguna**

Farmers Name	PV (W)	Battery (W)		Name of appliances	Numbers	Power per appliance (W)/services	Total Load (W)/ quantity	Remarks
		Ah	Volt					
SHS #1 (Nur Alam)	325	100	12	Light	3	7	21	Working well
				Fan	1	12	12	
				Mobile phone	1	8	8	
SHS #2 (Shah Alam)	325	100	12	Light	5	7	35	
				Fan	2	12	24	
				Mobile phone	2	8	16	
Water supply	1300			Sanitation and drip	500 L tank	Basin tap	2	Improved sanitation and hand wash
						Toilet tap	3	
						Bath tap	2	
						Yard tap	1	

**Table 82: Field performance of SHS at Barguna Sadar, Barguna**

Item	PV (W)	Battery (W)		Name of appliances	Numbers/ quantity	Power per appliance (W)/services	Total Load (W)/ quantity	Remarks
		AH	Volt					
SHS	325	100	12	Light	6	7	42	Working well
				Fan	2	12	24	
				Mobile phone	2	8	16	
Water supply	1300			Sanitation and drip irrigation	500 L tank	Basin tap Toilet tap Bath tap Kitchen tap	1 1 2 1	Improved sanitation and hand wash

**Table 83: Field performance of SHS at Lalmohon, Bhola**

Item	PV (W)	Battery (W)		Name of appliances	Numbers/ quantity	Power per appliance (W)/services	Total Load (W)/ quantity	Remarks
		AH	Volt					
SHS	325	100	12	Light	7	7	49	Working well
				Fan	4	12	48	
				Mobile phone	2	8	16	
Water supply	1300			Sanitation and drip irrigation	500 L tank	Basin tap Toilet tap Bath tap	2 3 2	Improved sanitation and hand wash

**Table 84: Field performance of solar pump and SHS at Char Fasson, Bhola**

Item	PV (W)	Battery (W)		Name of appliances	Numbers/ quantity	Power per appliance (W)/services	Total Load (W)/ quantity	Remarks
		AH	Volt					
SHS	325	100	12	Light	8	7	56	Working well
				Fan	3	12	36	
				Mobile phone	2	8	16	
Water supply	1300			Sanitation and drip irrigation	500 L tank	Basin tap Toilet tap Bath tap	2 3 2	Improved sanitation and hand wash

The multiple uses of solar pumps and solar panels in different household and solar home appliances at Patuakhali, Barguna and Bhola District were given below Fig. 94.



a. Solar home system at Amtali, Barguna



b. Solar home system at Barguna Sadar, Barguna



c. Solar home system at Kalapara, Patuakhali



d. Solar home system at Lalmohon

Solar home system at Char Fasson



e. Solar home system at Char Fasson



Household uses at Patuakhali



f. Solar home appliances at Barguna



Solar home system at Patuakhali



g. Household uses at Barguna



Household uses at Amtali



h. Solar home system at Char Fasson



**Fig.94: SHS and household uses of solar pump at different locations.**

### Appliances used in SHS under Mini Solar Pump

Different householders used different types and numbers of appliances under solar PV system. The appliances used under mini solar pump based solar PV system in solar home systems (DC mode) at different locations are given in Table 85-96. The performance of solar home systems was found quite satisfactory.

**Table 85: Field performance of mini solar pump based SHS at Gazi Mahmud, Barguna Sadar, Barguna**

System	Panel Power (W <sub>p</sub> )	Battery power (W)		Name of appliances	Numbers	Unit load (W)	Total Load (W)	Remarks
		Ah	Volt					
SHS	365	100	12	Light	5	7	35	Working well
				Fan	2	12	24	
				Mobile phone	1	8	8	
Irrigation		Solar pump (35.58 L/min)		1	280	280	Vegetables	
Water supply (500 L water tank)		Basin Tap		1			Improved sanitation and hand wash	
		Toilet tap		1				
		Bathroom tap		2				

**Table 86: Field performance of mini solar pump based SHS at Kotbaria, Barguna Sadar, Barguna**

System	Panel Power (W <sub>p</sub> )	Battery power (W)		Name of appliances	Numbers	Unit load (W)	Total Load (W)	Remarks
		Ah	Volt					
SHS	365	100	12	Light	3	7	21	Working well
				Fan	1	12	12	
				Mobile phone	1	8	8	
Irrigation		Solar pump (36.32 L/min)		1	280	280	Vegetables	
Water supply (500 L water tank)		Basin Tap		1			Improved sanitation and hand wash	
		Toilet tap		1				
		Bathroom tap		2				

**Table 87: Field performance of mini solar pump based SHS at Chunakhali, Amtali, Barguna**

System	Panel Power (W <sub>p</sub> )	Battery power (W)		Name of appliances	Numbers	Unit load (W)	Total Load (W)	Remarks
		Ah	Volt					
SHS	365	100	12	Light	2	7	14	Working well
				Fan	2	12	24	
				Mobile phone	1	8	8	
Irrigation		Solar pump (34.54 L/min)		1	280	280	Vegetables	
Water supply (500 L water tank)		Basin Tap		1			Improved sanitation and hand wash	
		Toilet tap		1				
		Bathroom tap		2				

**Table 88: Field performance of solar pump and SHS at Ghatkhali, Amtali, Barguna**

System	Panel Power (W <sub>p</sub> )	Battery, power (W)		Name of appliances	Numbers	Unit load (W)	Total Load (W)	Remarks
		Ah	Volt					
SHS	365	100	12	Light	6	7	42	Working well
				Fan	2	12	24	
				Mobile phone	1	8	8	
Irrigation		Solar pump (34.38 L/min)		1	280	280	Vegetables	
Water supply (500 L water tank)		Basin Tap		1			Improved sanitation and hand wash	
		Toilet tap		1				
		Bathroom tap		2				

**Table 89: Field performance of solar pump and SHS at Char Biswas, Galachipa, Patuakhali**

System	Panel Power (W <sub>p</sub> )	Battery, power (W)		Name of appliances	Numbers	Unit load (W)	Total Load (W)	Remarks
		Ah	Volt					
SHS	365	100	12	Light	5	7	35	Working well
				Fan	1	12	12	
				Mobile phone	1	8	8	
Irrigation		Solar pump (36.27 L/min)		1	280	280	Vegetables	
Water supply (500 L water tank)		Basin Tap		1			Improved sanitation and hand wash	
		Toilet tap		1				
		Bathroom tap		2				

**Table 90: Field performance of solar pump and SHS at Baro Char Kajol, Galachipa, Patuakhali**

System	Panel Power (W <sub>p</sub> )	Battery, power (W)		Name of appliances	Numbers	Unit load (W)	Total Load (W)	Remarks
		Ah	Volt					
SHS	365	100	12	Light	3	7	21	Working well
				Fan	2	12	24	
				Mobile phone	1	8	8	
Irrigation		Solar pump (33.44 L/min)		1	280	280	Vegetables	
Water supply (500 L water tank)		Basin Tap		1			Improved sanitation and hand wash	
		Toilet tap		1				
		Bathroom tap		2				

**Table 91: Field performance of solar pump and SHS at Soto Shiba, Galachipa, Patuakhali**

System	Panel Power (W <sub>p</sub> )	Battery, power (W)		Name of appliances	Numbers	Unit load (W)	Total Load (W)	Remarks
		Ah	Volt					
SHS	365	100	12	Light	3	7	21	Working well
				Fan	2	12	24	
				Mobile phone	1	8	8	
Irrigation		Solar pump (35.62 L/min)			1	280	280	Vegetables
Water supply (500 L water tank)		Basin Tap			1			Improved sanitation and hand wash
		Toilet tap			1			
		Bathroom tap			2			

**Table 92: Field performance of solar pump and SHS at Char Badai, Galachipa, Patuakhali**

System	Panel Power (W <sub>p</sub> )	Battery, power (W)		Name of appliances	Numbers	Unit load (W)	Total Load (W)	Remarks
		Ah	Volt					
SHS	365	100	12	Light	3	7	21	Working well
				Fan	1	12	12	
				Mobile phone	1	8	8	
Irrigation		Solar pump (32.17 L/min)			1	280	280	Vegetables
Water supply (500 L water tank)		Basin Tap			1			Improved sanitation and hand wash
		Toilet tap			1			
		Bathroom tap			2			

**Table 93: Field performance of solar pump and SHS at Panpotti, Galachipa, Patuakhali**

System	Panel Power (W <sub>p</sub> )	Battery, power (W)		Name of appliances	Numbers	Unit load (W)	Total Load (W)	Remarks
		Ah	Volt					
SHS	365	100	12	Light	3	7	21	Working well
				Fan	2	12	24	
				Mobile phone	1	8	8	
Irrigation		Solar pump (35.22 L/min)			1	280	280	Vegetables
Water supply (500 L water tank)		Basin Tap			1			Improved sanitation and hand wash
		Toilet tap			1			
		Bathroom tap			2			

**Table 94: Field performance of solar pump and SHS at Sonatola, Kalapara, Patuakhali**

System	Panel Power (W <sub>p</sub> )	Battery, power (W)		Name of appliances	Numbers	Unit load (W)	Total Load (W)	Remarks
		Ah	Volt					
SHS	365	100	12	Light	2	7	14	Working well
				Fan	2	12	24	
				Mobile phone	1	8	8	
Irrigation		Solar pump (32.17 L/min)			1	280	280	Vegetables
Water supply (500 L water tank)		Basin Tap			1			Improved sanitation and hand wash
		Toilet tap			1			
		Bathroom tap			2			

**Table 95: Field performance of solar pump and SHS at Dhaligouronagar, Lalmohon, Bhola**

System	Panel Power (W <sub>p</sub> )	Battery, power (W)		Name of appliances	Numbers	Unit load (W)	Total Load (W)	Remarks
		Ah	Volt					
SHS	365	100	12	Light	5	7	35	Working well
				Fan	2	12	24	
				Mobile phone	1	8	8	
Irrigation		Solar pump (33.26 L/min)			1	280	280	Vegetables
Water supply (500 L water tank)		Basin Tap			1			Improved sanitation and hand wash
		Toilet tap			1			
		Bathroom tap			2			

**Table 96: Field performance of solar pump and SHS at Matabbar Bari, Char Fasson, Bhola**

System	Panel Power (W <sub>p</sub> )	Battery, power (W)		Name of appliances	Numbers	Unit load (W)	Total Load (W)	Remarks
		Ah	Volt					
SHS	365	100	12	Light	3	7	21	Working well
				Fan	1	12	12	
				Mobile phone	1	8	8	
Irrigation		Solar pump (35.35 L/min)			1	280	280	Vegetables
Water supply (500 L water tank)		Basin Tap			1			Improved sanitation and hand wash
		Toilet tap			1			
		Bathroom tap			2			

### 11.5.2 BRRI Component

#### Performance of on-grid solar home system

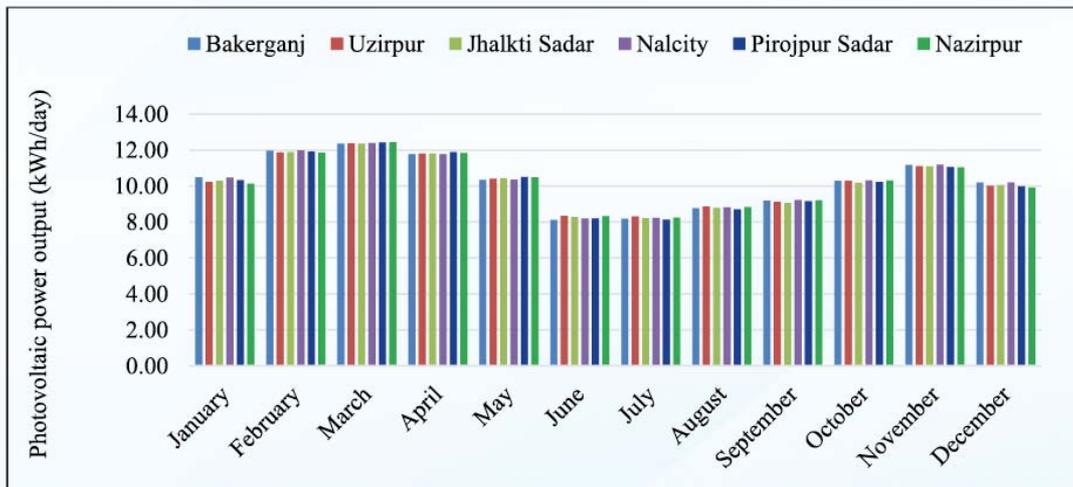
Initially solar home system was provided to the farmers in on-grid areas except Nazirpur upazila of Pirojpur in non-grid area. Daily average electricity production of on grid solar home system was about 5-6 kWh from each location depending on the availability of the solar radiation. But household electricity consumptions of some farmers were very low. As a result, they did not get full benefit from the system. The system has a restriction that the daily household electricity consumption should be greater than the daily production from solar home system installed in on-grid areas. In such cases, the maximum production of electricity can contribute to the national utility grid. Basically in solar PV systems, the produced electricity should share partially to meet the demand of the consumers and the rest of it contributing to the utility grid line. When the power consumption of the consumers became higher than the produced electricity from solar panels, the maximum power was contributed to the users from the panels. However, in case of lower power consumption, the additional power produced by the panels should contribute to the grid line. In this case, the drawback is that the analogue meter turns reversely. As a result, their meter reading goes up by a small amount. This phenomenon occurs due to unidirectional nature of the energy meter. This happened in the case of solar PV systems provided to the farmers in on-grid areas. To overcome this drawback, solar home systems need to be put to net metering system in all the locations. An application has been submitted to the SREDA to pay tariff based on exported solar energy to the grid line from the panels.

The site-specific available solar energy was estimated from the Global Solar Atlas by using solar resource database and photovoltaic simulation software © 2019 Solargis which are suitable for

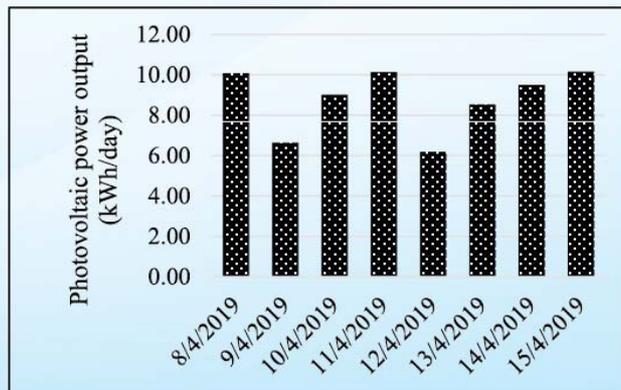
preliminary studies, as they consider default values for many factors that are important for a design of a photovoltaic system. Existing PV system configuration in each location is given below.

- PV system: Portable ground-mounted small scale
- Azimuth of PV panels: Default ( $180^{\circ}$ )
- Tilt of PV panels:  $23^{\circ}$
- Installed capacity: 2.65 kWp

By using the above software, simulated monthly average daily based photovoltaic power output (kWh) from the existing solar PV system is shown in Fig.95. It is clear that in November to May, above 10 kWh photovoltaic electricity can be produced per day. The maximum electricity production occurred in the month of March and the minimum was produced in the month of July. The Highest maximum energy production was obtained from Nazirpur (12.43 kWh/day) and the lowest from Pirojpur Sadar (8.12 kWh/day). This result was validated by the same model installed at Gazipur solar pumping plant which is connected to the on grid solar home system. In the month of April/2019, 8-day photovoltaic power output from the plant was recorded. The average daily photovoltaic power output was 8.77 kWh (Fig. 96) at Gazipur. Considering the whole month, the total amount stands at about 11-12 kWh/day. So, the efficiency of the simulated photovoltaic power output was good.



**Fig. 95: Simulated monthly averages photovoltaic power output for the selected locations**



**Fig. 96: Actual daily photovoltaic power output from the Gazipur solar pumping plant**

### Performance of off-grid solar home system

In on-grid areas, initially, a problem was faced from no electric supply from the solar PV system for household uses during load shedding periods as there was no storage system of power at the initial stage of the sub-project. To overcome this problem, storage batteries were supplied later to the farmers as was supplied in an off-grid system. A changeover was used in the system to separate and connect one of the 330W solar panel from rest of the seven panels enabling the system functioning as an off-grid system for that panel. The remaining seven panels were used in on-grid solar home system when the portable solar panels were kept in farmer's house during off season. In this system, two 5W LED tube lights, one DC 12V and 12W Table Fan and one 5W mobile charger were used in a farmer's house. Operating times of table fan, LED tube light (Reading room), LED tube light (Bed room) and mobile charger were about 12, 4, 3 and 1 hours, respectively in a day (Table 97). Total energy consumption from the solar home system was 184 Wh. A 100 AH lead acid battery was used with a 10 A solar charge controller. During irrigation season, the changeover was used to connect the separated panel to the remaining seven panels. Some pictorial views are shown in Fig. 97.

**Table 97: Daily energy consumption pattern of the solar home system\***

Loads	Morning	Afternoon	Evening	Night	Consumption time (hr)	Total Consumption (Wh)
Table Fan, 12W	10:00 - 12:00	01:00-02:00	-	07:00-09:00 10:00-05:00	12	144
LED Tube light (reading room), 5W	-	-	-	07:00-11:00	4	20
LED Tube light (bed room), 5W	-	-	-	07:00-10:00	3	15
Mobile charger, 5W	-	-	-	At least 1 hour	1	5
<b>Total consumption</b>						<b>184</b>

\*: Data were collected through interviews with the farmers





**Fig. 97: Loading arrangements in battery storage of solar home system**

### **Solar power operated household water supply system**

Solar power operated water supply system was used in Sadar upazila of Pirojpur and Jhalkati districts successfully. The source of water was the existing pond that received water from tidal flows. Almost every farmer used water from a pond near to his house. The portable solar panel system was used for household water supply using an overhead tank in combination with the existing solar irrigation pump. In the system, water was stored in a 500-liter overhead tank placed at a height of 10 feet above the ground. The water was delivered to the tank from the solar pump through a 2-inch pipe. Since the pump outlet diameter was 3 inch, a reducer (3" x 2") was used for the purpose. Again, the water for household use was supplied through 3/4-inch pipe from the tank to the house for cooking, dish washing, bathing, sanitary use etc. Farmers expressed their feelings that no extra electricity bill they had to pay for operating the pump and they were able to save time.

## **11.6 Analyzing the technical and economic feasibility of solar pump for multiple uses**

### **11.6.1 Technical feasibility**

The solar PV system for irrigation and household appliances is designed and upscale on information obtained from base line survey. Required materials for the fabrication of the solar PV system are available in the local market. Solar PV system, once installed, is just run or stops by using on-off switch button. The technology does not require any fuel or oil to run the system. The solar panels require radiation of the sun to produce power which is measured and found available in higher intensity at the sub-project implementation locations. A minimum change of spare parts is required in the life span of 25 years of the solar PV system. At field conditions, the solar pump has been found to run with full satisfaction of the users to deliver water for irrigation. Surface water is found available for irrigation and salinity values recorded in the sites were below hazardous levels and the crops were not affected at all. During off irrigation time, the solar PV system serves well to meet the power requirement for home appliances like, DC fan, LED bulb/tube light, TV and mobile chargers. Even at night, these electrical appliances can be operated using Lead Acid storage battery charged by solar panels during day time. Also the system performs well for domestic water supply. Performance of BRRI open drum thresher run by solar PV system was good. By organizing trainings for the local electricians and mechanics, skilled manpower for installing solar PV system for irrigation and household purposes was developed. Overall, the solar PV system has been found technically compatible with the needs of the farmers for irrigation and home applications.

## 11.6.2 Economic feasibility

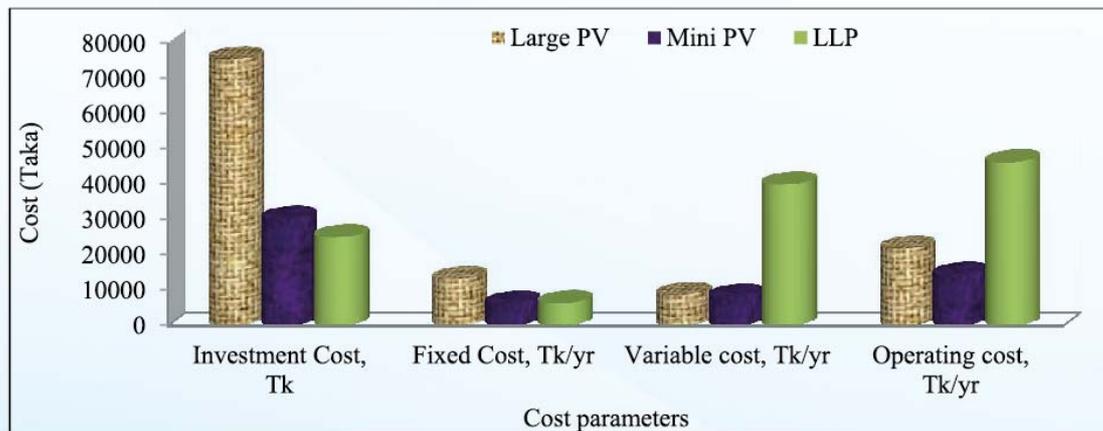
### 11.6.2.1 BARI Component

All types of cost component for solar PV pump (large and mini) and LLP are given in Table 98. Photovoltaic panel (1.3 kW) operated centrifugal pump of 1.2 hp with 180 liter/minute discharge capacity was selected for economic analysis. A 4.0 hp diesel operated centrifugal pump with the same discharge capacity as of a LLP and 0.375 hp dc motor operated centrifugal solar pump were selected for economic analysis. Life of solar panel was assumed 20 years and life of DC motor was assumed 5 years for economic analysis. From Table 98 it was observed that the total initial cost (Cost of panel, cost of pump with motor/engine, cost for pipe, foot valve, cable and accessories) of large solar pump, mini solar pump and LLP were 75400, 30180 and 25000 BDT, respectively. The cost per watt peak for large and mini solar pump (PV) and LLP was Taka 58.00, 82.68 and 8.39, respectively.

**Table 98: Cost components of solar PV pump, LLP and STW**

Item	Power (W <sub>p</sub> )	Cost of panel	Cost of motor with pump	Pipe, foot valve, Cable and Accessories, etc.	Total cost	Cost per W <sub>p</sub>
Large Solar Pump	Panel:1300 Pump: 910	42900	22500	10000	75400	58
Mini Solar Pump	Panel:365 Pump: 280	11680	10000	8500	30180	82.68
LLP	2.98 kW		16000	9000	25000	8.39

It can be illustrated from Fig. 98 that the maintenance cost, fuel/energy cost and operating cost were much higher in LLP than solar pump. Life of diesel engine and pump was considered five years. After five years, new engine and pump would to be required.

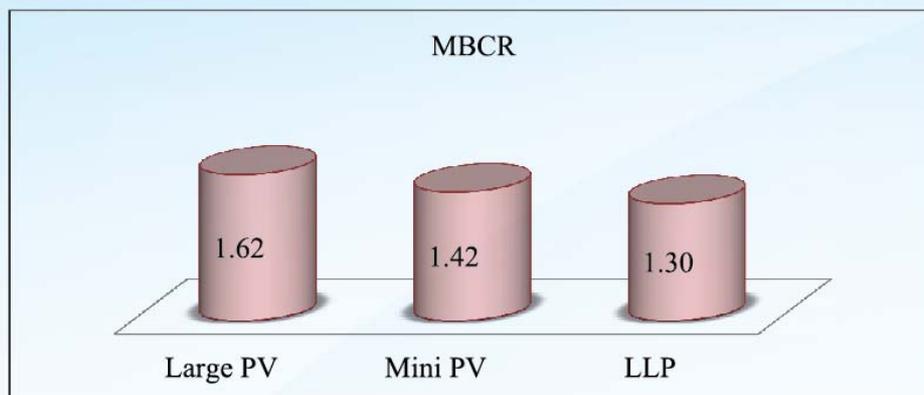


**Fig. 98: Different cost components for solar pump and LLP**

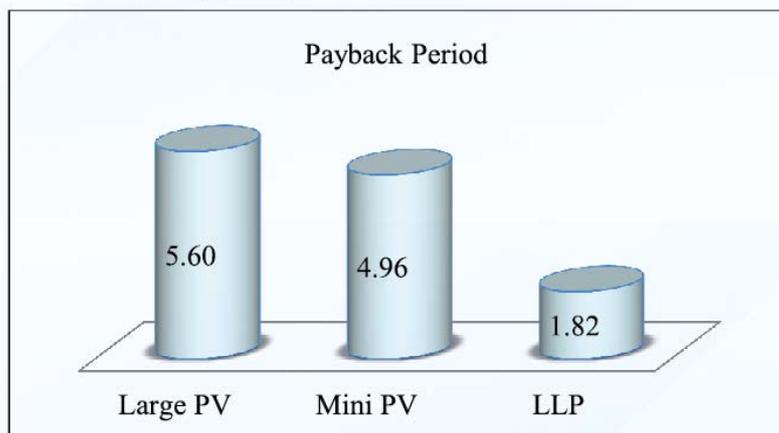
But, in case of solar pump only the motor and pump need to be changed after five years because the life of solar panel is assumed 20 years. Hossain *et. al.* (2014) found from a survey in Bangladesh that a 4.0 hp submersible solar pump was more cost effective than a 4.5 hp diesel engine operated shallow tube well.

The Fig. 99 implies that the marginal benefit cost ratio was higher (1.62) at large solar power operated pump than LLP (1.30). Payback period of large solar pump (Large PV), mini solar pump and low lift pump (LLP) were 5.60, 4.96 and 1.82 years, respectively, as shown in Fig 100. Biswas and Hossain (2013) also reported that a 10 hp solar operated pump became more economic

than a 10 hp diesel engine operated pump after 10 years of operation. Abu-Aligah (2013) reported that for long-term irrigation project (more than 5 years) solar pump was found more economic than the same sized-diesel pump.



**Fig. 99: Marginal benefit cost ratio for large solar pump (Large PV), mini solar pump (Mini PV) and low lift pump (LLP)**



**Fig. 100: Payback period of large solar pump, mini solar pump and low lift pump**

Net present value (NPV), benefit cost ratio (BCR), and internal rate of return (IRR) were calculated at 10% discounted factor for the economic analysis of the sub-project. Discounted measure of sub-project worth was used for financial analysis since undiscounted measure of sub-project worth was quite unable to take into consideration the timing of benefits and costs. The NPV, BCR, IRR and discounted payback period (DPBP) at 10% discounted factor are given in Table 99.

**Table 99: Comparison of NPV, BCR, IRR and DPBP for large solar PV, mini solar PV and LLP**

Item	Large solar pump	Mini solar pump	LLP	Remarks
NPV	83572	35626	93967	If greater than zero, accepted
BCR	1.39	1.26	1.21	If greater than unity, accepted
IRR	12%	13%	51%	If greater than prevailing interest rate, accepted
DPBP	14.40	15.04	18.18	If less than economic life, accepted

The large solar pump, mini solar pump and LLP were profitable for the owners in using irrigation practice. A cash flow chart was prepared for sub-project analysis. The sub-project analysis was done for 20 years sub-project period. According to the large solar pump cash out flow it was found that the NPV, BCR, IRR and DPBP were Taka 83572, 1.39, 12% and 14.40, respectively. The mini solar pump cash out flow stated that the NPV, BCR, IRR and DPBP were Taka 35626, 1.26, 13% and 15.04, respectively; whereas cash out flow of LLP stated that the NPV, BCR, IRR and DPBP were Taka 89060, 1.21, 51% and 18.18, respectively. The NPV indicates that the solar irrigation system was found financially sound and the sub-project could be financially viable because the higher IRR (12%) of solar irrigation system was greater than the bank interest rate (10%). So it was observed that the payback period was analyzed to be 14.40 years of the operated system. It means that the solar PV system investment would pay for itself after that period. Though the investment of solar PV system was more than LLP, the rate of return was high. So the Solar PV system used for irrigation in vegetable cultivation is less risky than that of prevailing LLP irrigation system.

From the above discussion it can be clearly stated that the solar pump is more economical than diesel operated pump for vegetable cultivation. Though the initial investment was high in solar pump but the maintenance cost, energy cost and operating cost were very negligible in comparison with diesel pump. In case of diesel pump, the initial investment was lower but the maintenance cost, energy cost and operating costs were very high. In most cases, the farmers of Bangladesh use LLPs on hiring basis for irrigation purpose. In such cases, farmers themselves would have to bear the fuel cost, operation cost and benefit of the pump owner. In the surveyed areas, irrigation water was used to supply through diesel engine operated LLPs. Only 18% people were the owner of those pumps and the rest 82% people used the pumps on hiring basis. The average irrigation cost per Bigha (0.33 acre) was calculated to be approximately Taka 3200 per season at the selected surveyed areas. But in case of solar pump there was no fuel and operating costs. So the irrigation rent was found less in solar irrigation system than LLP. The solar panels were used not only for irrigation purposes but also for charging battery which could be used for supply of electricity in household appliances.

#### **Trainings conducted in sub-project sites**

In the 1<sup>st</sup> year of sub-project, three batches of trainings were conducted in three districts on installation, use and maintenance of BARI developed solar pump based solar home system. Twenty participants attended the training course per batch. First batch of the training was held at upazila training room of Amtali upazila of Barguna district on 6 November 2019 where 19 trainees were male and 01 was female. On 07 November, the second batch of training was held at Chalitabunia School of Champapur Union of Kalapara upazila of Patuakhali district in which 18 male and 02 female trainees participated. Third batch of the training was held in a farmers' house of Lalmohon upazila of Bhola district on 4 December 2019 where all trainees were male. A training manual on installation, use and maintenance of BARI developed solar pump-based solar home system was also prepared and printed (500 copies) and these were distributed among the trainees. Some pictures of the training programs at Barguna is given in Fig.101, Patuakhali in Fig.102 and Bhola in Fig.103.



**Fig. 101: Training program at Amtali, Barguna**



**Fig. 102: Training program at Patuakhali Sadar**



**Fig. 103: Training program at Char Fasson, Bhola**

During the 2<sup>nd</sup> year of the sub-project, three batches of trainings were conducted in three districts on installation, use and maintenance of BARI developed solar pump based solar home system. Here also twenty participants attended the training programme in every batch. One batch training was held at Regional Horticultural Research Station (RHRS), Lebukhali, Dumki of Patuakhali District on 06 Oct 2020 in which 19 participants were male and 01 was female. The second training programme was also conducted at RHRS, Lebukhali, Dumki of Patuakhali District on 07 Oct 2020 where all participants were male. The last batch training was held on 04 November 2020 at Char Fasson of Bhola District at the home yard of the farmer selected under the sub-project. Here, in this training programme, all the participants were male. Second and improved version of the training manual on installation, use and maintenance of BARI developed solar pump-based solar home system was also distributed among the trainees. Some pictures of the training programs at Barguna and Patuakhali are given in Fig.104 and Bhola in Fig.105.



**Fig. 104: Training program for Barguna and Patuakhali district at RHRS, Lebukhali**



**Fig. 105: Training program at Char Fasson, Bhola**

The following training news were published in local and national media (Fig. 106).

**যায়যায়দিন** মঙ্গলবার, ২৪ ডিসেম্বর ২০১৯, ৯ শেখ ১৪২৩

**AGRIVIEW** Hall of Agriculture

**THE ASIAN AGE** Thursday, January 9, 2020 Today's Paper Video ePaper Second Edition Contact

**Solar pump irrigation for sustainable crop production in Bangladesh**  
Dr. Md Ayub Hossain

**বারি সোলার পম্প ডিজিটাল মোডার্ন হোম সিস্টেমের স্থাপন, ব্যবহার ও রক্ষণাবেক্ষণ বিষয়ক প্রশিক্ষণ ম্যানুয়াল**

Up scaling and Application of Solar Photovoltaic Pump for Sustainable Irrigation and Associated Agriculture in the Central Coastal Region of Bangladesh Su-2 project (ID: 001)

**Fig.106: Published news of solar pumping activities**

Field visiting was conducted (05 November-06 November, 2019) by BARC team as given below in Fig. 107-109.



**Fig.107: Some photographic views during the visit of Galachipa**



**Fig.108: Some photographic view during visit at Kalapara**



**Fig.109: Some photographic view during visit at Amtali**

### **Field demonstration**

Twelve field demonstration programs (Fig. 110- Fig. 121) were arranged at different sub-project sites on BARI developed solar pump based solar home system. In every programme, 40 participants were involved. The first field demonstration was held on 15 March 2020 at Lalmohon of Bhola district with the presence of BARC sub-project personnel. Second field day was held on 19 May 2020 arranged at FMPE divisional research field, BARI, Gazipur maintaining proper social distancing and health protection measures. In that programme, Honourable Director General, Director of Research, Director of Support Service, Director of Training and Communication, related scientists and 40 numbers of vegetables growing farmers were present. The third field day was held at Nijshuri of Galachipa upazila of Patuakhali District on 04 October 2020. Fourth field day was held at Amragassiya of Amtali of Barguna District on 05 October 2020. Fifth field day was held at Sathghor of Barguna Sadar on 08 October 2020. Sixth field day was held at Matabbarbari of Char Fasson of Bhola on 05 November 2020 on Morning 10.00 am. Seventh field day was held at lalmohon of Bhola on 05 november 2020 on afternoon 3.00 pm. Eighth field day was held at Pakhimara of Kalapara of Patuakhali on 06 November 2020. Ninth field day was held at Charkajol of Galachipa of Patuakhali on 07 November 2020 on morning 10.00 am. Tenth field day was held at Charkajol of Galachipa of Patuakhali on 07 November 2020 in afternoon 3.00 pm. Eleventh field day was held at East Ghotkhali of Amtali of Barguna. Twelveth field day was held at Gazi mahmud of Barguna Sadar of Barguna on 09 November 2020.



**Fig.110: Field day at Lalmohon**



**Fig. 111: Field day at On-station, Gazipur**



**Fig.112: Field day at Nijshuri, Galachipa, Patukhali**



**Fig. 113: Field day at Amragassiya, Amtali, Barguna**



**Fig. 114: Field day at Sathbhar, Barguna Sadar**



**Fig. 115: Field day at Char Fasson of Bhola**



**Fig.116: Field day at Lalmohon**



**Fig. 117: Field day at Pakhimara of Kalapara of Patuakhali**



**Fig.118: Field day at Ghotkhali of Amtali of Barguna**



**Fig. 119: Field day at Charkajol of Galachipa of Patuakhali**



**Fig.120: Field day at Charkajol of Galachipa of Patuakhali**



**Fig.121: Field day at Gazi Mahmud of Barguna Sadar**

### 11.6.2 BRRI Component

The financial analysis of solar pump was done from the viewpoint of machine owners. Based on field data, the present total cost of operation of diesel pump, single use of portable solar pump and multiple use of portable solar pump were estimated as Tk. 17150.00 per ha, Tk. 19713.00 per ha and Tk. 44157.00 per ha, respectively (Table 100). Fixed costs of operations of these pumps were Tk. 2355.00 per ha, Tk. 12443.00 per ha, and Tk. 20062.00 per ha, respectively and those of variable costs were Tk. 14795.00 per ha, Tk. 7270.00 per ha and Tk. 24095.00 per ha, respectively. The data were collected from fields, interviews with the service providers and farmers using diesel pumps. The custom hiring charge of all categories of pumps was Tk. 22050.00 per ha. Based on these information, the annual gross revenue received from different pump services were estimated. The average revenue obtained by an entrepreneur was found Tk. 44100.00 per year for both diesel and single use of portable solar pump and Tk.127025.00 per year for multipurpose uses of potable solar pump. Therefore, an entrepreneur or a local service provider (LSPs) can earn marginal profit Tk. 9800.00 for diesel pump, Tk.4675.00 for single use of portable solar pump and Tk. 38712.00 for multiple uses of portable solar pump. So the marginal profit of single use of portable solar pump (only irrigation) was smaller than that of diesel pump (only irrigation) but the same was the highest for multipurpose use of portable solar pump (Table 100).

**Table 100: Estimated major cost and return items of diesel pump, portable panel based solar pump and versatile use of portable panel based solar pump operation**

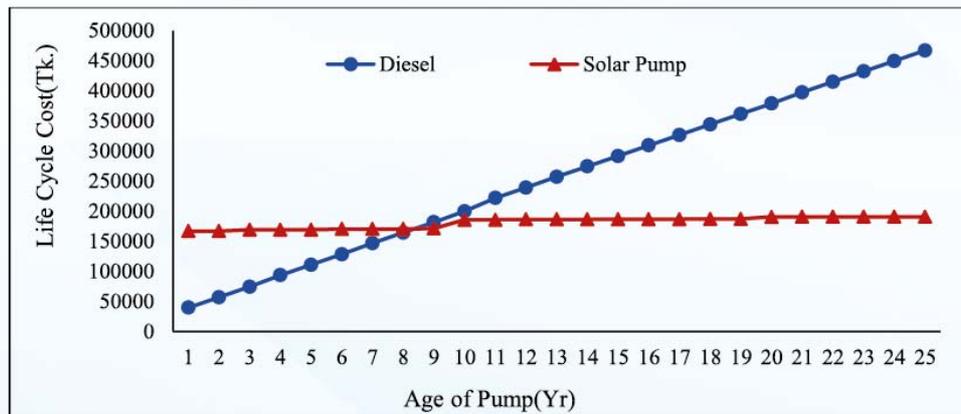
Cost Items	Unit	Diesel Pump	Solar Pump-1*	Solar Pump-2*
Purchase price or initial cost (including installation cost)	Tk.	23275	172950	251930
Annual use in area	ha	2	2	2
Economic life, L	year	10	25	25
Depreciation, D	Tk./yr.	2364	7300	14539
Fixed cost, FC	Tk./ha	2355	12443	20062
Variable cost, VC	Tk./ha	14795	7270	24095
Total cost of operation, TOC= FC+VC	Tk./ha	17150	19713	44157
Payment for replacement, PFR	Tk./ha	1716	3786	8779
Rent out charge	Tk./ha	22050	22050	63513
Revenue, R	Tk./yr.	44100	44100	127025
Marginal profit, PM= R-TOC	Tk/yr.	9800	4675	38712
Benefit cost ratio, BCR	-	1.29	1.12	1.44
Break Even Point, BEP	ha/yr.	0.65	1.68	-
Pay Back Period, PBP	year	7	15	8

\* Solar pump 1 & 2 indicate single use and multipurpose use, respectively, AC=Annual cost (Tk/yr)

### Sub-project worth analysis

The method 'discounted measures of sub-project worth' was used for financial analysis since the 'undiscounted measures of sub-project worth' does not consider the timing of benefits and costs. By discounted cash flow analysis, internal and external cash flows combining with the measures of NPV, ratio of profitability and BCR were estimated. The net present value of different irrigation pumps with the existing inflation conditions was estimated at 15% discount rate whereas the minimum percentage of interest rate associated with agricultural loans to purchase agricultural machinery holds 5% in 2021. The results revealed that the investment on multipurpose uses of

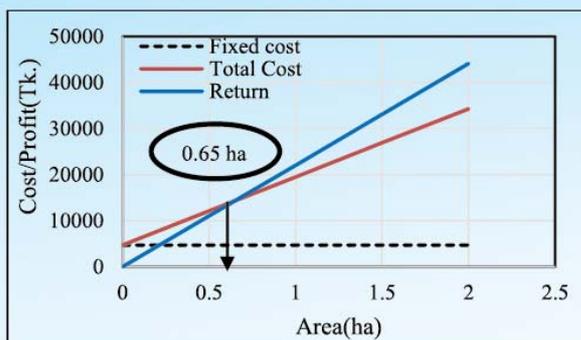
portable solar pump was profitable. Considering 15% discount rate, the NPV of single use of diesel pump, single use of portable solar pump and multipurpose use of solar pump in existing conditions were Tk.64639.00, Tk.30096.00 and Tk.248267.00, respectively. The NPVs indicate that all the irrigation pumps were found financially sound. The sub-project was revealed financially viable because IRR of diesel pump, portable solar pump and multipurpose uses of portable solar pump (20%, 17% and 39%, respectively) were greater than the bank interest rate (14%). The payback period was analyzed to be 7, 15 and 8 years of the diesel pump, portable solar pump and multipurpose uses of portable solar pump. All these values were smaller than the economic life of the pumps. It means that the investment made for all the irrigation pumps would pay in return after that period. The results also show that the average rates of return on investment (BCR) were 1.29, 1.12 and 1.44 for diesel pump, single use of solar pump and multipurpose uses of solar pump, respectively. All the BCRs were found higher than unity which indicates a substantial and profitable venture for an entrepreneur. When compared among all the irrigation pumps, it was observed that, the BCR of multipurpose uses of portable solar pump was higher than the single use of diesel pump and portable solar pump. The life cycle costs of all the pumps were calculated (Fig.122). It is seen from Fig.122 that the life cycle cost of diesel-operated pump was lower than that of solar pump up to 8 years. Thereafter it increases linearly and the solar pump becomes more economic. So, from the economic view point, the investment on multipurpose uses of portable solar pump is more profitable than the single use of diesel pump or single use of portable solar pump.



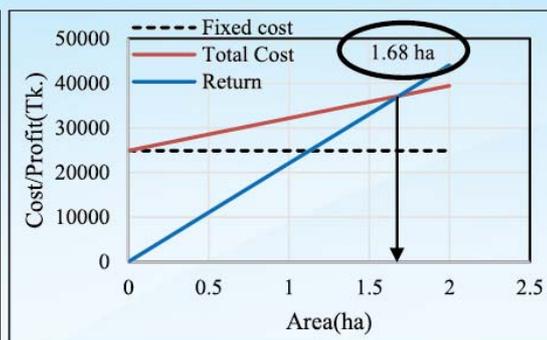
**Fig. 122: Life cycle costs of diesel and multipurpose use solar pumps**

### Break-even analysis

An attempt was made to calculate the break-even point of all types of irrigation pumps for the service providers. This was done based on fixed cost and variable cost of pump operations. The data were collected from farm level, machine price, depreciation cost, interest on investment, machine life, income from pump operation, etc. The Figures 123(a) and (b) show the economic use of diesel operated irrigation pump and portable solar panel based solar pump. The Break-even use of single use of diesel pump and single use of portable solar pump were estimated as 0.65 ha and 1.68 ha of land per year, respectively. This implies that a service provider has to irrigate more than 0.65 ha of land per year to make the diesel pump profitable. On the other hand, portable solar pump will be more profitable if the user irrigates more than 1.68 ha of land per year. Table 100 shows the summarized sketch for evaluation of sub-project worth of different irrigation pumps under custom hire services.



**Fig. 123 (a): BEP of diesel pump**



**Fig. 123 (b): BEP of solar pump**

As seen from Table 101 that the BCR, PBP, BEP, IRR and NPV (at 15% discount factor) of diesel pump, single use of portable solar pump and multipurpose uses of portable solar pump were estimated as 1.29, 7 yrs, 0.65 ha yr<sup>-1</sup>, 20%, Tk.64639.00 and 1.12, 15 yrs, 1.68 ha yr<sup>-1</sup>, 17%, Tk.30096.00 and 1.44, 8 yrs, 22%, Tk.248267.00, respectively. Thus the economic performances show that the estimated indicators are all above their accepting range, such as, BCR>1, PBP is less than the estimated life, IRR is greater than annual interest rate, and NPV>0. These results support that the investments on multipurpose uses of portable solar solar pumps used as custom hire service is attractive and profitable for a small holder farmer or an entrepreneur or LSP.

**Table 101: Sub-project worth evaluation**

Items	Values			Remarks
	Diesel pump	Single use of portable solar pump	Multipurpose use of portable solar pump	
Payback period (PBP), Year	7	15	8	If the payback period is less than the economic life, it is accepted.
Economic life, Year	10	25	25	
Break-even point (BEP), ha	0.65	1.68	1.68	If BEP is less than the service area, it is feasible.
Service area, ha/Year	2	2	2	
Benefit-cost ratio (BCR)	1.29	1.12	1.44	If greater than unity, it is economically feasible.
Internal rate of return (IRR), %	17	20	22	If greater than prevailing interest rate, it is accepted.
Prevailing interest rate, %	14	14	14	
Net present value (NPV), Tk.	64639.00	30096.00	248267.00	If greater than zero, it is profitable.

#### Conduction of training and demonstrations/field days

During the sub-project period a number of trainings and demonstrations/field days were conducted in the sub-project locations. The trainings were imparted to make the trainees enabled to handle the solar PV systems smoothly through proper installation, operation and maintenance. Field days/demonstrations were conducted to make the neighboring farmers acquainted with the system and its performance.

#### Conduction of training at sub-project sites

In 2<sup>nd</sup> year of sub-project duration, three batches of trainings were conducted in three districts on a day-long training of installation, use and maintenance of BRRRI developed portable solar panel-

based solar pump, rice threshing machine and solar home systems. Twenty participants (10 participants from each upazila) attended in each batch. First batch of the training was held at Nalcity upazila of Jhalkati on 13 December 2019 where 19 trainees were male and one was female. On 14 December, the second batch of training was held at Sadar upazila of Pirojpur district where 18 males and two female trainees participated. Third batch of the training was held on Bakerganj upazila of Barishal district on 15 December 2019 where all trainees were male. Coordination unit of BARC, DAE personnel and Head of the BRRI regional station, Barishal were present in the training programs.

In the 3<sup>rd</sup> year of the sub-project, three batches of trainings were conducted in three districts on the same topic. Twenty participants attended in each batch. Training of one batch was held at BRRI Regional station, Barishal, on 14 August 2020 where 12 participants were male and 8 were female. Another training was held at Sadar upazila of Jhalkati District on 16 August 2020 where 14 participants were male and 6 were female. The last batch training was held at Sadar upazila of Pirojpur District in the house of a selected farmer on 17 August 2020 where 12 participants were male and 8 were female. Coordination unit of BARC, DAE personnel and Head of the BRRI regional station, Barishal, were present in the training program.

In both the years, the Principal Investigator and Co-investigator together with the Scientific Officer of the sub-project conducted the training programs in each of the selected districts. Print media journalists were also present in all the training programs. The information about the training program was published in the national and regional newspapers with importance. Some pictorial views of the training programs are shown below.



Bakerganj upazila, Barishal



Nalcity upazila, Jhalkati



Sadar upazila, Pirojpur



Sadar upazila, Barishal

Fig. 124: Some pictorial views of farmers' training programs at Barishal, Jhalkati and Pirojpur districts



Fig. 125: A pictorial view of farmers' training programs published in the national and regional newspapers

### Conduction of field day/field demonstration

A total of twelve field demonstrations/field days and crop harvesting programs were conducted at different sub-project sites on BRFI developed portable solar panel based solar pump, rice threshing machine and solar home systems. In every program, 40 participants participated. The programs were conducted between 10 August 2020 and 31 January 2021. In the demonstrations/field days, personnel from BARC, DAE, BRRI, BARI and NGOs were present. Due to COVID-19 pandemic and lockdown all over the country, demonstrations/field days could not be conducted exactly on time. Some pictorial views of field days are given in Fig. 126.



a. Sadar upazila, Jhalkati



b. Nalcity upazila, Jhalkati



c. Nazirpur upazila, Pirojpur



d. Sadar upazila, Pirojpur

**Fig. 126: Some pictorial views of field days in sub-project locations**

## **12. Research highlight**

### **Title of the sub-project:**

### **Up-scaling and Application of Solar Photovoltaic Pump for Smallholder Irrigation and Household Appliances in the Central Coastal Region of Bangladesh**

#### **Background**

Solar photovoltaic power production is recognized as an important part of the future energy generation. There are about 320 solar power operated irrigation pump available in Bangladesh (Hossain, 2015). In order to promote more solar pumps, the government has targeted to install about 15,000 solar pumps by 2025 (Rahman, 2015). The available solar radiation in the country ranges from 4.0 to 6.5 kWhm<sup>-2</sup>day<sup>-1</sup> and the bright sunshine hours vary from 6 to 9 hours/day (Islam and Ahiduzzaman, 2011; Biswas and Hossain, 2013). This offers the opportunity to use solar radiation for solar pump and solar home systems adoption by the users in Bangladesh. Geographically, surface water is perceived abundant in parts of the southern region where river and canal networks have perennial flow, and salinity levels do not cross crop-damaging thresholds. Most of the farmers in the southern coastal region are small and marginal tenant farmers. There is a limited possibility of ground water utilization for crop cultivation in this region and the farmers mostly use surface water for irrigation using diesel and electricity operated low lift pumps. Solar pump may be an alternative to diesel and electricity operated pumps for irrigating crop lands in the off-grid areas. Using solar pumps on a large scale, energy demand in irrigation systems can be reduced substantially. Biswas and Hossain (2013) reported that though the initial cost of solar pump is higher than conventional diesel engine operated pump, solar pump has lower maintenance cost which makes it cost effective over the years. The solar pump has been proved technically sound, pollution free and environment friendly for water pumping in agriculture. Although, the initial cost of the system is high, with the advancement of technology, its price will come down remarkably to make solar PV system economically feasible. However, Sarker *et al.* (2016) suggested that solar pump might be economically viable for its multipurpose uses. Therefore, the sub-project was aligned to test the feasibility of solar system for multipurpose uses like crop irrigation, home electricity supply, and small agricultural machinery operation coping with the government policy of Bangladesh as well as the SDGs of the United Nations.

#### **General Objectives**

The general objectives of the sub-project for all three components were-

- i. Up-scaling of solar pump for smallholder irrigation in the central coastal region of Bangladesh
- ii. Field trials and demonstrations of solar pump irrigation systems with surface water for high value crops and rice
- iii. Application of solar photovoltaic panel (both portable and non-portable) to operate household appliances round the year during off irrigation period and
- iv. Analyzing the technical and economic feasibility of solar pump for multiple uses.

#### **Methodology**

The sub-project had one coordination component with BARC and two other implementing components, one at BARI and the other at BRRI.

Both BARI and BRRI components conducted separately the baseline surveys at the start of the sub-project in the southern region of the country to get basic information about the people, their education, land holdings, cropped lands, crops grown, irrigation modes, water application methods, solar power utilization, profitability, further demands etc. Based on these information, the solar panels, pumps and household appliances were designed as per field requirements. BARI

component designed their solar PV system for irrigating non-rice high value upland crops, home electricity and water supplies. BRRI component designed the system for similar home applications but this component also included operating small agricultural machinery like power thresher in addition to rice irrigation. On completion of the design, solar panels, pumps, motor, and household appliances were procured from the local markets and fabricated as per design. The solar PV system was then tested in the laboratory, modified them and finalized. After finalization, prototypes were made for solar pumps and household appliances as per field requirements.

With the solar PV systems ready to be demonstrated at field levels, farmers and lands were selected in 6 sites, namely, Kalapara and Galachipa of Patuakhali district, Barguna Sadar and Amtali of Barguna district and Charfassion and Lalmohon of Bhola district by BARI component. BRRI component also had the same number of sites at Ujirpur and Bakerganj upazila of Barishal district, Sadar and Nalcity upazila of Jhalokati district and Sadar and Nazirpur upazila of Pirojpur district. Each of the selected farmers in the above upazilas was provided with a solar PV system for irrigation as well as home applications. At the end of irrigation season, the solar PV systems were brought back to farmer's house for running the home appliances and water supply system. The farmers, mechanics and service providers were trained locally. Field demonstrations were conducted to make the neighboring farmers familiar with the fielded solar PV systems and their performances in irrigation and home applications. Data in respect of panel performance, pump operation, household uses, crop performance, thresher use, home water supply, irrigation, profitability, farmers' choice etc. were collected and analyzed. Reports were submitted by the components to PIU, BARC fulfilling the requirements and also some publications were made. Finally, a combined PCR was submitted to PIU from the coordination component, BARC.

### **Key Findings**

Since, all of the specific objectives of the implementing components (BARI and BRRI) were not the same; the key findings were also somewhat different from each other components. The component wise findings of BARI and BRRI are given below:

The key findings of BARI component were-

1. Average discharge of large and mini solar pumps were 180 L/min and 40 L/min., respectively
2. Water savings from alternate furrow and drip irrigation methods for tomato were found 33% and 47% and those for brinjal were 35% and 47%, respectively, in farmers' fields
3. There were significant differences in yields of tomato and brinjal between drip and furrow irrigation methods but not among the sequences of drip application methods
4. Solar panels were found to produce adequate power for crop irrigation, drinking water pumping, sanitary water supply, home lighting, fan operating, mobile charging etc.
5. The BCR of large and mini solar pumps were found to be 1.62 and 1.42, respectively.

And those of BRRI were-

1. The designed LLP run by solar PV system for surface water pumping at the rate 7-10 l/s were capable of irrigating 5 acres of rice land easily
2. During off irrigation season the portable solar panels were used to operate a 1.5 kW BRRI open drum thresher. It required two labors for the operation to thresh 250-350 kg of paddy per hour
3. Portable solar panels supplied electricity in 3-4 households during day time by using a 3 kW on-grid solar inverter. It also supplied electricity to grid line after fulfilling the household demands
4. A 330-watt solar panel was used as an off-grid solar home system by storing energy in a 100 AH lead acid battery and running two 5W LED tube lights, one DC 12V and 12W table fan and one 5W mobile battery charger in a farmer's house during off irrigation season.

5. The portable solar panel was also used for household water supply in a farmer's house for cooking, dish washing, bathing, sanitary water use etc.
6. Benefit cost ratio (BCR) of multipurpose uses of portable solar panel based solar PV system was around 1.44 which was greater than the BCR (1.12) of solar pump for irrigation only.

**Keywords: Solar pump, solar panel, LLP, BCR, solar home system, drip irrigation etc.**

## B. Implementation Status

### 1. Procurement

#### BARC Component

Description of equipment and capital items		PP Target		Achievement		Remarks
		Physical (No.)	Financial (Tk.)	Physical (No.)	Financial (Tk.)	
Office equipment	Computer Table	1	4900.00	1	4900.00	
	Computer Chair	1	3400.00	1	3400.00	
	Visitor/Front Chair	3	12000.00	3	12000.00	
	File cabinet	2	40000.00	2	40000.00	
	Almirah	1	24900.00	1	24900.00	
	Revolving chair	1	14900.00	1	14900.00	
	Office Table	1	14900.00	1	14900.00	
Office Furniture	Desktop computer with UPS	1	79800.00	1	79800.00	
	Printer	1	24500.00	1	24500.00	
	Laptop	1	59500.00	1	59500.00	
	Camera	1	25000.00	1	25000.00	
	Scanner	1	9947.00	1	9947.00	
	UPS	1	5000.00	1	5000.00	
	Photocopier	1	119500	1	119500	

#### BARI Component

Description of equipment and capital items		PP Target		Achievement		Remarks
		Physical (No.)	Financial (Tk.)	Physical (No.)	Financial (Tk.)	
Furniture and office equipment	File cabinet	01	20000.00	01	20000.00	
	Half secretariat table	01	12000.00	01	11882.00	
	Visitor/front chair	04	16000.00	04	16000.00	
	Computer table	01	5000.00	01	5000.00	
	Computer chair	04	3000.00	04	3000.00	
	Desktop Computer with UPS	01	60000.00	01	60000.00	
	Laptop	01	60000.00	01	60000.00	
	Laser Printer	01	20000.00	01	20000.00	
Lab Equipment	Solar meter	03	225000.00	03	225000.00	
	Flow meter	06	60000.00	06	60000.00	
	Digital multi-meter	03	15000.00	03	15000.00	
	EC meter	03	120000.00	03	120000.00	
Small Transport	Motor cycle	01	155000.00	01	155000.00	

## BRRI Component

Description of equipment and capital items		PP Target		Achievement		Remarks
		Physical (No.)	Financial (Tk.)	Physical (No.)	Financial (Tk.)	
Lab Equipment	Desktop Computer	01	60000.00	01	57609.00	
	Laptop	01	70000.00	01	73913.00	
	Laser printer + Scanner	01	30000.00	01	26087.00	
	UPS (Offline)	01	10000.00	01	3261.00	
	Digital Camera	01	25000.00	01	33696.00	
Furniture	Visitor Chair	04	16000.00	04	20652.00	
	Computer Chair	01	3000.00	01	7598.00	
	Computer Table	01	5000.00	01	7870.00	
	File Cabinet	01	18000.00	01	19755.00	
	Bookshelf/ Steel Almira	01	22000.00	01	16408.00	
	Rack/ Half secretariat table	01	12000.00	01	3270.00	
Field Equipment (Direct Purchase)	Digital multi-meter	03	15000.00	02	8021.00	
	Tool box	01	20000.00	01	13353.00	
Field Equipment (RFQ)	Solar meter	03	225000.00	02	236000.00	
	Flow meter (3 in. x 3in.)	06	48000.00	03	36000.00	
	EC Meter	03	120000.00	03	120000.00	
	GPS	01	40000.00	01	41000.00	
Small Transport	Motor cycle		155000.00	01	154500.00	
a) Portable Solar Irrigation System b) Solar home system	Panel, inverter, pump, grid tie inverter, suction pipe, mounting structure	06	2440000.00	06	1962000.00	
Solar open drum thresher	Open drum thresher and 2 hp AC motor	06	300000.00	06	300000.00	

## 2. Establishment/renovation facilities

**BARC Component:** Not Applicable

### BARI Component

Description of facilities	Newly established		Upgraded/refurbished		Remarks
	PP Target	Achievement	PP Target	Achievement	
Solar pump (180 L/min)	6 sets	6 sets	-	-	
Solar pump (40 L/min)	-	12 sets	-	-	
SHS	6 sets	18 sets	-	-	
Household uses	-	18 sets	-	-	

### BRRRI Component

Description of facilities	Newly established		Upgraded/refurbished		Remarks
	PP Target	Achievement	PP Target	Achievement	
Solar pump (1.5 kW)	06 sets	06 sets	-	-	
BRRRI Open Drum Thresher (1.5 kW)	06 sets	06 sets	-	-	
SHS	06 sets	06 sets	-	-	
Water supply	-	02 sets	-	-	

### 3. Training/study tour/ seminar/workshop/conference organized

#### BARC Component

Description	Number of participant			Duration (Days/weeks/ months)	Remarks
	Male	Female	Total		
Workshop (3 no)	99	13	112	31.07.2018, 24.04.2019, 12.10.2020	

#### BARI Component

Description	Number of participants			Duration (Days)	Location
	Male	Female	Total		
(a) Training	19	01	20	01 (06 Nov 2019)	Amtali, Barguna
	18	02	20	01 (07 Nov 2019)	Kalapara, Patuakhali
	19	01	20	01 (04 Dec 2019)	Lalmahan, Bhola
	20	0	20	01 (04 Oct 2020)	Char Fasson, Bhola
	19	01	20	01 (06 Oct 2020)	Galachipa, Patuakhali
	20	0	20	01 (07 Oct 2020)	Lebukhali, Patuakhali
(b) Field demonstration	34	06	40	01 (15 Mar 2020)	Lalmahan, Bhola
	28	12	40	01(19 May 2020)	BARI Gazipur
	33	07	40	01 (04 Oct 2020)	Galachipa, Patuakhali
	40	00	40	01 (05 Oct 2020)	Amtali, Barguna
	38	02	40	01 (08 Oct 2020)	Barguna Sadar
	36	04	40	01 (05 Nov 2020)	Char Fasson, Bhola
	29	11	40	01 (05 Nov 2020)	Lalmahan, Bhola
	38	02	40	01 (06 Nov 2020)	Kalapara, Patuakhali
	35	05	40	01 (07 Nov 2020)	Galachipa, Patuakhali
	39	01	40	01 (07 Nov 2020)	Galachipa, Patuakhali
	38	02	40	01 (08 Nov 2020)	Amtali, Barguna
30	10	40	01 (09 Nov 2020)	Barguna Sadar	

### BRRRI Component

Description	Number of participants			Duration (Days)	Location
	Male	Female	Total		
(a) Training	19	01	20	01 (13 Dec 2019)	Nalcity, Jhalkati
	18	02	20	01 (14 Dec 2019)	Pirojpur Sadar, Pirojpur
	20	0	20	01 (15 Dec 2019)	Bakerganj, Barishal
	12	08	20	01 (14 Aug 2020)	Jhalkati Sadar, Jhalkati
	14	06	20	01 (16 Aug 2020)	Nazirpur, Pirojpur
	12	08	20	01 (17 Aug 2020)	Uzirpur, Barishal
(b) Field demonstration /Field day	30	10	40	01 (10 Aug 2020)	Nalcity, Jhalkati
	27	13	40	01 (20 Oct 2020)	Jhalkati Sadar, Jhalkati
	31	09	40	01 (21 Oct 2020)	Bakerganj, Barishal
	34	06	40	01 (22 Oct 2020)	Barishal Sadar, Barishal
	30	10	40	01 (25 Oct 2020)	Pirojpur Sadar, Pirojpur
	32	08	40	01 (27 Oct 2020)	Nazirpur, Pirojpur
	29	11	40	01 (10 Jan 2021)	Nazirpur, Pirojpur
	32	08	40	01 (11 Jan 2021)	Jhalkati Sadar, Jhalkati
	35	05	40	01 (12 Jan 2021)	Bakerganj, Barishal
	33	07	40	01 (23 Jan 2020)	Barishal Sadar, Barishal
	37	03	40	01 (30 Jan 2021)	Nalcity, Jhalkati
	30	10	40	01 (31 Jan 2021)	Jhalkati Sadar, Jhalkati

### C. Financial and Physical Progress

Items of expenditure /activities	Total approved budget (Tk)	Fund received (Tk)	Actual expenditure (Tk)	Balance/unspent (Tk)	Physical progress (%)	Reasons for deviation
a. Contractual staff salary	9425114	28382370	9425114	0.00	100	
b. Field research/lab expenses and supplies	10817291		10817291	0.00	100	
c. Operating expenses	1953895		1953895	0.00	100	
d. Vehicle hire and fuel, oil & maintenance	1164564		1164564	0.00	100	
e. Training/workshop/seminar etc.	1996900		1996900	0.00	100	
f. Publications and printing	352727		352577	150.00	100	
g. Miscellaneous	583907		583907	0.00	100	
h. Capital expenses	2088122		2088122	0.00	100	
<b>Total</b>	<b>28382520</b>		<b>28382370</b>	<b>28382370</b>	<b>150.00</b>	<b>100</b>

### BARC Component

Items of expenditure /activities	Total approved budget (Tk)	Fund received (Tk)	Actual expenditure (Tk)	Balance/ unspent (Tk)	Physical progress (%)	Reasons for deviation
a. Contractual staff salary	4722752	6668030	4722752	0.00	100	
b. Field research/lab expenses and supplies	0.00		0.00	0.00	100	
c. Operating expenses	450386		450386	0.00	100	
d. Vehicle hire and fuel, oil & maintenance	92260		92260	0.00	100	
e. Training/workshop/seminar etc.	397300		397300	0.00	100	
f. Publications and printing	200000		199850	150.00	100	
g. Miscellaneous	367235		367235	0.00	100	
h. Capital expenses	438247		438247	0.00	100	
<b>Total</b>	<b>6668180</b>	<b>6668030</b>	<b>6668030.00</b>	<b>150.00</b>	<b>100</b>	

### BARI Component

Items of expenditure /activities	Total approved budget (Tk)	Fund received (Tk)	Actual expenditure (Tk)	Balance/ unspent (Tk)	Physical progress (%)	Reasons for deviation
a. Contractual staff salary	2459157	10769850	2459157	0.00	100	
b. Field research/lab expenses and supplies	5346599		5346599	0.00	100	
c. Operating expenses	764544		764544	0.00	100	
d. Vehicle hire and fuel, oil & maintenance	494668		494668	0.00	100	
e. Training/workshop/seminar etc.	799800		799800	0.00	100	
f. Publications and printing	17500		17500	0.00	100	
g. Miscellaneous	116700		116700	0.00	100	
h. Capital expenses	770882		770882	0.00	100	
<b>Total</b>	<b>10769850</b>	<b>10769850</b>	<b>10769850</b>	<b>0.00</b>	<b>100</b>	

### BRI Component

Items of expenditure /activities	Total approved budget (Tk)	Fund received (Tk)	Actual expenditure (Tk)	Balance/ unspent (Tk)	Physical progress (%)	Reasons for deviation
a. Contractual staff salary	2243205	10944490	2243205	0.00	100	
b. Field research/lab expenses and supplies	5470692		5470692	0.00	100	
c. Operating expenses	738965		738965	0.00	100	
d. Vehicle hire and fuel, oil & maintenance	577636		577636	0.00	100	
e. Training/workshop/seminar etc.	799800		799800	0.00	100	
f. Publications and printing	135227		135227	0.00	100	
g. Miscellaneous	99972		99972	0.00	100	
h. Capital expenses	878993		878993	0.00	100	
<b>Total</b>	<b>10944490</b>	<b>10944490</b>	<b>10944490</b>	<b>0.00</b>	<b>100</b>	

**D. Achievement of Sub-project by Objectives (Tangible form): Technology generated/developed**

<b>General objectives of the sub-project</b>	<b>Major technical activities performed in respect of the set objectives</b>	<b>Output (i.e. product obtained, visible, measurable)</b>	<b>Outcome (Short term effect of the research)</b>
Up-scaling of solar pump for smallholder irrigation in the central coastal region of Bangladesh	Base line survey conducted and two solar pump systems designed based on survey results.	Developed and fabricated better performing pumps (180 L/min, 40 L/min and 500 L/min) for water lifting	The innovations found feasible at farmers' fields.
Field trials and demonstrations of solar pump irrigation systems with surface water for high value crops and rice	Installed developed solar PV systems at farmers' fields, conducted experiments and field demonstrations on surface water irrigation by solar pump system for high value crops and rice	Developed portable and non-portable solar PV systems for irrigation and found very efficient	The developed solar PV systems were found efficient for surface water irrigation.
Application of solar photovoltaic panel (both portable and non-portable) to operate household appliances round the year during off irrigation period	The developed systems were set for household applications during off irrigation period and thus, it was used round the year.	Both portable and non-portable solar PV systems performed well to operate light, fan, TV, mobile charges and home water supply after irrigation season ensuring round the year use.	The developed solar PV system performed to the satisfaction of the farmers.
Analyzing the technical and economic feasibility of solar pump for multiple uses	Technical feasibility of developed solar PV system was judged by the field performance such as solar pump discharge, crop production, household operations etc. and economic feasibility was assessed by BCR, IRR etc.	The developed system was found very much sustainable for both irrigation and home applications.	The farmers were satisfied with the technology and were economically profited.

### E: Information/knowledge generated/policy generated

<b>General objectives of the sub-project</b>	<b>Major technical activities performed in respect of the set objectives</b>	<b>Output (i.e. product obtained, visible, measurable)</b>	<b>Outcome (Short term effect of the research)</b>
Up-scaling of solar pump for smallholder irrigation in the central coastal region of Bangladesh	Major technical activities included the design, fabrication and testing of the portable and non-portable solar pumps for up-scaling	A portable (500 L/min), and two non-portable (180 L/min and 40 L/min) solar pumps were developed with better performance.	The developed solar pumps performed better than LLP and useful for irrigation.
Field trials and demonstrations of solar pump irrigation systems with surface water for high value crops and rice	The developed solar pumps were installed in farmers' fields and demonstrated for surface water irrigation of rice and high value non-rice crops	The pump systems were found very much suitable for irrigation in respect of panel output, solar energy utilization and discharge.	Farmers were satisfied with the performance of the pumps.
Application of solar photovoltaic panel (both portable and non-portable) to operate household appliances round the year during off irrigation period	During off irrigation period, the solar PV systems were set in farmers' house to operate LED tube lights, DC fans, mobile charger, TV etc.	The home appliances were found to be operated nicely utilizing the PV panel produced power.	The farmers found the systems very much suitable for them. During day time they used solar power directly from the PV panels and at night from storage battery.
Analyzing the technical and economic feasibility of solar pump for multiple uses	Technical feasibility was assessed from panel output, pump discharge, simplicity in setting up of the system, operation and maintenance. Economic feasibility was done based on BCR, IRR, NPV and farmers productivity.	The farmers were benefitted using the new Solar PV systems over the existing LLP irrigation system.	Farmers' opinion were in favor of the new solar PV system for its multipurpose uses and higher benefits.

## F. Materials Development/Publication made under the Sub-project

### BARC Component

Publication	Number of publication		Remarks (e.g. paper title, name of journal, conference name, etc.)
	Under preparation	Completed and published	
Leaflet		2	১. সোলার পাম্প ভিত্তিক সোলার হোম সিস্টেম ২. ব্রি আন্ম্যমান সোলার প্যানেলের মাধ্যমে উৎপাদিত সৌরশক্তি কৃষি এবং গৃহস্থালির কাজে ব্যবহার
Booklet		1	Up-scaling and Application of Solar Photovoltaic Pump for Smallholder Irrigation and Household Appliances in the Central Coastal Region of Bangladesh
Journal publication	1 paper is submitted and 1 paper is under preparation		1. Hossain M.A, M.A. Hoque, S. S. A. Kamar, M.A. Rahman, N.N. Karim, M.S. Islam, T. Ashraf and M.Kader. 2021. Solar Photovoltaic Power System for Irrigation and Household Applications in the Southern Region of Bangladesh. Submitted to Water Resource Management. 2. Hossain A.B.M.Z., M.B. Hossain, P. K. Kundo, M.S.R. Khan, N.N. Karim, M.S. Islam and T. Ashraf. 2022. Portable Solar Photovoltaic Power System for Rice Irrigation and Household Applications in the Southern Region of Bangladesh.
Video clip		1	Documentary on Sub-project
Popular Article		1	Promotional printing in The Reflector

### BARI Component

Publication	Number of publications		Remarks (e.g., paper title, name of journal, conference name, etc.)
	Under preparation	Completed and published	
Training manual	-	1 <sup>st</sup> edition: November 2019 (500 copies) & 2 <sup>nd</sup> edition: October 2020 (1000 copies)	A training manual on installation, use and maintenance of BARI developed solar pump based solar home system
Electronic (TV, YouTube, Video Clip. etc.)	-	Completed	<a href="https://youtu.be/SF1w0TkBee0">https://youtu.be/SF1w0TkBee0</a> <a href="https://www.youtube.com/watch?v=SF1w0TkBee0&amp;t=15s">https://www.youtube.com/watch?v=SF1w0TkBee0&amp;t=15s</a>
Newspaper	-	Completed	Articles on solar pump demonstrations, trainings or visits. Dainik Motobad, Dainik Barishal Somoy, etc.
Popular article	-	Solar pump for sustainable crop production in Bangladesh	The Asian Age, 9 January 2020

## BRRRI Component

Publication	Number of publication		Remarks (e.g. paper title, name of journal, conference name, etc.)
	Under preparation	Completed and published	
Training manual.	01		A training manual on “Installation, use and maintenance of BRRRI developed solar pump based solar home system.”
Electronic (TV, YouTube, Video Clip, etc.)	-	Completed	<a href="https://www.facebook.com/watch/?v=533861027461664">https://www.facebook.com/watch/?v=533861027461664</a> <a href="https://www.facebook.com/watch/live/?v=183322413506735&amp;ref=watch_permalink">https://www.facebook.com/watch/live/?v=183322413506735&amp;ref=watch_permalink</a> (439) Multipurpose Uses of BRRRI Portable Solar Panel Based Solar Energy in Agriculture - YouTube
News Paper/Popular Article	-	Completed	The Daily Prothom Alo, AgriNews24.com, agrilife, Krishisangbad, NewsBarishal.com

## G. Description of generated Technology/Knowledge/Policy

### 1. BARI Component

#### i. Technology fact sheet

**Title of the technology: Solar pump based solar home system**

#### **Introduction**

Solar photovoltaic power production is recognized as an important part of future energy generation as it is non-polluting, free in its availability, and is of high reliability. The farmers who are cultivating vegetables in a land area of 0.4 ha – 1.00 ha may be the beneficiaries of the solar pump-based solar home systems. These technologies have been found feasible for multipurpose use in farmers’ fields. The maximum number of the existing LLP and STW systems for irrigation use costly diesel and those systems also require frequent repairing works involving huge costs of spare parts and maintenance. The developed technologies require minimum repair and maintenance and are environment friendly.

#### **Description of the technologies**

Two types of solar pump based solar home systems were developed under the project. All the required materials for the fabrication of the solar systems are available in the local market.

##### **i. Large solar pump based solar home system**

In the large solar pump system, four pieces of solar panel, each of 325W, a solar pump (910 W, 48 V, 180 L/min, 51 mm centrifugal pump) with flow meter, two circuit breaker, a charge controller, a solar battery and necessary equipment such as conductors, pipes etc. were used.

##### **ii. Mini solar pump based solar home system**

The mini model system requires only one piece of solar panel (365 W), a solar pump (280 W, 24 V, 40 L/min, 25 mm centrifugal pump) with flow meter, one circuit breaker, a charge

controller, a solar battery and necessary equipment such as conductors, pipes etc. Only one panel was found enough to supply required power to run the home appliances and the pump.

**Suitable locations:** The pump can be used all over Bangladesh where the surface/ground water exists within 6.5 m from the soil surface and 4-6 W/m<sup>2</sup>/day of solar energy is available. However, the southern region of Bangladesh has been found very suitable for the use of these technologies.

**Benefits:**

- Suitable for irrigation of high value crops, such as, tomato, brinjal, watermelon, chili etc.
- Home appliances like fans, bulbs, mobile phone charger etc. can be run by solar panel produced electricity
- The technology can be used for household water supply system
- Environment friendly as the systems do not require to burn any fuel that releases greenhouse gases in the atmosphere
- The technologies, having 25 years of discounted life and minimum repair and maintenance, are highly cost effective compared to diesel operated irrigation pumps
- The BCR of large and mini solar pumps were found to be 1.62 and 1.42, respectively

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**ii. Effectiveness in policy Support**

As the agricultural mechanization is concerned, government has already emphasized on the use of renewable energy for agricultural development in the country at a faster rate. In conjunction with that, this research sub-project was an initiative/effort in its own characteristics to find alternate way of solar energy utilization for irrigation, house hold appliances, sanitary & household water supply and running of small agricultural machinery. From the available information of the conducted research, the SP system was found technically and economically feasible. So, for the effectiveness in policy support, the sub-project has shown judicially very encouraging outcomes.

**2. BRRRI Component**

**i. Technology Fact Sheet**

**Title of the technology: Utilization of solar energy in agriculture and home appliances through BRRRI portable solar PV system**

**Introduction**

In Bangladesh, the energy crisis is severe that threatens the proper economic development in the country. Using solar pumps on a large scale, energy demand can be fulfilled to a greater extent. In agriculture, especially in irrigation and machine use, the fuel energy input can be

reduced substantially by using solar PV system. The initial cost of solar pump is higher than conventional diesel engine operated pump, but solar pump has lower maintenance cost which makes it cost effective over the years. Moreover, solar pump is a pollution free and environment friendly water pumping system. Although, the initial cost of solar panels is high, the price is rapidly decreasing with the technological advancement. The solar pumps may be economically viable for its multipurpose uses. Thus, the sub-project was designed to up-scaling of solar irrigation and home systems for smallholders complying with the government policy of Bangladesh and the SDGs of the United Nations.

#### **Description of the Technology**

A portable solar panel based solar pump was developed for rice irrigation, thresher operation and household appliances use. The designed solar PV system requires 8 panels for irrigation and 1 for home electricity supply, each panel capacity being 330 watts. The panels can be folded and unfolded as per requirement. All the required materials for the fabrication of the solar systems are available in the local market. Portable solar panels supplied electricity in 3-4 households during day time by using a 3 kW on-grid solar inverter. It also supplied electricity to grid line after fulfilling the household demands. Using a portable solar PV system, 2 ha of rice can be irrigated. The developed portable solar PV system has been found technically and financially profitable to farmers.

#### **Suitable location:**

Any location having adequate sunlight and availability of surface and groundwater within the suction limit. The project was conducted in the southern region of Bangladesh.

#### **Benefits:**

- Reduces the cost of irrigation over times by minimizing the variable costs
- Reduces the threshing cost by decreasing the threshing losses and cost of power
- Minimizes overall rice production cost to benefit the farmers
- Home appliances like fans, bulbs, tv, mobile phone charger etc. can be run by solar panel produced electricity
- The technology can be used for household water supply system
- Environment friendly as the systems do not require to burn any fuel that releases greenhouse gases in the atmosphere
- Benefit cost ratio (BCR) of multipurpose uses of portable solar PV system was 1.44

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## **ii. Effectiveness in Policy Support**

As the agricultural mechanization is concerned, government has already emphasized on the use of renewable energy for agricultural development in the country at a faster rate. Government has a target to install/replace diesel operated pumps by solar pumps which will ensure 150 MW energy generations from irrigation sector. In conjunction with that, this research sub-project was an initiative/effort in its own characteristics to find alternate way of solar energy utilization for irrigation, house hold appliances, sanitary & household water supply and operation of small agricultural machinery. From the available information of the conducted research, the solar pump (SP) system was found technically and economically feasible. A solar pump system becomes sustainable when it works round the year for multiple uses. Portable type solar panel based solar pump creates new dimension to increase the opportunity for multiple uses in the agricultural sector. On the other hand, solar irrigation has vast potential in Bangladesh to contribute to socioeconomic development and the attainment of the commitments to reduce greenhouse gas emissions. So, for the effectiveness in policy support, the sub-project has shown judicially very encouraging outcomes.

## **H. Technology/ Knowledge generation/ Policy Support**

### **i. Immediate impact on generated technology (commodity & non-commodity)**

In Bangladesh context, the technology has been found technically and economically feasible for small holdings and can be implemented anywhere in the country having adequate availability of sunshine and surface water. The farmers of the demonstrated areas were highly satisfied with the developed technology and expressed their desire to own a system for irrigation and home applications.

### **ii. Generation of new knowledge that help in developing more technology in future**

From the testing of the developed solar PV system at farmers' fields, it was evident that the up-scaling of solar PV system in respect of crop production, domestic water supply, electrical appliance use and small agricultural machinery operation was found very much successful. So, further study can be done in other regions of the country using surface/groundwater and diversified water application methods like low cost sprinkler system, alternate furrow irrigation, surge irrigation etc. for shallow rooted crops like onion, garlic and other low water requiring crops following certain cropping patterns.

### **iii. Technology transferred that help increased agricultural productivity and farmers' income**

The developed technology 'Solar PV system (portable and non-portable) for irrigation and home applications' transferred to the farmers of the southern region of the country can be used to irrigate crops, operate small agricultural machinery and run the home appliances such as, LED tube light, mobile phone, DC fan etc. The solar PV system can also be used to supply water for washing, bathing, latrine use etc. Thus, the farmers can make easier life style and save electricity cost from these operations to a large extent. The technology also allows the women to operate the system.

During dry season, solar pump system can be used to irrigate Boro rice/non-rice crop with the free solar energy keeping the environment free of pollution and requiring almost nothing for the maintenance of the system. The system also allows the users to operate threshers free of energy cost. It involves minimum operation and maintenance costs (annual basis) compared to those of LLP or STW. Further, the annual return from crop production is either at par or better than the existing LLP or STW system and the life time of the developed solar PV system is around 5 times longer than LLP or STW. As a result, the ratio of the return (annual basis) from

crop production to the cost involved (annual basis) in the production system being higher, the agricultural productivity is better for the developed solar PV system compared to LLP or STW irrigation systems.

Thus, the farmers will be more benefitted from higher income generation using the developed solar PV system thereby upgrading their socioeconomic conditions.

#### iv. Policy support

Though the solar powered systems are growing faster in the world, its development in Bangladesh is progressing at a slower rate. The energy use in Bangladesh agriculture is much less than any of the developed or developing countries. Bangladesh government, in the Sustainable Development Goals and in Bangladesh Delta Plan 2100, has emphasized on the use of power including solar energy in agriculture as this factor is an indicator of agricultural development of a country. Since both portable and non-portable solar PV system has been found technically and economically feasible in the southern region of the country, the government should take adequate steps to rapid propagation of the technology in the area. In doing so, the initial cost of the system must be taken into consideration. In order to boost agricultural production and to upgrade the financial and social conditions of the users, adequate subsidy is to be ensured to the interested farmers. The following steps can be considered-

- Take into account target groups and the long term sustainability of markets when considering financial instruments to support solar pumping
- Focus on after-sales support and capacity building
- Assess the direct and indirect impacts on water resources
- Monitor performance and gather data
- Consider the influence of availability and cost of energy on the choice of crops grown
- Adopt an integrated approach to programme design

#### I. Information regarding Desk and Field Monitoring

##### i. Desk Monitoring [description & output of consultation meeting, monitoring workshops/seminars etc.)

Coordination component BARC organized an inception workshop of the sub-project on 31 July 2018, first and second annual progress workshop on 24 April 2019 and 12 October 2020 respectively. The component also organized a series of meetings, time to time, during reporting period for discussing the relevant issues of the sub-project.

##### ii. Field Monitoring

###### BARC

Date	No. of Visit	Name and addresses of team visit	Location
20.01.2019	2	1. Dr Sultan Ahmmed Ex-Member Director, NRM Division, BARC 2. Dr. Nazmun Nahar Karim Member Director (Livestock) and CSO (A C), Agricultural Engineering Unit, BARC 3. Dr. Shirazul Islam Ex-Director (Res), BARI & Consultant (PBRG Sub-project ID-001), BARC	BARI, Gazipur & BRRI Gazipur

Date	No. of Visit	Name and addresses of team visit	Location
04.11.2019-07.11.2019	1	1. Dr. Nazmun Nahar Karim Member Director (Livestock) and CSO (A C), Agricultural Engineering Unit, BARC 2. Dr. Shirazul Islam Ex-Director (Res), BARI & Consultant (PBRG Sub-project ID-001), BARC 3. Tanki Ashraf Scientific Officer, PBRG Sub-project ID-001, Agricultural Engineering Unit, BARC	Patuakhali, Barguna, Barishal, Jhalokati
03.12.2019-05.12.2019	1	1. Tanki Ashraf Scientific Officer, PBRG Sub-project ID-001, Agricultural Engineering Unit, BARC	Bhola
12.12.2019-15.12.2019	1	1. Dr Sultan Ahmmed Ex-Member Director, NRM Division, BARC 2. Dr. Nazmun Nahar Karim Member Director (Livestock) and CSO (A C), Agricultural Engineering Unit, BARC 3. Dr. Shirazul Islam Ex-Director (Res), BARI & Consultant (PBRG Sub-project ID-001), BARC 4. Tanki Ashraf Scientific Officer, PBRG Sub-project ID-001, Agricultural Engineering Unit, BARC	Barishal, Jhalokati, Projpur
14.03.2020-16.03.2020	1	1. Dr. Shirazul Islam Ex-Director (Res), BARI & Consultant (PBRG Sub-project ID-001), BARC 2. Tanki Ashraf Scientific Officer, PBRG Sub-project ID-001, Agricultural Engineering Unit, BARC	Bhola
03.11.2020-10.11.2020	1	1. Dr. Shirazul Islam Ex-Director (Res), BARI & Consultant (PBRG Sub-project ID-001), BARC 2. Tanki Ashraf Scientific Officer, PBRG Sub-project ID-001, Agricultural Engineering Unit, BARC	Bhola, Patuakhali, Barguna
10.12.2020-14.12.2020	1	1. Dr. Shirazul Islam Ex-Director (Res), BARI & Consultant (PBRG Sub-project ID-001), BARC 2. Tanki Ashraf Scientific Officer, PBRG Sub-project ID-001, Agricultural Engineering Unit, BARC	Barishal, Jhalokati, Projpur

**iii. Weather data, flood/salinity/drought level (if applicable) and natural calamities**

Cyclone Bulbul 2019, cyclone Fani 2019, cyclone Amphan 2020, cyclone Yaas 2021, Covid-19, etc.

## J. Sub-project Auditing

### Coordination component: BARC

Types of audit	Major observation/ issues/ objections raised; if any	Amount of Audit (Tk.)	Status at the sub-project end	Remarks
Internal	None	1790013.00	1st year (2018-19)	29.09.2019
FAPAD	None	1790013.00	1st year (2018-19)	29.10.2019
FAPAD	None	1587546.00	2nd year (2019-20)	09.12.2020
FAPAD	None	1685303.00	3rd year (2020-21)	11.10.2021

### Component 1: BARI

Types of audit	Major observation/ issues/ objections raised; if any	Amount of Audit (Tk.)	Status at the sub-project end	Remarks
FAPAD	None	3086387.00	1st year (2018-19)	17.11.2019
FAPAD	None	4004637.00	2nd year (2019-20)	02.11.2020

### Component 2: BRRI

Types of audit	Major observation/ issues/ objections raised; if any	Amount of Audit (Tk.)	Status at the sub-project end	Remarks
FAPAD	None	49,66,428.00	1st year (2018-19)	30.10.2019
FAPAD	None	21,42,470.00	2nd year (2019-20)	30.11.2020

## K. Lessons Learned

- i. From the study, solar pump system has been found feasible both technically and economically for small and medium farmers of the southern coastal region of Bangladesh to produce high value non-rice / rice crops. In addition, supplying irrigation, sanitary and household water and running of small agricultural machinery could be done smoothly by the developed solar pump system
- ii. The farmers are convinced that the technology is a useful one. However, some of them think that the initial costs are high. So, they expressed their desire to have the technology at a subsidized rate
- iii. Adequate and effective training to be imparted to farmers, technicians / electricians so that they can easily install, operate and maintain the system
- iv. Natural calamities, sometimes, become the largest obstruction to crop irrigation and crop harvest in the southern belt
- v. Since the system has been used only for surface water withdrawal and its utilization, it should also be tested for groundwater pumping and see the difference in performances
- vi. Women can successfully be involved in the operating systems
- vii. The system is an environment friendly one
- viii. It is important to think/plan about the regulating authority of the group based solar pump farmers.

## **L. Challenges**

- i. Inadequate fund availability with the small and marginal farmers to purchase the solar pump system is the main challenge in the extension of the system
- ii. It is a new technology to the farmers of the region and it requires adequate knowledge and skills to install, operate and maintain the system. It would be very difficult to make the system successful unless they are well trained about the system
- iii. Natural disaster is a challenge to implement the system in the southern region of the country
- iv. Continuous gloomy weather for days together can be another obstacle to smooth running of the system, especially, for using household appliances and home water supply.
- v. Excessive day temperature in the month of March and April need to be considered during designing a PV solar pump system to prevent the pump from stopping due to overloading.

## **M. Suggestions for future planning**

- i. The solar pump system can be installed and operated in other locations of the country where the surface water is available. However, in areas of scarce surface water, efforts to be made to test the solar PV system for small submersible pumps to lift groundwater
- ii. The water application method like low cost sprinkler system can be tested to irrigate low water requiring crops like onion, garlic etc. which require frequent but small quantity of water per irrigation.
- iii. Alternate furrow irrigation can be tested along with drip and sprinkler water application methods
- iv. Government subsidy to be provided to farmers for purchasing the solar pump systems like other agricultural machinery
- v. Government can take initiative to permit net metering for solar PV systems under smallholders to offer more benefits to the users
- vi. More light sensitive solar panels to be selected so that these can be operated under less gloomy weather.

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Signature of the Coordinator

Date ... 9.12.2021 .....

Seal **Dr. Nazmun Nahar Karim**  
 Coordinator  
 Solar Pump Project-G01  
 &  
 Chief Scientific Officer  
 Agricultural Engineering Unit  
 Natural Resource Management Division  
 Bangladesh Agricultural Research Council  
 Farmgate, Dhaka-1215



Counter signature of the Head of the organization/authorized representative

Date ... 13.12.2021 .....

Seal **Dr. Shaikh Mohammad Bokhtiar**  
 Executive Chairman  
 Bangladesh Agricultural Research Council  
 Farmgate, Dhaka-1215

**Annexure-1**  
**a. Survey questionnaire for farmers**

প্রকল্পের নাম: Up-scaling and Application of Solar Photovoltaic Pump for Smallholder Irrigation and Household Appliances in the Central Coastal Region of Bangladesh

সেচযন্ত্র ব্যবহারকারীদের জন্য জরিপপত্র

ক্রমিক নং -

তারিখ:

১। অবস্থান

নাম.....

জেলা: .....

উপজেলা: .....

ইউনিয়ন/পৌরসভা: .....

গ্রাম: .....

পেশা: .....

২। মোবাইল নাম্বার ..... বয়স.....বছর

৩। শিক্ষাগত যোগ্যতা

নিরক্ষর

প্রাথমিক

মাধ্যমিক

উচ্চ মাধ্যমিক

ডিগ্রী এবং উচ্চতর

৪। শস্য বিন্যাস কি?.....

৫। জমি পরিমান (শতাংশ).....

মোট জমি	চাষ অযোগ্য জমি (বাড়ি, পুকুর, ইত্যাদি)	চাষযোগ্য জমি	সেচের আওতায় জমি	সেচছাড়া জমি

৬। আপনার নিজস্ব সেচ পাম্প আছে কি? হ্যাঁ  / না

ক। যদি হ্যাঁ, তাহলে কি ধরনের পাম্প?

STW/DTW/LLP/ অন্যান্য (উল্লেখ করুন).....

খ। পাম্পের শক্তি কত?.....

গ। পানির উৎস:

অগভীর

গভীর

ভূপৃষ্ঠ

পাতকুয়া

পুকুর

নদী

খাল

ঘ। শুকনা মৌসুমে খালে/পুকুরে কত ফুট পানি থাকে.....ফুট

ঙ। শক্তির উৎস কি? ডিজেল  / বিদ্যুৎ

চ। পাম্পের মোট স্থাপন ব্যয় কত?.....

ছ। মৌসুম প্রতি পাম্প রক্ষণাবেক্ষণ খরচ কত?.....

জ। ডিজেল চালিত হলে, ডিজেলের খরচ?

(১) জ্বালানির হার..... লিটার / ঘন্টা?

(২) দৈনিক কত ঘন্টা চলে?.....

(৩) সেচ মৌসুমে ডিজেলের মূল্য.....টাকা/লি

(৪) মোট খরচ.....টাকা/মৌসুম

ঝ। বিদ্যুৎ চালিত হলে, বিদ্যুৎ বিল..... টাকা/মৌসুম বা..... টাকা/মাস

৭। ফসল প্রতি সেচ খরচ (১ বিঘা =.....শতক)

ফসল	ডিজেল পাম্পের খরচ (টাকা/বিঘা)		বৈদ্যুতিক মোটর পাম্পের খরচ (টাকা/বিঘা)	
	নিজস্ব পাম্প	ভাড়া করা	নিজস্ব পাম্প	ভাড়া করা
বোরো ধান				
আমন ধান				

৮। সেচ মৌসুমে ডিজেলের প্রাপ্যতা:

(১) পর্যাপ্ত পরিমাণ

(২) অপরিপূর্ণ পরিমাণ

(৩) অপ্রতুল

৯। সেচ মৌসুমে প্রতিদিন কতঘন্টা লোড শেডিং হয়?.....

১০। সেচ মৌসুমে পানির প্রাপ্যতা? (১) পর্যাপ্ত পরিমাণ

(২) অপরিপূর্ণ পরিমাণ

(৩) অপ্রতুল

১১। সর্বোচ্চ সেচকালীন সময়ে এবং তার পূর্বে ভূগর্ভস্থ পানির স্তর কোথায় থাকে?

পূর্বে ..... ফুট সেচকালীন সময়ে (..... মাস) ..... ফুট।

১২। আপনি কি মনে করেন সৌর পাম্প ডিজেল / বিদ্যুতের বিকল্প হতে পারে?.....

সাক্ষাতকার গ্রহনকারীর স্বাক্ষর

নাম:

পদবি:

## b. Survey questionnaire for pump users

প্রকল্পের নাম: Up-scaling and Application of Solar Photovoltaic Pump for Smallholder Irrigation and Household Appliances in the Central Coastal Region of Bangladesh

সৌর পাম্প ব্যবহারকারীদের জন্য জরিপপত্র

ক্রমিক নং -

তারিখ:

১। অবস্থান

নাম:..... জেলা: .....

উপজেলা: ..... ইউনিয়ন/পৌরসভা: .....

গ্রাম: ..... পেশা.....

মোবাইল নাম্বার ..... বয়স..... বছর

২। শিক্ষাগত যোগ্যতা

নিরক্ষর

প্রাথমিক

মাধ্যমিক

উচ্চ মাধ্যমিক

ডিগ্রী এবং উচ্চতর

ট্রেনিং কয়টি

৩। সৌর শক্তি কি কাজে ব্যবহার করেন?

সেচের কাজে

বসতবাড়িতে

উভয়ই

৪। কত সালে এই সৌর পাম্প স্থাপিত হয়েছে?.....

৫। সৌর পাম্প প্ল্যান্ট কোথায় স্থাপন করেছেন?

ফসলের জমিতে

বসতবাড়িতে

৬। সৌর মোটরের ক্ষমতা কত?.....

৭। প্যানেলের ক্ষমতা কত?..... ওয়াট (পিক)

৮। মোটরের ধরন?

ডিসি

এসি ১- ফেজ

এসি ৩- ফেজ

৯। যদি সেচের কাজে হয়, তাহলে সেচের জমির অবস্থা ও পরিমাণ এবং সেচের ফসল:

ফসলের নাম	সেচের আওতায় জমির পরিমাণ			
	নিজের জমি (পরিমাণ)	জমির অবস্থা (উঁচু/মাঝারি/নিচু)	অন্যের জমি (পরিমাণ)	জমির অবস্থা (উঁচু/মাঝারি/নিচু)
ধান				
গম				
ভুট্টা				
সবজি				

১০। সৌর পাম্প কে সরবরাহ করেছে?

ডিএই  বিএডিসি  এনজিও  অন্যান্য

১১। যদি এনজিও হয়, তাহলে তার নাম?.....

১২। জমিতে পানি সরবরাহ করেন কিভাবে?

ভূপৃষ্ঠস্থ কাঁচা চ্যানেল  ভূপৃষ্ঠস্থ পাকা চ্যানেল  হোস পাইপ  বারিড পাইপ

ক) যদি পাকা চ্যানেল হয়, তাহলে ইহার খরচ কত?.....

খ) যদি হোস পাইপ হয়, তাহলে ইহার খরচ কত?.....

গ) যদি বারিড পাইপ হয়, তাহলে ইহার খরচ কত?.....

১৩। বিঘা (\*১ বিঘা = .....শতাংশ) প্রতি সেচ খরচ প্রতি ঋতুতে

ফসল	সৌর পাম্প					বৈদ্যুতিক মোটর চালিত পাম্প				
	পানির উৎস	সেচকাল (কত দিন)	পাম্প থেকে জমির দূরত্ব	পানি পরিবহনের মাধ্যম	ভাড়া টাকা/বিঘা	পানির উৎস	সেচকাল (কত দিন)	পাম্প থেকে জমির দূরত্ব	পানি পরিবহনের মাধ্যম	ভাড়া টাকা/বিঘা
ধান										
গম										
ভুট্টা										
আলু										

ফসল	ডিজেল ইঞ্জিন চালিত পাম্প					এক্সিয়াল ফ্লো পাম্প				
	পানির উৎস	সেচকাল (কত দিন)	পাম্প থেকে জমির দূরত্ব	পানি পরিবহনের মাধ্যম	ভাড়া টাকা/বিঘা	পানির উৎস	সেচকাল (কত দিন)	পাম্প থেকে জমির দূরত্ব	পানি পরিবহনের মাধ্যম	ভাড়া টাকা/বিঘা
ধান										
গম										
ভুট্টা										
আলু										
সবজি										

১৪। পানির উৎস:

- অগভীর     গভীর     ভূপৃষ্ঠত     পাতকুয়া  
 পুকুর  
 নদী  
 খাল

১৫। পাম্পের ধরন?

- সেন্ট্রিফিউগাল     টারবাইন     এক্সিয়াল ফ্লো পাম্প

১৬। যদি সোলার হয়, তাহলে, রাতে বা মেঘলা দিনে কিভাবে সেচের কাজ করেন?

- ব্যাটারি     জলাধার  
 (ক) যদি ব্যাটারি হয়, তাহলে, ব্যাটারির ক্ষমতা কত?.....  
 (খ) যদি জলাধার হয়, তাহলে, জলাধারের সাইজ কত?.....  
 (গ) জলাধারের ধরন?

- প্লাস্টিক     ধাতব     কংক্রিট  
 (ঘ) জলাধারের খরচ কত?.....

১৭। গৃহস্থালীর কি কি জিনিসপত্র ব্যবহার করছেন?

নাম	ডিসি	এসি	ক্ষমতা

১৮। আপনি কি মনে করেন সৌর পাম্প সেচের জন্য উপযুক্ত?

১৯। সৌর পাম্পের কি কি সুবিধা আছে আপনি মনে করেন?

২০। সৌর পাম্পের কি কি অসুবিধা আছে আপনি মনে করেন?

২১। বাংলাদেশে সৌর পাম্প চালু করার জন্য আপনার পরামর্শ কি?

সাক্ষাতকার গ্রহনকারীর স্বাক্ষর

নাম:

পদবি:

### c. Survey questionnaire for pump service providers

প্রকল্পের নাম: Up-scaling and Application of Solar Photovoltaic Pump for Smallholder Irrigation and Household Appliances in the Central Coastal Region of Bangladesh

সৌর পাম্প সেবা প্রদানকারীদের জন্য জরিপপত্র

ক্রমিক নং -

তারিখ:

১। উদ্যোক্তাদের নাম:.....

ঠিকানা.....

২। সেবা প্রদানকারীর ধরন.....

পদবি:..... বয়স..... বছর

৩। সৌর পাম্পের সঙ্গে আপনার কোম্পানী কত সময় ধরে জড়িত? ..... বছর

৪। এ পর্যন্ত কতগুলি সৌর পাম্প স্থাপন করেছেন?.....

৫। গ্রাহকের ধরন?.....

৬। সৌর পাম্প কি কাজে ব্যবহার করা হয়: সেচ / খাবার পানি / অন্যান্য / (নির্দিষ্ট করুন .....)

স্থাপনের বছর	স্থাপনের জায়গার বিবরণ		পাম্প হাউজের বিবরণ		বেড়ার বিবরণ	
	পরিমাণ (শতক)	ভাড়া টাকা/বছর	ধরন (পাকা/কাঁচা/টিনের)	খরচ	ধরন	খরচ

৭। সৌর পাম্প স্থাপনের তথ্য

৮। একটি সৌর পাম্পের খরচ (.....ওয়াট সর্বাধিক)

সৌর পাম্পের দাম	জিনিসপত্র এবং অবকাঠামোগত খরচ	স্থাপন ব্যয়	জমির ভাড়া	পরিচালনা খরচ	রক্ষণাবেক্ষণের খরচ	পাহাড়া খরচ	অন্যান্য খরচ	মোট খরচ (টাকা)

৯। সৌর পাম্প থেকে কতজন মানুষ সেবা পাচ্ছে?.....

১০। পরিষেবা প্রদানের (খরচ) জন্য আপনি কি পদ্ধতি অনুসরণ করেন? মৌসুমি / বার্ষিক / অন্যান্য.....

১১। ব্যবহারকারীদের কাছ থেকে মূল্য সংগ্রহ

সেচ	খাবার পানি ও গৃহস্থালির কাজে ব্যবহারের পানি	অন্যান্য ব্যবহার/ (নির্দিষ্ট করুন)

১২। মেঘলা আবহাওয়ায় আপনারা কিভাবে সেচকাজ সম্পাদন করেন?

১৩। সোলার পাম্প ব্যবসায় আপনি কি কি সমস্যার সম্মুখীন হচ্ছেন?

১৪। বাংলাদেশে সোলার পাম্পের ব্যবহার বাড়ানোর জন্য আপনার পরামর্শ কি?

.....

সাক্ষাতকার গ্রহনকারীর স্বাক্ষর

নাম:

পদবি



Ministry of Agriculture



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