Sub-Project ID-002

Program Based Research Grant (PBRG)

Sub-project Completion Report

on

Groundwater Resources Management for Sustainable Crop Production in Northwest Hydrological Region of Bangladesh

Sub-project Duration
27 February, 2018 to 26 February, 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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Implementing Organization

Irrigation and Water Management Division
Bangladesh Agricultural Research Institute (BARI)

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

Agricultural Engineering Division
Bangladesh Institute of Nuclear Agriculture (BINA)

Project Implementation Unit
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The execution of PBRG sub-project has successfully been completed by Irrigation and Water Management Division of Bangladesh Agricultural Research Institute (BARI), Irrigation and Water Management Division of Bangladesh Rice Research Institute (BRRI) and Agricultural Engineering Division of Bangladesh Institute of Nuclear Agriculture (BINA) under the coordination of Agricultural Engineering Unit, Natural Resources Management Division, Bangladesh Agricultural Research Council (BARC) using the research fund of WB, IFAD and GoB through Ministry of Agriculture. We would like to acknowledge to the World Bank for arranging the research fund and supervising the PBRGs by BARC. It is worthwhile to mention the cooperation and quick responses of PIU-BARC, NATP-2 in respect of field implementation of the sub-project in multiple sites. Preparing the sub-project completion report required to contact a number of persons for collection of information and processing of research data. Without the help of those persons, the preparation of this document could not be made possible. All of them, who have made it possible, deserve appreciation. Our thanks are due to the Director PIU-BARC, NATP-2 and his team who given their whole hearted support to prepare this document. We hope this publication would be helpful to the agricultural scientists of the country for designing their future research projects in order to technology generation as well as increasing production and productivity for sustainable food and nutrition security in Bangladesh. It would also assist the policy makers of the agricultural sub-sectors for setting their future research directions.

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Abbreviation and Acronyms

Abbreviation	Full Name
ABCP	Aus Based Cropping Pattern
AFI	Alternate Furrow Irrigation
AGRM	Artificial Groundwater Recharge Method
ASM	Available Soil Moisture
AWD	Alternate Wetting and Drying
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BBCP	Boro Based Cropping Pattern
BCR	Benefit Cost Ratio
BINA	Bangladesh Institute of Nuclear Agriculture
BMD	Bangladesh Meteorological Department
BMDA	Barind Multipurpose Development Authority
BRAC	Bangladesh Rural Advancement Committee
BRRI	Bangladesh Rice Research Institute
BWDB	Bangladesh Water Development Board
CP	Cropping Patterns
CRI	Crown Root Initiation
DAE	Department of Agricultural Extension
DAS	Day After Sowing
DI	Drip Irrigation
DRV	Deficit Recharge Volume
DTW	Deep Tube Well
EB	Economic Benefit
FAO	Food and Agricultural Organization
FLM	Farmer’s Levee Management
FM	Farmer’s Management
FNU	Formazin Nephelometric Units
g	gram
GWT	Groundwater Table
ha	hectare
ILM	Improved Levee Management
IR	Irrigation Requirement
IWM	Institute of Water Modeling
IWP	Irrigation Water Productivity
Kg	Kilogram
KR	Kelly’s Ratio
LSD	Least Significant Difference
lpcd	liters per capita per day
MAR	Magnesium Adsorption Ratio
MAXGWT	Maximum Ground Water Table
MCT	Minimum Area Coverage by Technology
MINGWT	Minimum Ground Water Table
NBBCP	New Boro Based Cropping Pattern

Abbreviation	Full Name
NTU	Nephelometric Turbidity unit
OW	Observation Well
PW	Pumping Well
PWDS	Pipe Water Distribution System
RD	Recharge Depth
REY	Rice Equivalent Yield
RM	Research Management
RPRF	Recharge Period Rainfalls
RUP	Reduced Utilization Percent
SAR	Sodium Adsorption Ratio
SSP	Soluble Sodium Percentage
STW	Shallow Tubewell
t	ton
T. Aman	Transplanted Aman
T. Aus	Transplanted Aus
TH	Total Hardness
TI	Towfiqul Islam
UNDP	United Nations Development Program
WHO	World Health Organization

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Executive Summary

Agriculture is the major user of water in Bangladesh, with rice cultivation as the single most important economic activity. Rice is the staple food in the country, and is grown on 75% of the total cultivated land, constituting 90% of the total food grain production. The dramatic increase in *boro* production was due largely to the extensive exploitation of groundwater. Presently, about 80% of groundwater is used for irrigation, of which 73% is used exclusively by *boro* farmers. However, groundwater irrigation also has serious consequences as energy costs are increasing, water levels are declining in the intensive irrigated areas of northwest hydrological region (especially Barind area) of Bangladesh. Due to high installation, operational, and management costs, the large-scale development of surface water resources in Bangladesh will remain a challenge in near future. Groundwater irrigation will therefore remain crucial to sustain agrarian growth to meet Bangladesh's future food requirements. Recognizing the important role that groundwater will play in the future to support rural economies within Bangladesh, its availability in terms of quantity and quality must be ensured. Therefore, it is imperative to understand the issues and challenges of groundwater use in Bangladesh and to evaluate options for its sustainable management. Therefore, proper management and sustainable utilization of the scanty groundwater reserves in an efficient manner are imperative to secure continuous supplies of groundwater for the future generations. With this perspective, a coordinated sub-project entitled "Groundwater resources management for sustainable crop production in northwest hydrological region of Bangladesh" was initiated by BARC as a coordinating body implemented by the different NARS institutes like BARI, BRRI and BINA with a view to sustainable management of groundwater resources of northwest hydrological region through optimizing water demand and supply. The sub-project general objectives were: i) To assess groundwater availability and recharge pattern in different districts of northwest hydrological region of Bangladesh, ii) To optimize groundwater abstraction for irrigation, and iii) To suggest plan for sustainable use of groundwater for crop production.

The study locations were in the north-west hydrological region of Bangladesh as follows: Component-1: BARI – Rajshahi (Godagari and Tanore upazila), Joypurhat (Joypurhat Sadar and Kalai upazila); Component-2: BRRI – Rangpur (Mithapukur and Pirganj upazila), Pabna (Ishwardi and Santhia upazila) and Component-3: BINA – Chapainawabganj (Nachole upazila) and Naogaon (Niamatpur upazila) districts. Recharge to groundwater was assessed using water balance and water-table fluctuation method, tracer technique. Trend of water-table fluctuations was determined using MAKSENSE, discrete space-state model and analytical model (designated as TI). Trend of rainfall was determined through non-parametric method (*Rho*-test). Historical weekly groundwater level data of 39 years (1980 – 2018) from observation wells in the study areas were collected and used to predict the trend of change of groundwater level by using discrete Space-state modeling approach. Irrigation, domestic and municipal water requirement were assessed to predict long term yearly groundwater abstraction pattern. Groundwater abstraction, recharge pattern, withdrawal rate and deficit and positive recharge were calculated and analyzed. A relationship between groundwater recharge deficit and withdrawal rate of water was developed.

A hydrologic model MODFLOW was used to optimize of groundwater abstraction. MODFLOW simulation model was calibrated using field data and used to develop scenario of water-table position under different cropping patterns. Simulating withdrawal rate, total deficit recharge after a long period and safe withdrawal rate per year for recovering deficit was determined using conceptual model known as Towfiqul Islam (TI) model.

Based on an extensive investigation on the existing cropping patterns in the study areas, four to five promising cropping patterns from each study area were selected and cropping pattern based field trials with rice and non-rice crop were conducted with adoption of water saving technologies like AWD, levee management practices in rice cultivation to conserve rain water, alternate furrow irrigation, etc.

Groundwater level declination was found more in Tanore upazila than other three upazilas of Rajshahi and Joypurhat district. The rate of GW level declination was on an average 27.43 cm/yr at Tanore, 14.02 cm/yr at Godagari, 11.28 cm/yr at Joypurhat sadar and 15.85 cm/yr at Kalai. It will be almost double by the year 2040 in Tanore. A declining trend of groundwater table persists in Rangpur and Pabna districts except at Pirganj upazila. The maximum total depletion is 205 cm with the maximum 6.6 cm per year depletion in 30 years. The number of years of negative recharge is more than that of positive recharge during 32 years. The maximum groundwater table depth remained below suction limit at Ishwardi causing inoperative (no or less discharge of shallow tubewell, STW) during dry season. Yearly recharge (Naogaon and Chapainawabganj districts) at Nachole area varied from 106.6 to 211.7 mm/year under different methods (7.68 – 15.3% of yearly rainfall) for the study period. The average result was found as 195.8, 122.8, and 102.6 mm under tracer technique, water balance method, and water-table fluctuating method, respectively. At Niamatpur area, yearly recharge was found as 210 mm, 149.1 mm, and 137.6 mm under tracer technique, water balance method, and water-table fluctuating method, respectively. In terms of annual rainfall, it was about 15.14%, 10.7%, and 9.92 % of rainfall. Aquifer properties were favourable for sustainable groundwater abstraction of the area and all the values were suitable for sustainable groundwater development. The water quality indices, north-west hydrological region of studied districts, such as SAR, SSP, RSC and KR indicated that quality of groundwater samples fall under excellent and good categories for irrigation use. As per water quality index (WQI), all the samples were under “good” category.

As the increasing demand of water is triggering more in Rajshahi than in Joypurhat, so more groundwater need to be abstracted in future from Rajshahi of Barind areas. Abstraction will be increasing by 33-35% in Joypurhat study areas while it will be increasing by 40-45% in Rajshahi in the next 20 years. When the abstraction was reduced to 90%, the computed heads from ground surface rose significantly, and the values were 7.970m, 11.150m, and 18.106m, respectively at the three observation wells. On the other hand, if the abstraction would be increased to 110%, the MODFLOW computed heads at the observation wells were found as 20.707m, 21.745m, and 24.413m, respectively which indicated a substantial drop in the head development. Analytical model quantified that maximum 66.67 percent deficit recharge occurred in aquifer of Rangpur and Pabna districts and maximum reduced utilization of groundwater per year should be 13.33 percent if it is targeted to recover deficit recharge within five years. The maximum coverage (69.44 % of Boro area) by the alternate wetting and drying (AWD) technology will be able to recover deficit recharge within five years in the study area through retarding declination of groundwater per year. The same model indicated recharge recovery of groundwater if Boro is replaced by Aus in cropping pattern in Chapainawabganj and Naogaon districts.

In Rajshahi and Joypurhat, rice equivalent yield (REY) and water productivity (WP) were found higher in cropping patterns where high yielding rabi crops like tomato, potato and maize were included and water saving irrigation technologies (AWD, alternate furrow irrigation, levee management, supplemental irrigation, etc.) were adopted. Among the cropping patterns, the highest REY and WP were obtained from Tomato-Boro-T.Aus followed by Potato-Boro-T.Aman pattern while the lowest was from Mustard-Boro-T.Aman pattern. Use of water saving irrigation technologies increased REY by 8-24% and saved about 20-25% water over existing farmers’

practice. In Pabna and Rangpur, in terms irrigation water productivity (IWP), rice equivalent yield (REY) and economic for the sub-project site, Aus based CP such as T. Aman- Lentil – T. Aus performed best. But in terms of rice equivalent yield, Boro based CP such as T. Aman-Mustard-Boro and T. Aman-Potato-Boro performed well. As REY of these two CPs (Boro based) were good, they were also good in terms of economic benefit (EB). Beside that their irrigation water productivity was also remarkable. Benefit of Improved Levee Management (ILM) was remarkable in areas of scare or uneven distribution of rainfall. For example, the maximum yield advantage (26% higher) was obtained in ILM at Pabna in 2018 as rainfall was lower than in 2019 and 2020. In Naogaon and Chapainawabganj districts, the pattern “Aman-Rabi (lentil /mustard /wheat)-Aus” saved an average of about 55 and 57 percent irrigation water and increased the equivalent rice yield to about 10-19 and 14-16 percent (along with higher benefit-cost ratio), compared to existing two cropped pattern “Aman-Fallow-Boro” at Nachole and Niamatpur, respectively.

The sustainable use and management of groundwater is now a great challenge in the northwest hydrological region of Bangladesh. Due to cultivation of water intensive crops, irrational irrigation management, indiscriminate installation of pumps and non-availability of modern technologies, the use of groundwater is much higher in this region compared to other parts of the country leading to declination of groundwater table at an alarming rate. Because of this threat, it is important to exploiting groundwater annually not exceeding the replenished amount from annual seasonal rainfall. Therefore, the key challenges are now to increase agricultural productivity without deteriorating the groundwater resources. Safe abstraction of groundwater resources is only possible if the irrigation water is utilized judicially by practicing water saving technologies with low water consuming cropping patterns simultaneously and by optimizing water abstraction on the basis of the existing and future scenarios of the climatic variability, e.g. recharge through rainfall. Thus, sustainable groundwater resources management will sustain agricultural production in this region.

Key Words: Aquifer, cropping pattern, water-table, sustainability, groundwater, economics, Barind area

PBRG Sub-project Completion Report (PCR)

A. Sub-project Description

1. **Title of the PBRG sub-project:** Groundwater resources management for sustainable crop production in northwest hydrological region of Bangladesh
2. **Implementing organizations:**
   a. Bangladesh Agricultural Research Institute
   b. Bangladesh Rice Research Institute
   c. Bangladesh Institute of Nuclear Agriculture
3. **Name and full address with phone, cell and E-mail of Coordinator, Associate Coordinator, PI/Co-PIs:**

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4. Sub-project budget (Tk.):

4.1 Total (approved): Tk. 3,72,79,896.00

4.2 Latest Revised (approved): Tk. 3,47,79,840.00

5. Duration of the sub-project:

5.1 Start date (based on LoA signed): 27 February, 2018

5.2 End date: 26 February, 2022

6. Background of the sub-project:

The increase of food production with less irrigation water use has been the main policy target in farm management over the recent years, particularly in countries with limited water and land resources (FAO, 2012). It has been estimated that if sustainable irrigation water management strategies are not implemented, there will be an estimated loss of agricultural production of 7.8% by 2080 (Cline, 2007). Bangladesh is one of the world's most densely populated countries, where food security has been a continuous challenge since its liberation. The expansion of irrigated crop land has probably been the most dramatic development in Bangladesh agriculture during the last 25 years mainly through groundwater irrigation. In Bangladesh, agriculture is responsible for more than 65 percent of total fresh water withdrawal (Shamsudduha *et al.* 2011), where nearly 80 percent of this irrigation water comes from groundwater resources due to uncertainty of year-round surface water availability (Rahman Saha, 2012). Clearly, the availability of groundwater for irrigation has contributed to manifold increase in crop productivity. Studies found that the contribution of groundwater has increased from 41% in 1982-83 to 77% in 2006-07. The ratio of groundwater to surface water use is much higher in north-western districts of Bangladesh compared to other parts of the country. Climatically, this area belongs to dry humid zone with annual average rainfall vary between 1,400 and 1,900 mm. The seasonal distribution of this amount of rainfall shows that almost 92.7% rainfall occurs during May to October and less than 6% rainfall occurs during the dry season irrigation period of cultivating rice (November to April). All the rivers and canals become dry during the dry season and make the people completely dependent on groundwater (Shahid, 2008; Shahid and Behrawan, 2008) to meet up the demand of cultivating crops especially for boro rice.

Though the groundwater dominates the total irrigated area, its sustainability is at risk in terms of quantity in the northwest region (Zaman *et al.*, 2017; Ashraf and Ali, 2015; Ali *et al.*, 2012; Simonovic, 1997; Shahid, 2011) through over extraction of this resources. Researchers have revealed that over extraction of groundwater for irrigation due to lack of proper knowledge, cultivation of water intensive crops, irrational irrigation management, indiscriminate installation of pumps and non-availability of modern technologies are the major reasons behind the current crisis (Adhikary*et al.,* 2013; Ali *et al.,* 2012; Shahid & Hazarika, 2010). In addition, global climate change effects and reduced water flow in major rivers due to upstream water diversion by India has made the situation worse (Adhikary *et al.,* 2013). Different studies have documented that groundwater table has been declined by at least 10 meters during the last 14 years (Ali *et al.,* 2012; Shahid & Hazarika, 2010) in some areas of the Barind tract of northwest region. Decline of groundwater [strong declining trends

(0.5 – 1.0 meter/year) in the central part of the country, moderately declining trend (0.1 – 0.5 meter/year) in western, north-western and north-eastern areas during dry season] is a threat of water resources for future if annually not replenished from annual seasonal rainfall. This substantial declination of groundwater level during the last decade causing threat to the sustainability of water use for irrigation in this region and impacting upon other sectors as well (Jahan *et al.,* 2010 and Ali *et al.*, 2011). Frequent shortage of water has had impacts that can be ranged as economic, social and environmental. If this over-utilization continues, it may results in its exhaustion after a few years that may have serious impact on the agriculture-based economy of the country. So, emphasis should be given on the sustainability of these valuable resources.

Although maximizing crop production through greater expansion of irrigated lands is a basic requirement, sustainable utilization of the country's limited water resources is also a major concern. The key challenges are now to increase agricultural productivity without deteriorating the groundwater resources (Shahid & Hazarika, 2010). This is possible only if safe extraction of groundwater resources, the irrigation water is utilized judicially by implementing appropriate irrigation methods, and practicing water saving cropping patterns simultaneously. Policy level interventions are also needed to achieve sustainable use of groundwater for irrigation through adaptation of effective measures by the farmers aiming to achieve food security and ecological balance.

7. Sub-project general objectives:

i. To assess groundwater availability and recharge pattern in different districts of northwest hydrological region of Bangladesh,
ii. To optimize groundwater abstraction for irrigation, and
iii. To suggest plan for sustainable use of groundwater for crop production

8. Sub-project specific objectives (component wise):

Coordination Component: BARC

To coordinate, supervise, monitor and evaluate the sub-project activities of component institutes.

Component-1: BARI

i. To determine aquifer recharge and groundwater utilization pattern,
ii. To assess availability of groundwater for crop irrigation,
iii. To develop various scenarios for sustainable crop production using groundwater models,
iv. To find out optimum management techniques and suitable cropping patterns for sustainable groundwater use, and
v. To assess the quality of groundwater

Component-2: BRRI

i. To analyze groundwater table in different districts of northwest region,
ii. To determine groundwater withdrawal level for retarding water table declining,
iii. To determine low water requiring cropping pattern for groundwater scarcity zone,
iv. Up scaling of water saving technologies for sustainable crop production, and
v. To determine suitable method for safe groundwater recharge and quality of groundwater in selected area

Component- 3: BINA

i. To characterize the aquifer properties and assess groundwater availability for safe withdrawal limit,
ii. To assess the groundwater recharge, and
iii. To identify suitable cropping pattern adapted to available water resource for sustainable use of the resource

9. Implementing locations:

The study locations were in the north-west hydrological region of Bangladesh as follow (Fig. 9.1).

Component	Location
BARI	Rajshahi (Godagari and Tanore upazila) Joypurhat (Joypurhat Sadar and Kalai upazila)
BRRI	Rangpur (Mithapukur and Pirganj upazila) Pabna (Ishwardi and Santhia upazila)
BINA	Chapainawabganj (Nachole upazila) Naogaon (Niamatpur upazila)

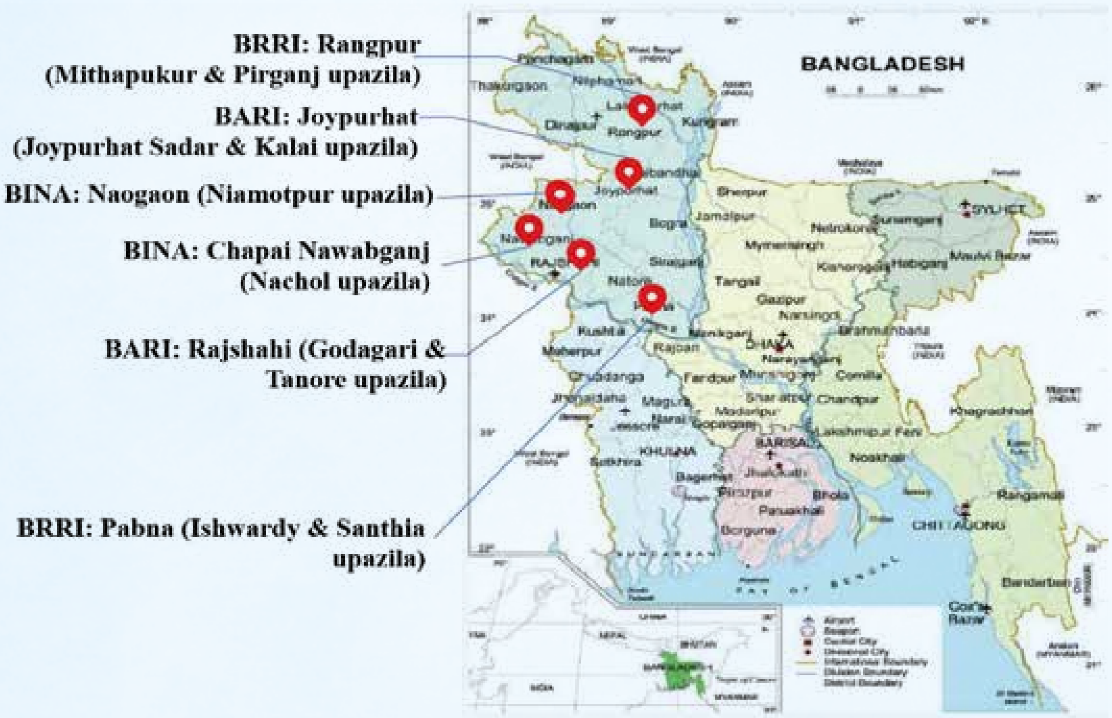


Fig. 9.1. Location of the study area

10. Methodology

Coordination Component: BARC developed the methodology & implementation strategy for the sub-project through a 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 the stipulated timeframe. All the reports as required by the NATP-2 authority were submitted regularly. Procurement of all computer and furniture related capital items were performed by 16 May 2019 following the public procurement rule (PPR) 2008. 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 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 all the three participated component institutes.

Baseline status for each site was recorded through baseline survey at the beginning of the study. The coordination component, BARC called for baseline questionnaire from the three component institutes BARI, BRRI and BINA. Consequently, the component institutes submited the questionnaire to coordination component. Then, this component developed a common baseline survey questionnaire in consultation with the implementing institutes, BARI, BRRI and BINA (Survey questionnaire are attached in Annexure I). Then the unified questionnaire was sent to individual component institutes for executing the baseline survey. To unify the baseline survey report, this coordination component provided some guidelines for the component institutes in writings with pie chart, tabular form or discussion format. Accordingly, the component institutes executed the baseline survey program in their respective sub-project locations. The interviewers collected information within the stipulated time frame. In order to get a valid and relevant information from the farmers, all possible efforts were made to achieve the purpose of the survey. Whenever any farmer felt difficulty in understanding any question, the interviewer took utmost care to explain and clarify properly. After completion of baseline program, the data, collected from the selected farmers were systematically recorded, edited, compiled, tabulated and analyzed. Thus, the baseline survey report was prepared and submitted to the coordination component: BARC.

10.1 Groundwater availability and recharge assessment

10.1.1 Component-1 BARI

10.1.1.1 Trend of groundwater level fluctuation position

Secondary data of weekly groundwater level fluctuations at the selected observation wells of the study areas were collected from Bangladesh Water Development Board. For Tanore upazila, historical weekly groundwater level data from January 1980 to September 2018 for the selected observation wells of Bangladesh Water Development Board were used. Collected data were used to predict the trend of change of groundwater level by using discrete Space-state and MAKSENS modeling approach. Location of observation wells of Rajshahi and Joypurhat districts have been shown in Table 10.1 and Fig. 10.1. Time series of groundwater level data of the selected observation wells of the study areas are illustrated in Fig. 10.2 below.

Table 10.1. Coordinates of the observation wells of Rajshahi and Joypurhat districts

Area	Observation well ID No	Location	
		latitude	longitude
Rajshahi (Tanore)	GT 8194046	24.68^{0}N	88.53^{0}E
	GT 8194048	24.57^{0}N	88.55^{0}E
	GT 8194049	24.63^{0}N	88.58^{0}E
Rajshahi (Godagari)	GT 8134017	24.40^{0}N	88.43^{0}E
	GT 8134020	24.52^{0}N	88.38^{0}E
	GT 8134021	24.49^{0}N	88.46^{0}E
	GT 8134022	24.43^{0}N	88.46^{0}E
Joypurhat (Joypurhat sadar)	GT 3847001	25.13^{0}N	89.06^{0}E
	GT 3847003	25.12^{0}N	89.12^{0}E
Joypurhat (Kalai upazila)	GT 3861004	25.02^{0}N	89.15^{0}E
	GT 3861005	24.98^{0}N	89.12^{0}E

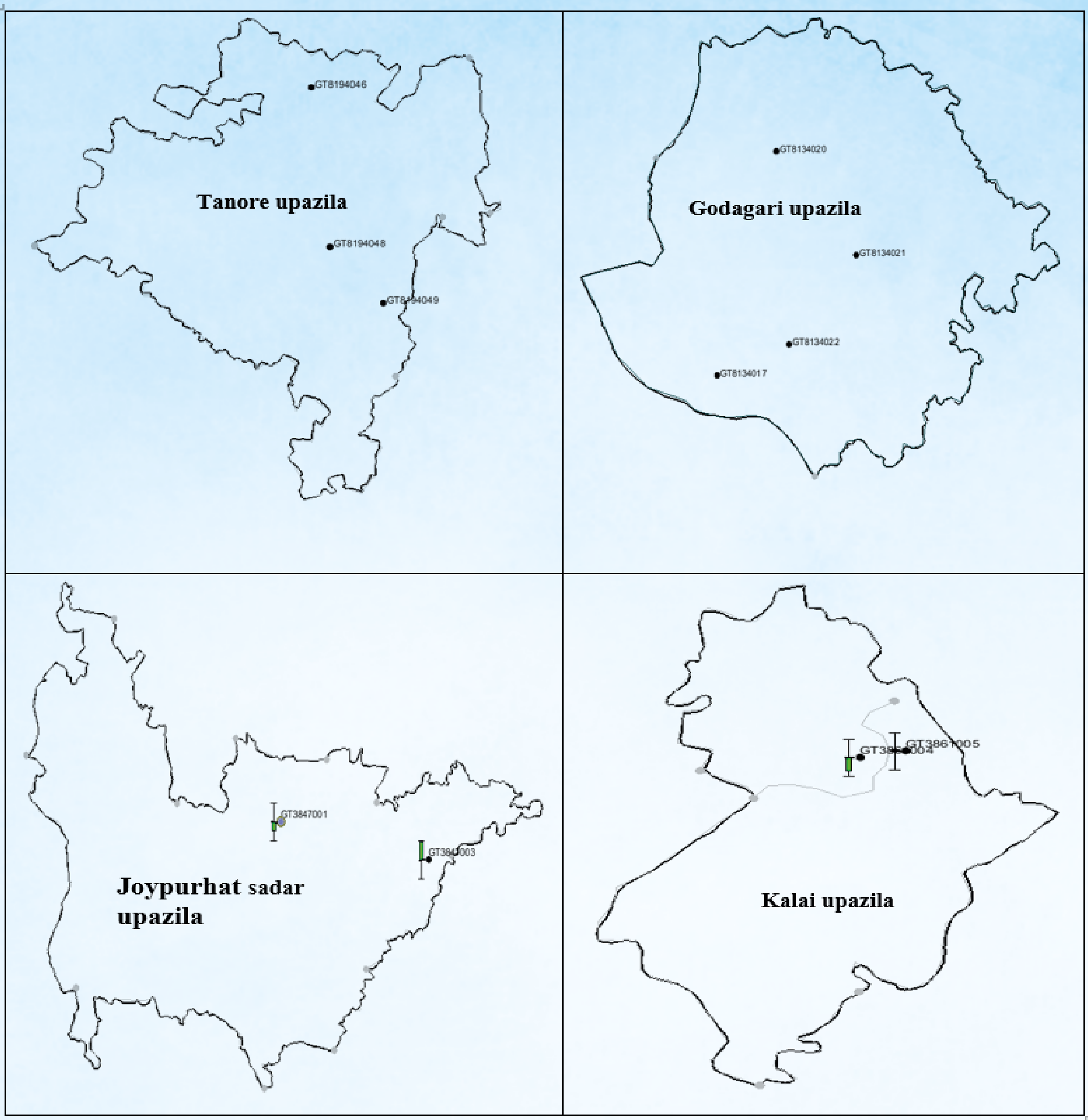


Fig. 10.1. Locations of the observation wells in Rajshahi and Joypurhat districts

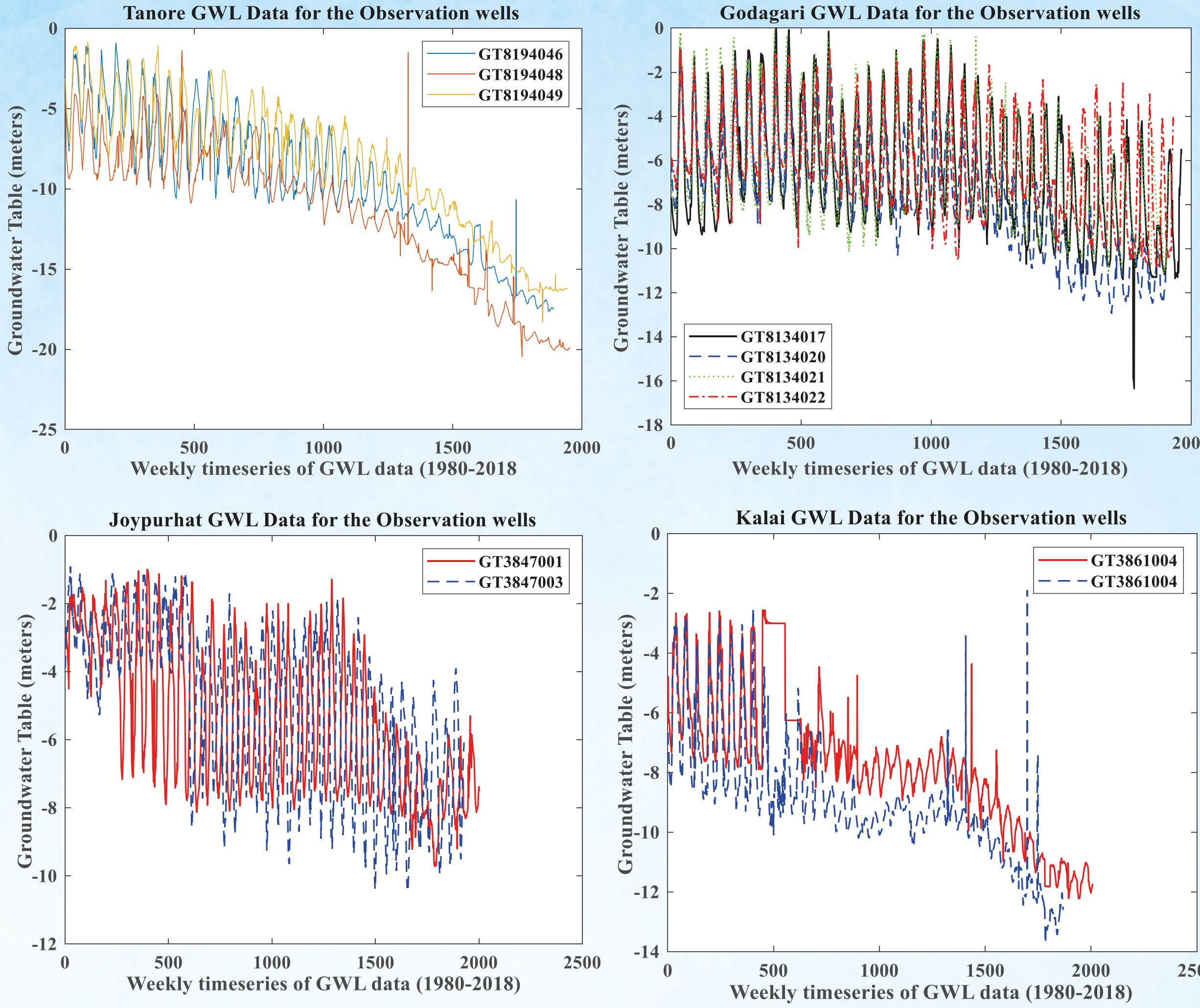


Fig. 10.2. Groundwater level time series data for the selected observation wells of the study areas

a. Groundwater level analyzed by Discrete Space-State model

This study utilized a discrete Space-State model as a prediction tool for future groundwater level forecasting (Ljung L, 1999). The groundwater table can be modeled as a state-space system with noise input and measured water table data as output. The measured water table is proportional to the system state, i.e.

$$x_{n+1} = Ax_n + Ke_n \tag{10.1}$$

$$y_n = Cx_n + e_n \tag{10.2}$$

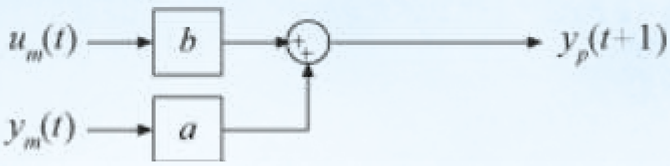
Where, x_n is the state vector, contains the weekly water table values; y_n is the output from the model; e_n is the noise and A, C, K are to be identified.

In Space-State modeling approach, a model is identified to accurately compute a dynamic system with response to an input. Two different approaches exist to generate an identified model response: (a) Simulation that computes model response using input data and initial conditions, and (b) Prediction that computes the model response at some specified amount of time in the future using the current and past values of measured input and output values, as well as initial conditions. The present study utilized the prediction focused approach of the system identification process in which the overall goal is to create a realistic dynamic system model that can be used or handed off for an application goal. During the model identification process, a one-step prediction focus was used as it generally produces the best results. By using both input and output measurements, one-step prediction accounts for the nature of the disturbances. Accounting for disturbances provides the most statistically optimal results.

Prediction refers in projecting the model response k steps ahead into the future using the current and past values of measured input and output values. k is called the prediction horizon, and corresponds to predicting output at time kT_s, where T_s is the sample time. In other words, given measured inputs $u_m(t_1, \ldots, t_{N+K})$ and measured outputs $y_m(t_1, \ldots, t_N)$, the prediction generates the final output $y_p(t_{N+K})$.
For example, if the input and output signals of a physical system are $u_m(t)$ and $y_m(t)$, respectively, then the first order equation of this system can be represented by

$$y_p(t+1) = a y_m(t) + b u_m(t) \tag{10.3}$$

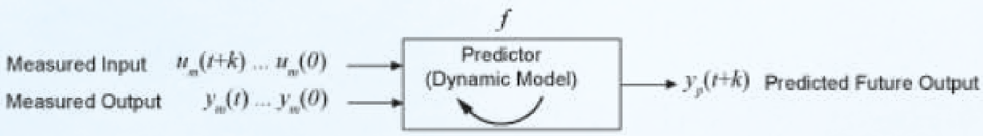
where y is the output and u is the input. The system can be represented by the following block diagram



In general, to predict the model response k steps into the future ($k \geq 1$) from the current time t, one must know the inputs up to time $t+k$ and outputs up to time t such that:

$$y_p(t+k) = f\big(u_m(t+K), u_m(t+k-1), \ldots, u_m(t), u_m(t-1), \ldots, u_m(0), y_m(t), y_m(t-1), y_m(t-2), \ldots, y_m(0)\big) \tag{10.4}$$

Where, $u_m(0)$ and $y_m(0)$ are the initial states. $f()$ represents the predictor, which is a dynamic model whose form depends on the model structure.



A MATLAB command was used to identify a discrete state-space model from the measured data (Mathworks, 2019b).
Historical weekly time series of water table data for 38 years was used for developing the time series model, which was used for future water level predictions for a period of the next 22 years (up to 2040).
The original time series of groundwater table data was divided into identification (training) and validation data. Eighty percent of the entire time series data was used to train the model whereas the rest 20% was used to validate the developed model. After satisfactory training of the models, the trained and validated models were used for future predictions. Fig. 10.3, 10.4, 10.5 and 10.6 present the partitioning of the time series dataset into training and validation dataset for the three selected observation wells in Tanore, Godagari, Joypurhat sadar, and Kalai upazilas, respectively.

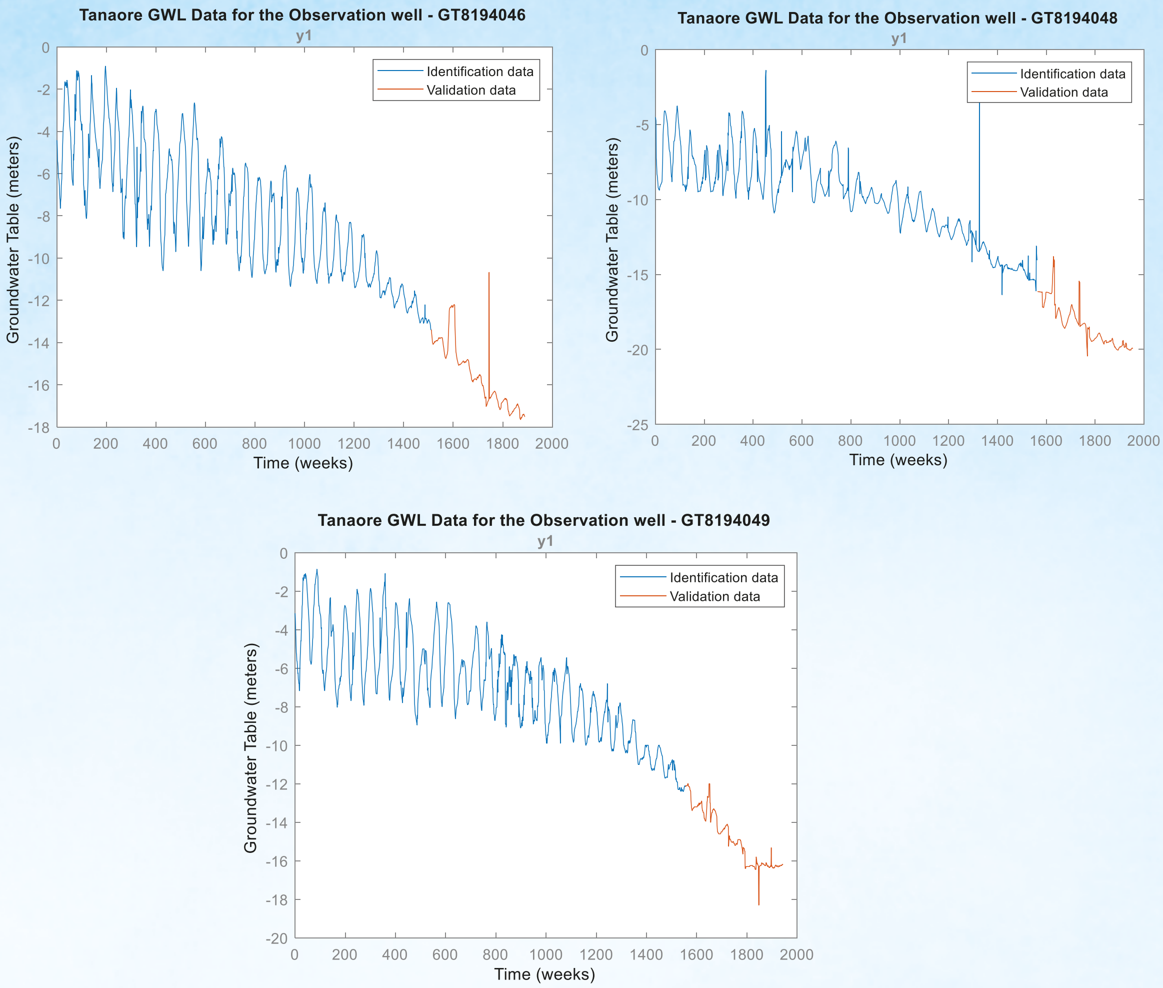


Fig. 10.3. Partitioning of the data into identification and validation data sets at Tanore upazila

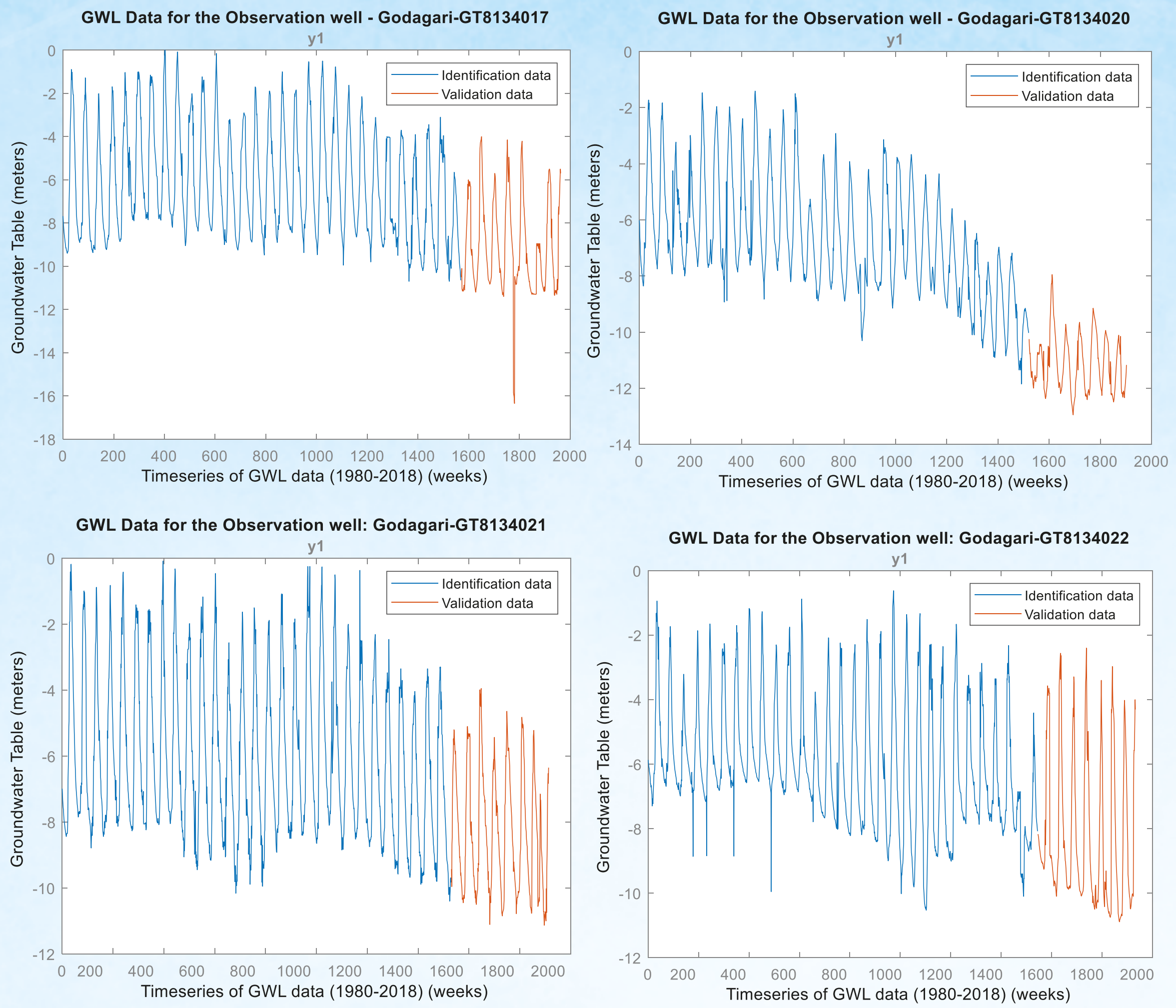


Fig. 10.4. Partitioning of the data into identification and validation datasets at Godagari upazila

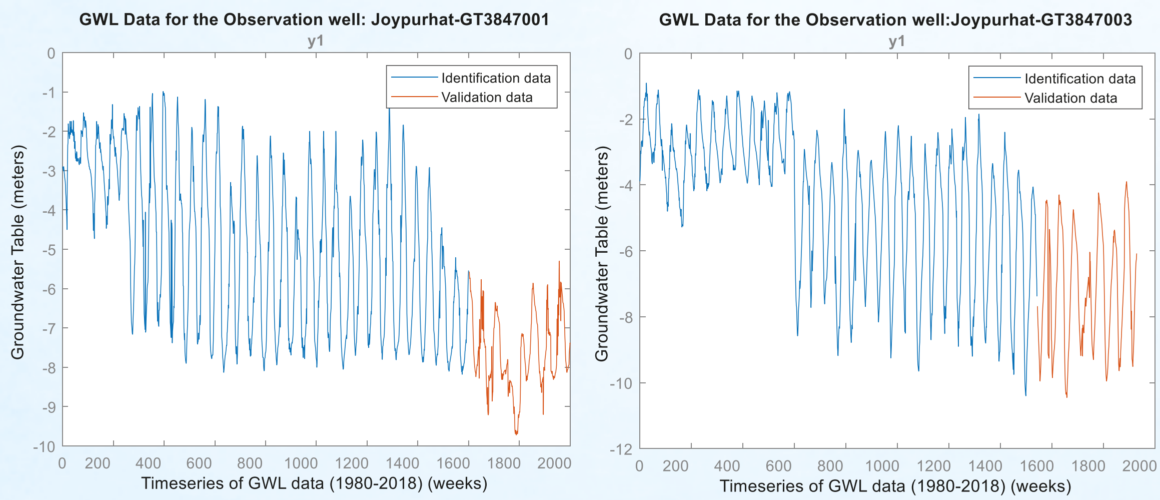


Fig. 10.5. Partitioning of the data into identification and validation datasets at Joypurhat sadar upazila

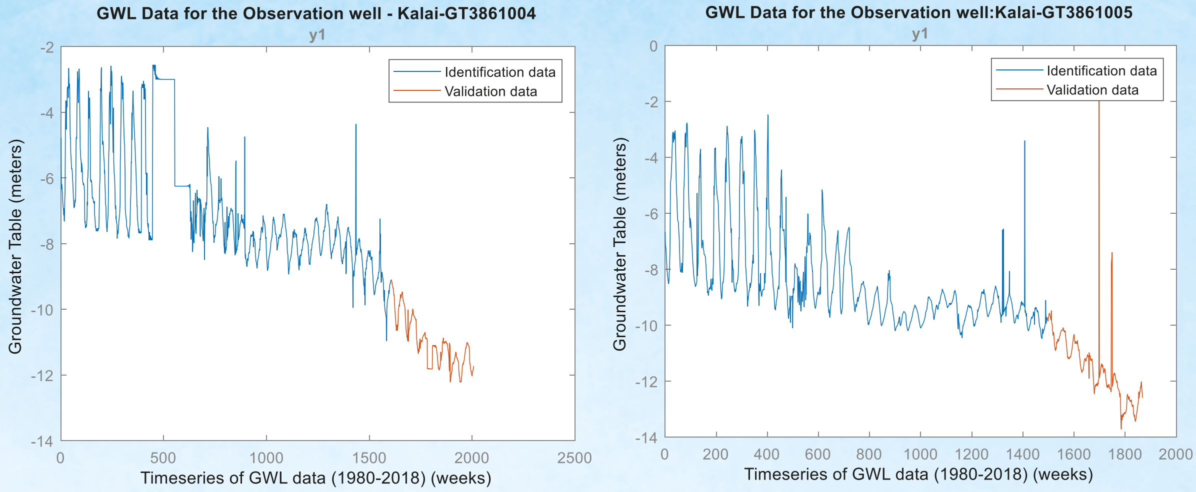


Fig. 10.6. Partitioning of the data into identification and validation datasets at Kalai upazila

Final Prediction Error (FPE) criterion provides a measure of model quality by simulating the situation where the model is tested on a different data set. According to Akaike's theory, the most accurate model has the smallest FPE. Akaike's Final Prediction Error (FPE) is defined by the following equation (Akaike, H., 1969):

$$FPE = \det\left(\frac{1}{N}\sum_{1}^{N} e\left(t,\hat{\theta}_N\right)\left(e\left(t,\hat{\theta}_N\right)\right)^{T}\right)\left(\frac{1+{}^{d}/_{N}}{1-{}^{d}/_{N}}\right) \quad (10.5)$$

Where, N is the number of values in the estimation data set, $e(t)$ is a ny-by-1 vector of prediction errors, θ_N represents the estimated parameters, d is the number of estimated parameters. If number of parameters exceeds the number of samples, FPE is not computed when model estimation is performed.

$$\text{Mean Squared Error (MSE)} = \frac{1}{N}\sum_{i=1}^{N}(Actual_i - Prdicted_i)^2 \quad (10.6)$$

As the first step of the model development, a 1-step ahead prediction was performed for the selected observation well locations at Godagari, Tanore, Joypurhat sadar and Kalai. For instance, in observation well GT8194046 of the Tanore upazila, the system identified 440 numbers of free coefficients to develop a Space-State model for which estimation data fit was found to be 91.35% (prediction focus). The FPE and MSE values of 0.07358 and 0.06796, respectively were found, which indicated a very good prediction model. The corresponding values of free coefficients, FPE and MSE values of observation wells GT8194048 and GT8194049 were presented in Table 10.2. The modelling approaches for the other three upazilas were performed using the similar procedures, and the obtained results indicated the good modelling performance on the basis of prediction focus, FPE, and MSE values.

Table 10.2. Prediction performance of the developed models at observation wells GT8194048 and GT8194049 at Tanore upazila

Observation Well	Free coefficients	Fit to estimation data (prediction focus), %	FPE	MSE
GT8194048	440	81.42	0.292	0.2704
GT8194049	440	89.98	0.07411	0.06861

The identified models minimized the 1-step ahead prediction. Then, the model was validated using a 10-step ahead predictor, i.e., given $y_{0,\ldots,}y_n$, the model was used to predict y_{n+10}. Note that the measured and predicted values, $y_0-\hat{y}_0,\ldots,y_n-\hat{y}_n$, were used to make the y_{n+10} prediction. The 10-step ahead prediction results for the identification and the validation data for observation wells of Tanore, Godagari, Joypurhat sadar, and Kalai upazilas were presented in Fig. 10.7, 10.8, 10.9 and 10.10 respectively.

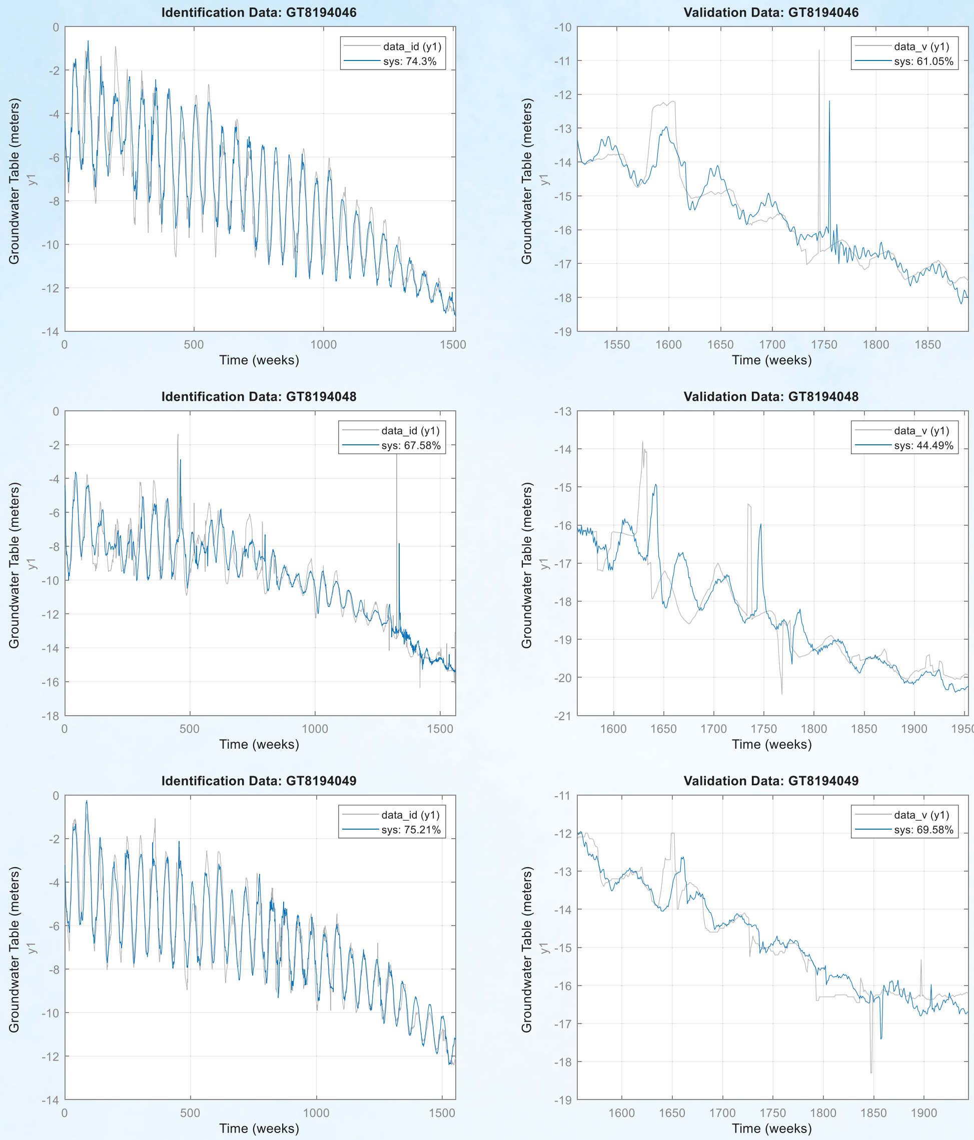


Fig. 10.7. 10-step ahead prediction for the identification and validation data for observation wells GT8194046, GT8194048, and GT8194049 at Tanore upazila

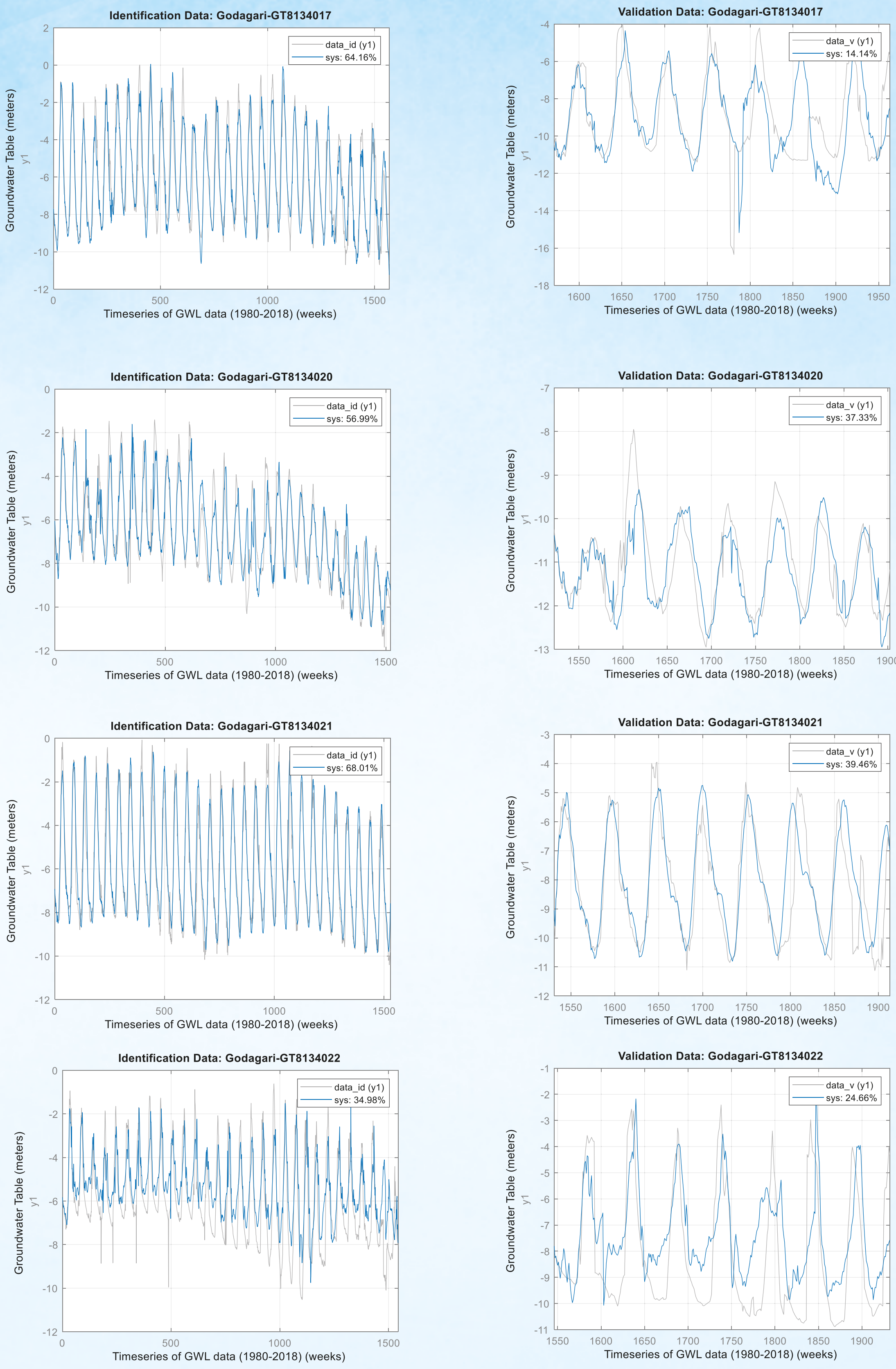
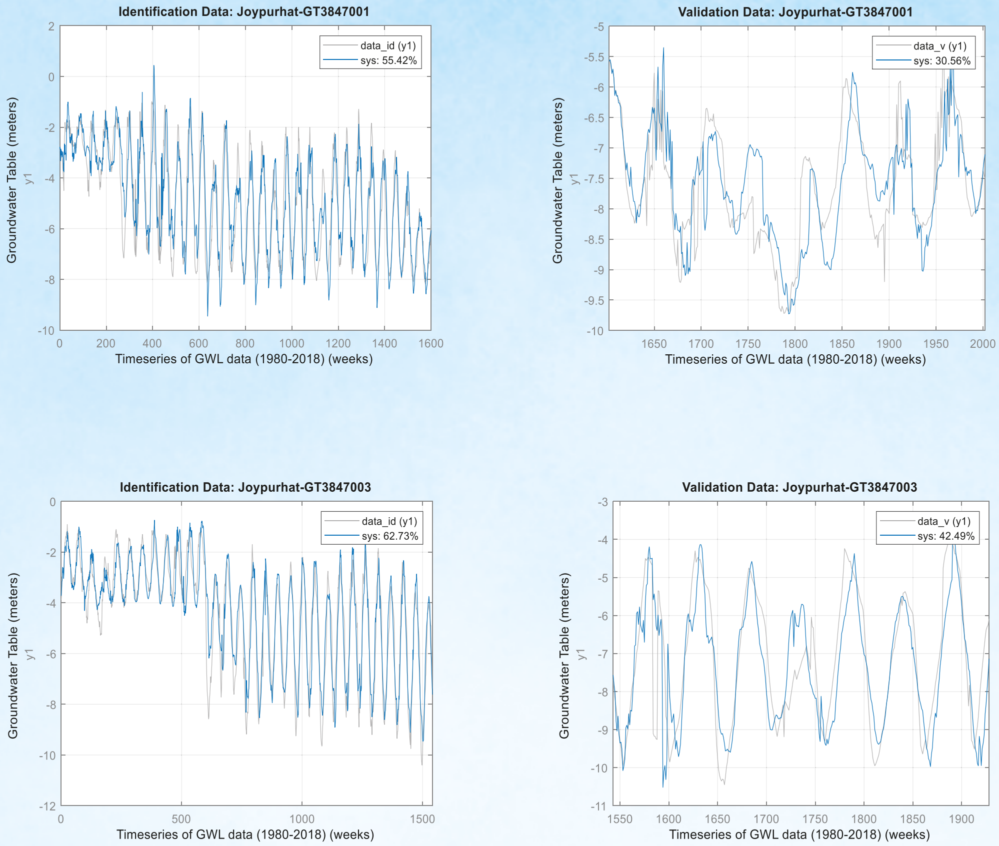


Fig. 10.8. 10-step ahead prediction for the identification and validation data for observation wells GT8134017, GT8134020, GT8134021, GT8134022 at Godagari upazila



10.9. 10-step ahead prediction for the identification and validation data of observation wells GT3847001 and GT3847003 at Joypurhat sadar upazila

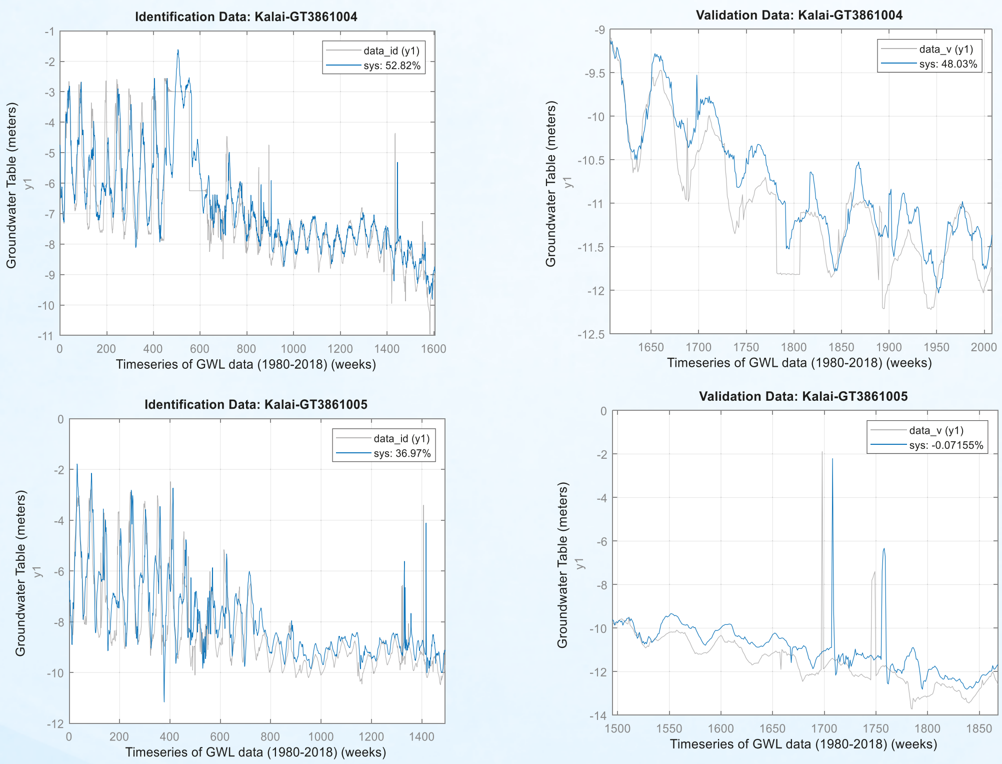


Fig. 10.10. 10-step ahead prediction for the identification and validation data of observation wells GT3861004 and GT3861005 at Kalai upazila

It was observed from Fig. 10.7, 10.8, 10.9 and 10.10 that both identification and validation data sets of the observation wells of the four upazilas showed that the predictor matched well with the measured data. Then to further verify the developed prediction model, forecasting within the range of the validation data was performed. Forecasting used the measured data record $y_0, y_1, \ldots, y_n - \hat{y}_n$ to compute the model state at time step *n*. This value was used as initial condition for forecasting the model response for a future time span. It forecasted the model response over the time span of the validation data and then compared the two.

b. Groundwater level analyzed by MAKESENS model

Historical weekly groundwater level data of thirty five years (1984 - 2018) were collected from three observation wells of Bangladesh Water Development Board (BWDB). The sites differed in hydrologic, climatic and agricultural peculiarities. The collected GWL data were arranged in month wise and then reduced to mean value. The trend of computed monthly GWL was detected and estimated by MAKESENS trend model. It is a computer model, which was developed using Microsoft Excel 97 and the macros were coded with Microsoft Visual Basic (Salmi *et al.*, 2002). MAKESENS implements statically analyses in two ways. Firstly, the presence of a monotonic increasing or decreasing trend was tested with the non-parametric Mann-Kendal test and, secondly, the slope of a linear trend was estimated with the non-parametric Sen's Method (Gilbert, 1987). The model was used to analyse the trend of change of arranged climatic parameters. The testing was done at the significance level of 0.001, 0.01, 0.05 and 0.10. The changes of groundwater levels were computed based on the trend analysis results as:

$$\text{Groundwater level} = B + Q\ (2018-1984). \qquad (10.7)$$

Where

B = the intercept,

Q = the slope of the trend line

10.1.1.2 Groundwater quality assessment

Groundwater samples were collected before starting (November/December, 2018) and at the end (February/March, 2019) of dry season irrigation to examine its suitability for irrigation over the season. The water samples were collected from different sources like STWs and DTWs of the study areas in white plastic bottles filling up to the brim and immediately sealed to avoid exposure to air. Then the samples were labeled and brought to the laboratory for chemical analysis. The samples were analyzed for different water quality parameters such as pH, EC, PO_4^{2-}, NO_3^{2-}, Cl^-, HCO_3^-, Na^+, K^+, Ca^{2+} and Mg^{2+}.The analysis was done in the laboratories of BRAC, Gazipur and Soil Science Division, BARI, Gazipur.

Groundwater suitability for irrigation purpose in this study area was assessed using SAR (Sodium Adsorption Ratio), RSC (Residual Sodium carbonate), SSP (Soluble Sodium percentage) and KR (Kelly's ratio). All determined groundwater concentrations used in assessing these indices were in meq/l.

SAR (Sodium Adsorption Ratio) is a measure of suitability of water for irrigation with respect to the sodium hazard. The SAR values were calculated using the following equation:

$$\text{SAR} = \frac{Na^+}{(\sqrt{Ca^{+2}+Mg^{+2}})/2} \qquad (10.8)$$

The residual sodium carbonate is a measure of the hazard involved in the use of high carbonate waters. RSC is calculated as follows:

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{+2} + Mg^{+2}) \quad (10.9)$$

Kelly (1940) and Paliwal (1967) introduced another factor to assess quality and classification of water for irrigation purposes based on the concentration of Na^{+} against Ca^{2+} and Mg^{2+}. It can be calculated using the following equation:

$$KR = \frac{Na+}{Ca2+ + Mg\,2+} \quad (10.10)$$

KR > 1 indicates an excess level of Na^{+} in waters. Therefore, water with a KI ≤ 1 has been recommended for irrigation, while water with KI ≥ 1 is not recommended for irrigation due to alkali hazards (Ramesh and Elango 2012; Karanth 1987).

To get a comprehensive picture of overall quality of groundwater, the WQI was used. WQI is defined as a rating reflecting the composite influence of different water quality parameters on the overall quality of water. The FAO standard specified for irrigation water was used for the calculation of WQI. The WQI was computed through three steps. First, each of the measured parameters (pH, EC, TDS, Na, Ca, Mg, K, CO_3, HCO_3, Cl, SO_4, NO_3, PO_4, Fe, Zn and B) was assigned a weight (W_i) according to its relative importance in the overall quality of water for irrigation purposes. The maximum weight 5 was assigned to parameters like pH, EC, TDS, Na^{+}, Cl^{-}, and SO_4^{2-} due to their importance in water quality assessments. A minimum weight of 1 was assigned to zinc because of its insignificant role. Other parameters were assigned weights between 1 and 5 based on their relative importance in the evaluation of water quality.

In the second step, the relative weight (W_i) of the chemical parameter was computed using the following equation:

$$W_i = w_i / \sum_{i=1}^{n} w_i \quad (10.11)$$

Where W_i is the relative weight, w_i is the weight of each parameter, and n is the number of parameters.

In the third step, a quality rating scale (q_i) for each parameter is assigned by dividing its concentration in each water sample by its respective standard according to the guidelines (FAO, 1997) and the result is multiplied by 100:

$$q_i = (C_i/S_i) \times 100 \quad (10.12)$$

Where q_i is the quality rating, C_i is the concentration of each chemical parameter in each water sample in mg/L, and S_i is the irrigation water standard for each chemical parameter in mg/L.

For computing WQI, the sub index (SI) is first determined for each chemical parameter, as given below:

$$SI = W_i \times q_i \quad (10.13)$$

$$WQI = \sum SI_{i-n} \quad (10.14)$$

Where SI_i is the sub index of i^{th} parameter; W_i is relative weight of i^{th} parameter; q_i is the rating based on concentration of i^{th} parameter, and n is the number of chemical parameters. The computed WQI values are classified into five categories: excellent water (WQI <50); good water (WQI = 50–100); poor water (WQI = 100–200); very poor water (WQI = 200–300); and water unsuitable for irrigation (WQI >300).

10.1.2 Component-2: BRRI

10.1.2.1 Trend of groundwater level fluctuation

Historical data of groundwater table of about 30 years (1987 to 2017) of Mithapukur, Pirganj, Ishwardi and santhia were collected from BWDB and analyzed of those data using analytical excel model method for groundwater availability assessment.

10.1.2.2 Recharge assessment

A suitable method was developed for ensuring safe water recharge into aquifer. In this method a prototype recharge well with different filter for purring surface turbidity runoff water was constructed. Raw and filtrated water were analyzed in the laboratory to determine the quality of water. Since the water quality test needs laboratory so this experiment was carried out at BRRI farm, Gazipur. The filter that gave the best quality water was selected for recharging. Based on the results of quality test, this method can be recommended for implementing in the project sites or elsewhere of the country also. A prototype of 1 m × 1 m ×1 m (original size 3 m × 3 m ×3 m) recharge tank was constructed with mild steel sheet. A 4 cm diameter (original 10 mm) strainer of 33 cm long (original 1 m) was placed at the bottom of the tank. Different filter materials were placed according to order into the tank. The experiment involved three different filter media as follows;

FM1= Fine sand+ medium sand+ coarse sand
FM2= Fine sand+ medium sand+ Gravel+ Khoa
FM3= Soil+ fine sand+ Coarse sand+ Charcoal+ stone+ Khoa

Locally available filter materials were collected and placed them in the recharge tank according to order. Coarser materials were placed at the bottom of the tank and finer materials at the top. Runoff water from rainfall was collected from a canal network. Water was lifted in to the tank using a plastic beaker. The time of filling the tank was recorded. Initial water sample was collected for analysis its quality. Three tanks were filled with same water. The times of starting water fall through the outlet of the tanks were recorded. Discharge of the tanks at regular interval was monitored. Water samples after filtration from each method were collected to identify the final quality of recharged water. Different quality parameters like turbidity, pH, free chlorine, hydraulic conductivity, Magnesium, Calcium, color, iron, sodium, potassium etc. were analyzed both in source water and recharged water using spectrophotometer in laboratory. Microbial activities in the filtrated water were also observed.

10.1.2.3 Groundwater quality assessment

For groundwater quality assessment twenty four water samples taking six STWs from each site were collected during the peak irrigation period (March to April during 2018-2020). The quality of water for irrigation was analyzed in laboratory. The data of recharge rate, chemical properties of water like sodium, calcium, magnesium, alkalinity, pH, free chlorine, iodine, carbonate, nitrate, total hardness etc. were determined. The irrigation water quality index including SAR, MAR, KR, SSP were calculated using the following specific equations.

Sodium Adsorption Ratio: SAR was calculated by the equation of Richards (1954) as given by

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+}+Mg^{2+})/2}} \tag{10.15}$$

Where, SAR = Sodium Adsorption Ratio, Na^{+} = sodium ion concentration, meqL^{-1}, Ca^{++} = calcium ion concentration, meqL^{-1}, Mg^{++}= magnesium ion concentration, meq L^{-1}

Soluble Sodium Percentage: Soluble sodium percentage was calculated by the following equation (Todd, 1980):

$$SSP = \frac{(Na^{+}+K^{+})}{(Ca^{2+}+Mg^{2+}+Na+K^{+})} \times 100 \tag{10.16}$$

Where, SSP = Soluble Sodium Percentage, Na^{+} = sodium ion concentration, $meqL^{-1}$, K^{+} = potassium ion concentration, $meqL^{-1}$, Ca^{++} = calcium ion concentration, $meqL^{-1}$, Mg^{++}= magnesium ion concentration, meq L^{-1}

Total Hardness: Total Hardness was calculated by the following equation (Raghunath, 1987)

$$TH = (Ca^{++} + Mg^{++}) \times 50 \tag{10.17}$$

Where, TH = Total Hardness, Ca^{++} = calcium ion concentration, $meqL^{-1}$, Mg^{++} = magnesium ion concentration, $meqL^{-1}$

Magnesium Adsorption Ratio: MAR was calculated by (Szobocles and Darab, 1968)

$$MAR = \frac{Mg^{++}}{Ca^{++}+Mg^{++}} \times 100 \tag{10.18}$$

Where, MAR = Magnesium Adsorption Ratio, Ca^{++} = calcium ion concentration, $meqL^{-1}$
Mg^{++} = magnesium ion concentration, $meqL^{-1}$

Kelly's Ratio: The Kelly's ratio was calculated by the equation (Kelly, 1963) expressed as,

$$KR = \frac{Na^{+}}{Ca^{2+}+Mg^{2+}} \tag{10.19}$$

Where, KR = Kelly's Ratio, Na^{+} = sodium ion concentration, $meqL^{-1}$
Ca^{++} = calcium ion concentration, $meqL^{-1}$, Mg^{++} = magnesium ion concentration, $meqL^{-1}$

10.1.3 Component-3: BINA

10.1.3.1 Determination of aquifer hydraulic properties by pumping test

The north-western region of Bangladesh is mainly occupied by Pleistocene deposits (Morgan and McIntire, 1959). It covers the district of Rajshahi, Natore and Bogura and situated between 24°22´ to 24°51´ North Latitude and 89°18´ to 89°22´ East Longitude. According to the topography, this area can be divided into two parts, such as (i) Barind region and (ii) Diar region. Barind region is the main part of east of the river Mahananda, is known as Barind region. The area is located on the banks of the river Mahananda and the climate of this region is rough and extreme. The lithology types include alluvial sand, alluvial silt, Barind clay residuum, and Marsh clay and peat (Alam *et al.*, 1990). Hydrogeologically, the area covered by semi-impervious clay-silt aquitard of Recent-Pleistocene period (thickness 3.0 – 47.5 m) is characterized by single to multiple layered (2 – 4) aquifer system of Plio-Pleistocene age (thickness 5.0 – 42.5 m) (Jahan *et al.*, 2010). The maximum and minimum average temperatures are 44° C and 4°C, respectively and annual average rainfall is 186 cm. The present study was, however, based on part of a configuration of two upazila (Nachole and Niamatpur). Two observation wells were installed in line at about 91.44m and 143.26m at Nachole and 45.72m and 91.44m at Niamatpur from the test (production) well (hereafter called 1st and 2nd observation well), at the same depth of the test well (Fig. 10.11). The lithologic study was conducted by collecting depth-wise (3.04m interval) sample during installation of two observation wells. Depth-wise sample collection and mechanical sieve analyses of aquifer materials were performed to know about the nature of the aquifer and other hydraulic parameters of the study area.

For determining hydraulic properties of the aquifer, pumping test was conducted at Nijampur union of Nachole, and Rasulpur union of Niamatpur upazila following standard procedure (e.g. time-drawdown, distance- drawdown, and recovery data). Before starting the pump, the water level in the pumping well and observation wells were checked and recorded, and it was static water level. The well was then pumped at a constant rate until steady state condition reached (~38 hours for Nachole and 29 hours for Niamatpur). The water levels in the wells (pumping and observation wells) were checked and recorded at specific time interval.

The discharge rate of the pump was measured (60 minute interval) with water flow meter attached near the outlet of delivery pipe (Fig. 10.12) and it was observed for Nachole and Niamatpur respectively, 24.50 litter/sec and 19 litter/sec. The horizontal distance between each observation well and the pumping well was measured. The vertical elevation of a fixed reference point on each observation well and on the pumping well (e.g., "top of casing") was established. To examine the expected influence of the pumping well, one well (submersible drinking well of the villager) at about 152.4m apart, and 243.84m apart from the test well were monitored. Once the pumping stopped after steady-state condition had reached, the recovery of the water level (i.e. rising water level) was monitored at specific time intervals (2 min. interval for the first 10 minutes, 5 minutes interval for the next 30 min., etc.) until the water level returns to about 80 percent of its original level.

Fig. 10.11. Pictorial view of installing observation well

Fig. 10.12. Pictorial view of setting water flow meter for discharge measurement

The aquifer of the studied sites (both Nachole and Niamatpur) was unconfined or water-table aquifer. The pumping test data were analyzed using Jacob's time-drawdown, distance-drawdown and time recovery method as well as Dupit Steady State Radial Flow (Dupit 1863, later modified by Thiem, 1906) Method. Besides, Laboratory Method was used to determine specific yield (Sy) of the aquifer materials.

In the Cooper-Jacob distance –drawdown method, drawdown data were plotted along the vertical axis (arithmetic scale) and distance data along the horizontal axis (logarithmic scale). If the aquifer and test conditions satisfied the Theis assumptions and the limitations of the Jacob's method, drawdown measured at the same time in different wells should plot in a straight line. The slope of the straight line would be proportional to the pumping rate and to the transmissivity. Jacob (1947) derived the following equations for determination of the transmissivity (T, which measures the water transmitting capacity of the aquifer) and storage coefficient (S, which measures the water storage capacity of the aquifer) from distance-drawdown graphs:

$$T = \frac{2.3\,Q}{2\pi\Delta s} \tag{10.20}$$

$$S = \frac{2.25\,Tt}{r_0^2} \tag{10.21}$$

Where, T = Transmissivity, m^3/day/m
Q = Pumping rate, m^3/day

Δs = Drawdown across one log cycle, m
t = Time, at which the drawdowns were measured, hour, and
r_0 = distance from the pumping well to the point where the straight line intersects the zero drawdown line, m

Jacob's Time-drawdown method is applicable only to the zone in which steady state conditions prevail or to the entire cone only after steady state conditions have been developed. A time-drawdown graph was prepared on a semi-log paper with drawdown on the vertical axis (arithmetic scale) and time on the horizontal axis (logarithmic scale). The slope of the straight line would be proportional to the pumping rate and to the transmissivity. Jacob (1947) derived the following equations for determination of the transmissivity and storage coefficient from time-drawdown graphs:

$$T = \frac{2.3\,Q}{4\pi\Delta s} \tag{10.22}$$

$$S = \frac{2.25\,Tto}{r^2} \tag{10.23}$$

Where, T = Transmissivity, m^3/day/m
Q = Pumping rate, m^3/day

Δs = Drawdown across one log cycle, m
t_o = Time, at which the straight line intersects the zero drawdown, hour, and
r = distance of the observation well from the pumping well, m

Time-recovery data was used in determining the formation constant is more accurate than that of time-drawdown or distance-drawdown data, because of the fact that residual drawdown measurements could be more accurate than the drawdown measurement. Because, the pumping rate may often vary and become difficult to control accurately in the field (Todd, 1980). The time-recovery method is based on residual drawdown data to give estimate of the transmissivity value. The equations for residual drawdown and transmissivity are given below:

$$s' = \frac{2.30\, Q \log\left(\frac{t}{t'}\right)}{4\pi T} \quad (10.24)$$

Thus, a plot of residual drawdown *s′* versus the logarithm of *t/t′* forms a straight line. The slop of the line equals *2.30 Q/4πT* so that for *Δs′*, the residual drawdown per log cycle of *t/t′*, the transmissivity becomes,

$$T = \frac{2.3\, Q}{4\pi \Delta s'} \quad (10.25)$$

Where, T = Transmissivity, m^3/day/m
Q = Pumping rate, m^3/day

Δs′ = Residual drawdown across one log cycle, m
s′ = Residual drawdown, m
t = Time since pumping started, hr.
t′ = Recovery period, hr.

No comparable value of Storage co-efficient could be determined directly using the recovery method (Todd, 1980).

After prolonged pumping from the well at steady state condition, Dupit (Dupit 1863, later modified by Thiem, 1906) derived the following equation to determine the transmissivity (T) of unconfined aquifer:

$$T = \frac{QH \ln(r2 - r1)}{\pi (h2^2 - h1^2)} \quad (10.26)$$

Where, T = Transmissivity of water table aquifer (=KH), m^3/day/m
Q = pumping rate, m^3/day
H = saturated thickness of the aquifer before pumping start, m
r_1 = distance of 1st observation well from the pumping well, m
r_2 = distance of 2nd observation well from the pumping well, m
h_1 = saturated thickness of 1st observation well, m
h_2 = saturated thickness of 2nd observation well, m

10.1.3.2 Trend of groundwater level fluctuation

The water-table (WT) data of 30 years (from 1989 to 2018) for Nachole and Niamatpur were collected from Bangladesh Water Development Board (BWDB) and also from Barind Multipurpose Development Authority (BMDA). The 30 years (from 1989 to 2018) rainfall data of Nachole and Niamatpur were collected from BWDB. The patterns and trends of water-table data were examined by graphical method (Microsoft Excel) and MAKSENSE model (Salmi *et al*, 2002).

10.1.3.3 Analysis of Climatic Parameters

a. Significant test of trend of Rainfall by non-parametric method

Trends were examined by 'Spearman's Rho' test (Conover, 1980). The advantage of the non-parametric test is that it does not depend on absolute values of data and is equally applicable for linear and non-linear trends. These tests are distribution free, i.e. they do not require any assumption to be made about population following normal or any other distribution. As the test uses relative values, missing data is not a problem.

The test statistic T of 'Spearman's Rho' test is given by:

$$T = \sum_{i=1}^{n}[R(X_i) - R(Y_i)]^2 \quad (10.27)$$

where X_i is the value of rainfall (or temperature) corresponding to the year Y_i, $R(X_i)$ is the rank of rainfall (or temperature) X_i, and $R(Y_i)$ is the rank of the year Y_i. For n greater than 30, the quantiles of T is approximated by (Conover, 1980):

$$w_p \cong \frac{1}{6}n(n^2-1) + x_p \frac{1}{6}\frac{n(n^2-1)}{\sqrt{n-1}} \quad (10.28)$$

where x_p is the p^{th} quantile of a standard normal random variable. Upper quantile was estimated from the equation:

$$w_{1-p} = \frac{1}{3}n(n^2-1) - w_p \quad (10.29)$$

In all cases, the two tailed test was done at level $\alpha = 0.05$.

b. Significant test of trend of Rainfall by slope test

Trend was also examined by testing the significance of slope of the linear regression line. For this purpose, climatic variables were plotted (Y-axis) against the relative year values (year rank, e.g. for 1975 to 2019, relative year values are 1 to 45). The slope of the plot represents the trend. The slope was then subjected to *t*-test for significance at 5 % level.

10.1.3.4 Study on groundwater availability assessment and its utilization

Safe yield estimation has been made to estimate groundwater availability for pumping in terms of potential groundwater recharge using a simplified hydrological balance method. In hydrological balance, total precipitation can be divided into evapotranspiration, runoff and recharge (Fig.10.13). But in the analysis, this has been neglected as because seepage water from irrigated fields and early monsoon rainfall usually fulfill this deficiency. The simplified hydrological balance equation for safe yield of groundwater was as follows (Rashid *et al*., 1990; Rashid and Mojid, 1990):

$$Ys = P(1-r) - E - SyH + c\alpha I + aD + (S_i - S_o) + R + F \quad (10.30)$$

Where,

Y_s = Annual safe-yield of the groundwater basin, mm

P = Total rainfall during monsoon while rainfall exceeds evaporation, mm

r = Ratio of runoff to total rainfall during monsoon

E = evaporation from free water surface during monsoon, mm

H = Fluctuation of static groundwater level from full recharged condition of the aquifer up to the start of irrigation season, mm

S_y = Specific yield of the upper saturated formation of the aquifer subjected to water level fluctuation

c = Percent of irrigation water applied in the field that reached the groundwater reservoir

α = Ratio of irrigated area to the total basin area

I = Total depth of irrigation water applied in the field during the irrigation season, mm

a = Ratio of total surface water body to the total basin area

D = Depth of water that reached the groundwater reservoir from surface water bodies, mm

S_i = Groundwater inflow to the basin from adjacent aquifer (s), mm

S_o = Groundwater outflow from the basin to the adjacent aquifer (s), mm

R = Contribution from river to groundwater reservoir or to river from groundwater storage, mm and

F = Contribution to groundwater storage from flood water, mm

The hydraulic gradients of groundwater system in Bangladesh is very low (1:10000 to 1: 25000) and hence the rates of movement of groundwater from basin to basin are usually very slow and the quantity of water thus moved is extremely low (UNDP, 1982). Therefore, the inflow and outflow terms (Si and So) might be ignored.

The available literature (UNDP, 1982; Rashid *et al*., 1990; Rashid and Mojid, 1990 and Khan *et al.*, 2001) revealed that water stored as bank storage during flood period is discharged to the river streams after the flood period without playing any significant role on the adjacent groundwater reservoirs. Based on these, the last two parameters (R and F) in Eq. 10.40 have also been dropped.
Thus, the simplified equation reduces to:

$$Ys = P(1-r) - E - SyH + c\alpha I + aD \qquad (10.31)$$

The parameters and coefficients of the hydrological balance have been calculated based on available information for the study area and long-term aquifer yield can be assessed based on the average annual values.

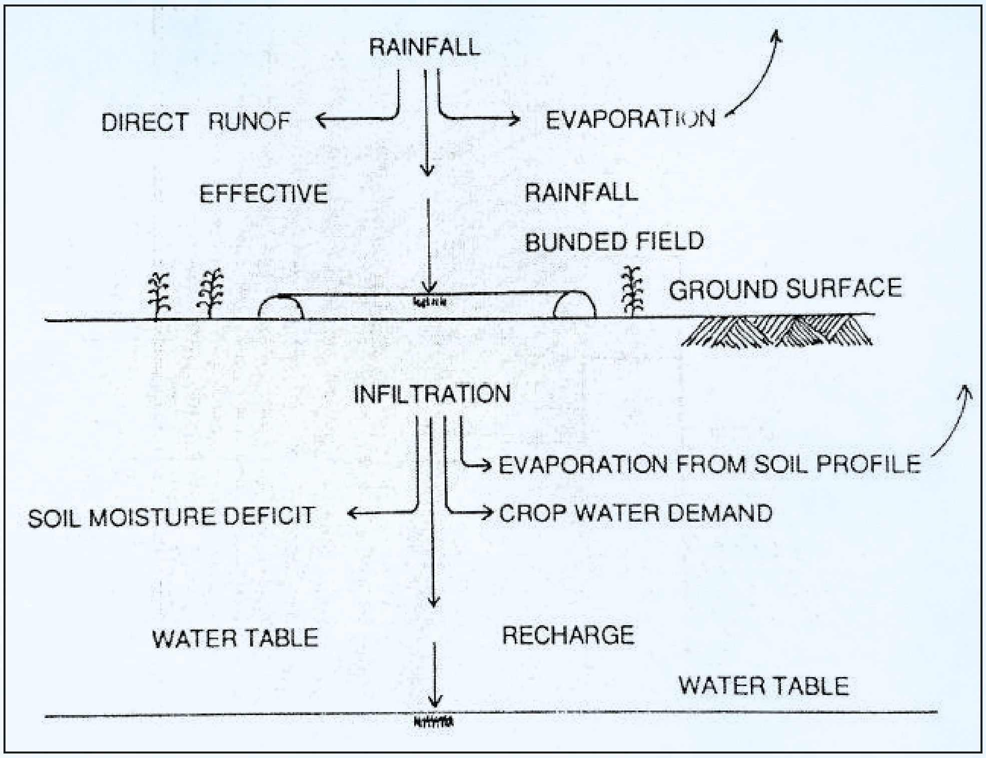


Fig. 10.13. Schematic Rainfall-Recharge Diagram

10.1.3.5 Groundwater recharges assessment

a. Tracer technique method

Before the beginning of rainy season, a rice field of Nachole and Niamatpur (medium land) was selected for tracer application. To prepare the 'Test tracer plot', a square of 1.5 m × 1.5 m was first selected and marked. At the outer edge, a 0.6 m deep small hole (15cm wide) was dug. A continuous polythene sheet was placed in the hole, and then the soil was covered. This was done to eliminate the lateral flow of water and chloride from the 'Test' unit. Within the test plot, chloride ion solution [prepared by dissolving analytical grade KCL in distilled water, with sufficient concentration, about 250 ppm, so that it can be traced easily] was applied/pushed at 20 cm soil depth by 'siring/hand-pump', at the centre and four mid-corners (Fig.10.14). At each point, the amount was about 25 ml.

The tracer was applied at 20 cm soil depth to avoid surface runoff of the applied tracer.

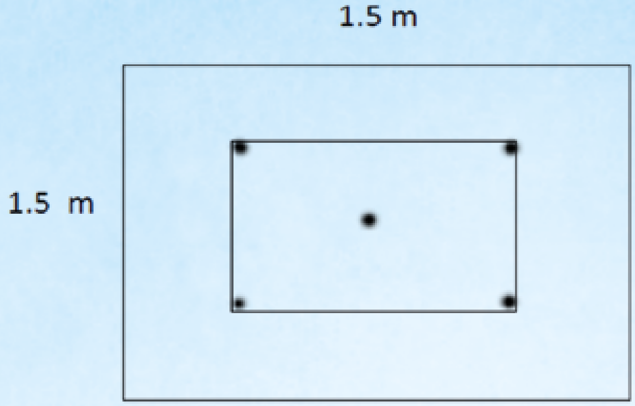


Fig. 10.14. Schematic of tracer test unit (indicating tracer application point)

Infiltration of precipitation/rainfall transports the tracer downward. At the end of rainy season (in October), a trench was dug at the centre of the 'test plot' and samples were collected up to 200 cm, at 10 cm interval. The chloride concentration of the collected samples was determined by Mohr method (Doughty, 1929; Harris, 2007), using micro-burette having 0.01 mm readable facility. The subsurface distribution of applied tracer was determined from the concentration graph of chloride.

The vertical distribution of the tracer was used to estimate the velocity (v), and the recharge rate (R) was calculated as (Chand *et al.* 2005; Scanlon *et al.*, 2002; Ali, 2017):

$$R = v\theta = \frac{\Delta z}{\Delta t}\theta \quad (10.32)$$

Where, Δz is the depth of the tracer peak, Δt is the time between tracer application and sampling, and θ is the average volumetric water content.

b. Water Balance Method

A simplified form of water balance equation (Yin *et al*., 2011) was used to estimate recharge as follows:

$$P = R_0 + R + ET_a + \Delta SM \quad (10.33)$$

where: P = rainfall (mm), R_0= surface runoff (mm), R = recharge, ET_a = actual evapo-transpiration (mm), and ΔSM= change in soil moisture (mm) for the specified time interval. Neglecting the change in soil moisture, and re-arranging, the recharge (R) can be expressed as:

$$R = P - R_0 - ET_a \quad (10.34)$$

The USDA-SCS runoff equation is (USDA-SCS, 1985) used for runoff estimation:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad (10.35)$$

Where: Q= runoff (mm), P = rainfall (mm), S= potential maximum retention after runoff begins (mm). The potential retention (*S*) can range from zero on smooth, impervious surface to infinity in deep gravel.

The conceptual basis of the curve number method for runoff estimation has been the object of both support and criticism (Rallison, 1980; Boughton, 1989; Bales and Betson, 1981). Various investigators (Ponce and Hawkes, 1996; Boughton, 1989; Woodward *et al.*, 2019; Patel, 2019; Lim *et al.*, 2006; Tandon and Nimbalkar, 2014; Price, 1998; Chen, 1981; Willeke, 1997; Smith, 1997; Yu, 1998; Mani *et al.*, 2002; Hawkins, 1975; Hawkins, 1978a; Hawkins, 1981; Hawkins and Cate, 1998; Hawkins *et al.*, 2002) have expressed concern that the CN procedure does not reproduce measured runoff from specific events. The SCS runoff estimation equation is an empirical method, and originally developed for runoff estimation from single storms (Mockus, 1949; Mockus, 1964, cited by Woodward *et al.*, 2019). But it is commonly used for higher time intervals (daily or monthly). For longer time interval, water loss by ET plays a significant role. The major disadvantages of the method include sensitivity of the method to curve number (CN) values, fixing the initial abstraction ratio (Patel, 2019), In many climates, a more important source of variability is the rainfall intensity and its pattern within the storm, and this can't be accounted for by the CN methodology (Willeke, 1997; Smith, 1997; Mani *et al.*, 2002). The *CN* also exhibits an inherent seasonality beyond its spatial variability (Gundalia and Dholakia, 2014).

The initial abstraction, I_a (which was equated to 0.2S by SCS) consists of interception, initial infiltration, surface storage and other factors. For higher time interval, ET plays an important loss-factor (Patel, 2019). Lim *et al.* (2006) investigated the effect of 5% rate of initial abstraction (I_a) to storage (S) to estimate daily direct runoff with modified CN values for a 5% I_a/S values with L-THIA model along with GIS. They found improved long-term direct runoff prediction. Woodward *et al.* (2019) cautioned that the CN procedure was developed as a design methodology (for engineering structure) or a method to evaluate the downstream impacts of various management alternatives. Discussing the limits of application of the SCS runoff procedures, Kent (1966) indicated: "The procedures are primarily for establishing safe limits in design, and for comparing the effectiveness of alternative systems of measures within a watershed project. They are not used to recreate specific features of an actual storm."

In this research, a modified form of SCS equation (Ali, 2017; Ali *et al.*, 2019) was used:

$$Q = \frac{[(P - ETa) - 0.2S]^2}{(P - ETa) + 0.8S} \tag{10.36}$$

Based on the field condition during the monsoon rainfall (i.e. grassy/cropped), the 'S' value is considered as 3.0 cm; and monthly values of runoff (and hence monthly recharge) was calculated. Daily reference crop evapotranspiration (ET_0) was calculated using 'ET_0 Calculator' software of FAO (FAO, 2012). Traditionally, actual crop evapotranspiration (ET_a) is calculated as:

$$ET_a = ET_0 \times K_c \times K_s = (ET_0 \times K_c) \times K_s = ET_p \times K_s \tag{10.37}$$

where: ET_0 is the reference crop evapotranspiration (mm), K_c is the crop coefficient, K_s is the soil moisture stress factor (or dryness factor), ET_p is the potential crop evapotranspiration.

From daily values, monthly values of ET_a were calculated. Based on the 'dryness (or water deficit)' and 'wetness (or water surplus)' condition (i.e. P - ET_p, P is the rainfal), the monthly actual crop evapotranspiration (ET_{am}) was calculated as (Ali, 2017):

$$ET_{am} = \begin{cases} ET_{mp}, & \text{If } P_m > ET_{mp} \quad (\text{i.e. } K_s = 1) \\ P_m, & \text{If } P_m < ET_{mp} \end{cases} \tag{10.38}$$

where: P_m is the monthly rainfall, ET_{mp} is the monthly potential evapotranspiration.
Thus, the equation (10.38) deduced as:

$$R = P - R_0 - ET_{am} \quad (10.39)$$

Where, all the values are in monthly time scale.

c. Water-table fluctuation method

Using water-table fluctuation method (WTF), the recharge can be estimated as (for unconfined aquifer):

$$R = \Delta h \times S_y \quad (10.40)$$

where,

R = recharge occurring between times t_0 and t_j
Δh = difference in water-table position during the given time period
S_y= specific yield (dimensionless, or in percent).

In the study site, drilling was done for bore-log and installation of observation wells. The water-table data were taken from our installed observation well as well as from available nearby observation well (300 m apart from the test well).

Specific yield of each study site was determined from the following methods:

a) From pumping test data
   - From distance drawdown data

b) From aquifer materials
   In this approach, specific yield was determined by saturating the material and then facilitating for gravity drainage. The drainage volume (expressed as percentage of material volume) represents the specific yield (Raghunath, 1987; Ali, 2017). This was done for each sampling depth (10 ft). Then the weighted average of all depths was determined.

Thereafter, the arithmetic mean of S_y for the two methods was determined, which was used in equation (10.40) to determine the recharge amount.

Consideration/correction for withdrawal of drinking and irrigation

From the test well of Nachol, pumping for irrigation during Aman rice season (recharge period) is practiced. In Niamatpur location, in addition to pumping for irrigation, drinking water is supplied throughout the year from the well. Considering both these items, the recharge equation can be written as:

$$R_T = (S_y \times \Delta h) + (Q_{ir} + Q_{dr}) \quad (10.41)$$

Where, Q_{ir} and Q_{dr} are the volume for irrigation and drinking, respectively.
Then, recharge rate (R_r) is:

$$R_r = \frac{S_y[\Delta h + h_{ir} + h_{dr}]}{\Delta t} \quad (10.42)$$

Where, $h_{ir} = Q_{ir}/A$, ratio of the pumped volume (Q) during the recording interval to the areal extent of the aquifer (A) (or influenced area); $h_{dr} = Q_{dr}/A$.

10.1.3.6 Groundwater quality assessment

For groundwater quality assessment water samples from STWs of Nachole and Niamatpur area were collected during the peak irrigation period (March to April during 2018 to 2020). The quality of water for irrigation was analyzed in laboratory. Different water quality parameters like zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), potassium (K), total hardness (TH), alkalinity, sulphate (SO_4), nitrate (NO_3), phosphate (PO_4), chloride (Cl) and dissolved oxygen (DO) were determined by COD Multi-parameter Photometer. The EC, pH, total dissolved solids (TDS) were determined by water testing Kit (Lovibond Tintometer). Calcium (Ca), sodium (Na), magnesium (Mg) were determined by standard lab method.

Water Quality Index, a technique of rating water quality, is an effective tool to assess quality and ensure sustainable safe use of water for drinking (Yisa and Jimoh, 2010). In computing WQI two steps have been followed. In the first step, Quality rating (qn) for the water quality parameters is calculated followed by the equation of Brown et al., 1972. In the Second step, Unit weight (Wn) for various water quality parameters is calculated which is inversely proportional to the recommended standards value Sn of the corresponding parameters. The computation of the WQI was done for observed data by the weighted arithmetic index method for different parameters. This method has been implemented by many researchers (Ahmad, 2014; Brown *et al.*, 1972; Bhutiani *et al.*, 2014; Randey *et al.*, 2016).

Sub Index of Quality Rating (q_n) is calculated using the following expression:

$$q_n = 100\,[V_n - V_{io}]/[S_n - V_{io}] \qquad (10.43)$$

Where,
q_n = Quality rating for the nth water quality parameters
V_n = Estimated value of the nth parameter at a given sampling station.
S_n = Standard permissible value of the nth parameters
V_{io} = Ideal value of nth parameter in pure water. (i.e., 0 for all other parameters except the parameter pH and dissolved oxygen (7.0 and 14.6 mgL^{-1} respectively) (Tripaty and Sahu, 2005).

Quality rating for pH is calculated from the following relation:

$$qpH = 100\,[(VpH - 7.0)/(8.5 - 7.0)] \qquad (10.44)$$

Where, VpH= observed value of pH during the study period.
If quality rating qn= 0 means complete absence of pollutants,
While $0 < qn < 100$ implies that, the pollutants are within the prescribed standard.
When $qn > 100$ implies that, the pollutants are above the standards.

Calculation of unit weight (W_n) for various water quality parameters are inversely proportional to the recommended standards value Sn of the corresponding parameters.

$$W_n = K/S_n \qquad (10.45)$$

Where, Wn= Unit weight for the nth parameters.
Sn= Standard value for nth parameters.
K = Proportional constant, this value considered (1) here, also can be calculated using the following equation:

$$K = 1/\Sigma\,(1/S_n) \qquad (10.46)$$

The overall Water Quality Index was calculated by aggregating the quality rating with the unit weight linearly.

$$WQI = \Sigma\ qnWn / \Sigma\ W_n \qquad (10.47)$$

Water quality parameters were calculated following the equations that are given in section 10.1.2.3.

10.1.4 Coordination Component: BARC

Analysis of water table fluctuation data of BARI component was done by using improved version of discrete space state model. Coordination component: BARC had taken steps to analyze the BRRI and BINA water table fluctuation data with the help of discrete space state model to ensure the result output using same method. For this, BARC personnel collected 30 years water table data from BRRI and BINA and analyzed those data with the updated model. Then the output results were incorporated in PCR.

10.2 Groundwater abstraction pattern

10.2.1 Componenet-1: BARI

10.2.1.1 Irrigation water requirement

The people of the study area are dependent on groundwater for irrigation and domestic uses. Thus, a large portion of groundwater is abstracted to meet up irrigation water requirement while a small portion is abstracted for domestic and municipal water requirements. Irrigation in the study area is provided either by DTWs or STWs or LLPs. Under the present situation, DTWs are of different capacities while STWs are mainly of same capacity. Most of the DTWs (80%) are of 56 l/s cusec and some are of 28 l/s cusec (about 20%), STWs and LLPs are of 14 l/s capacity (BBS, 2019). Abstraction due to irrigation was estimated by the field irrigation water requirement (FIWR) for each crop. FIWR was calculated utilizing evapotranspiration (ET_0), effective rainfall, crop coefficient, crops and cropping patterns of the study areas. Thus, total irrigation water requirement for the entire area is FIWR of crops and area under each crop. Crop coverage under each crop for entire area was estimated from the Upazila wise area weighted average crop coverage.

10.2.1.2 Domestic and municipal water Requirement

In Bangladesh, about 97% of total potable water is met up from groundwater sources. It was understood from the field survey that domestic and municipal water source of the study area was solely based on groundwater. Therefore, assessment of domestic and municipal water requirement is important to see the abstraction effect on groundwater table. Estimation of the present population and projected population is necessary for assessing the present and future domestic and municipal water demand. The Per Capita water demand is the annual average daily water consumption of one person. Thus, average daily demand over a year means the annual average daily demand. The total quantity of water required by the community can be computed using the following equation.

$$Q = P \times q \qquad (10.48)$$

Where, Q is the present or projected quantity of water required by the community per day, P is the present or projected population and q is the rate of water consumption per capita per day.

The projected population is estimated by the Geometric Progression method (Ahmed and Rahman, 2003):

$$P_p = P_b\,(1 + r)^n \qquad (10.49)$$

Where, P_p = projected population in the year n

P_b = Base population

r = rate of natural increase of population per year

n = number of years being considered.

On the basis of population projection by geometric progression method and per capita water demand, the domestic and municipal water requirement was estimated. According to the NWMP, 2001 report, per capita gross water demand for municipal town and rural areas are 166 lpcd and 30 lpcd respectively. The gross water demand of municipal town includes 119 lpcd net domestic water demand, 20% of it as a system loss, 10% as gross commercial demand and 15% as industrial demand. On the other hand, it has 50% returned flow from the commercial demand and 75% returned flow, thus the net water demand for municipal town becomes 76 lpcd. The gross water demand for rural areas doesn't include any loss and commercial and industrial demand. Thus, the net water demand for rural areas is same as the gross water demand.

10.2.1.3 Optimization of groundwater abstraction by hydrologic model

Previous studies in the Bengal Delta modeled a very large area (Faneca Sanchez *et al.*, 2015; Michael and Voss, 2009) by assuming groundwater abstraction per unit area of the model domain. The withdrawals were dispersed based on estimations done for each administrative unit. Of note, it is difficult to show point pumping in the model domain as individual bores because of the large number of unreported wells and the large scale of the study area. Therefore, the exact location of the point pumping was approximated in the present study on the basis of the land-use pattern of the study area. In conformance with the total water abstraction and for simplicity in the model, total water abstraction was distributed among the individual wells during the calibration process. Total irrigated area for Tanore upazila in the study area was obtained from the district statistics (Bangladesh Bureau of Statistics (BBS), 2013). The total irrigated area was multiplied by an abstraction rate of 1 m/pumping season/m^2 of irrigated area (Harvey *et al.*, 2006).

The entire model domains of all four upazilas were discretized into finite difference grids with a cell size of 300m×300m. The type and thickness of aquifer material layers were chosen in accordance with the lithological data of the study area. As most of the physical processes are occurred in the first few meters of the aquifer, the aquifer thicknesses of 95 m, 80m, 65m, and 70 m were chosen for Tanore, Godagari, Joypurhat sadar, and Kalai upazilas, respectively. The total depth of the aquifer was divided into three layers of materials for all upazilas. In Tanore upazila, first layer below the ground surface consists of silty clay with a thickness of 45 m, followed by a layer of fine to medium sand with 25 m thickness, followed by a soil type of medium to coarse sand with a thickness of 25 m. In Godagari upazila, first layer below the ground surface consists of silt with a thickness of 25 m, followed by a layer of medium sand with 30 m thickness, followed by a soil type of coarse sand with a thickness of 25 m. In Joypurhat sadar upazila, first layer below the ground surface consists of sandy clay with a thickness of 20 m, followed by a layer of medium sand with 25 m thickness, followed by a soil type of medium to coarse sand with a thickness of 20 m. In Kalai upazila, first layer below the ground surface consists of silty clay with a thickness of 20 m, followed by a layer of fine to medium sand with 25 m thickness, followed by a soil type of very coarse sand with a thickness of 25 m. An average estimate of hydraulic conductivity was assigned to each model layer. The aquifer material within each model layer was assumed homogeneous, only vertical heterogeneity in terms of hydraulic conductivity was considered. The hydraulic conductivity values used in this study were in accordance with previous studies conducted in the Bengal Delta (Faneca Sanchez *et al.*, 2015; Michael and Voss, 2009). A vertical anisotropy of 4 was chosen (GMS user's manual). The 3-D view of the model domains with finite difference grids is shown in Fig. 10.15.

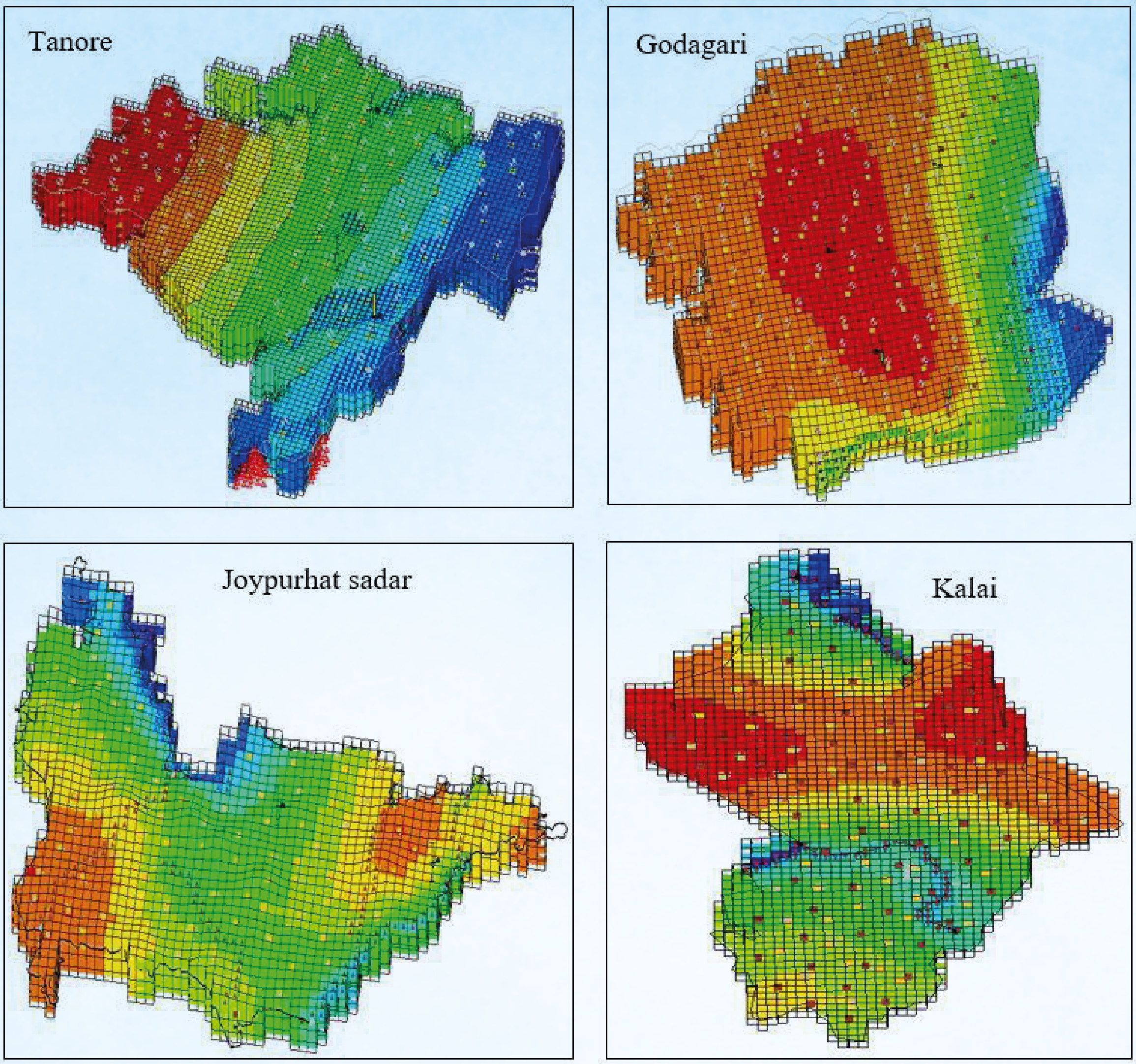


Fig. 10.15. Three dimensional view of the study areas

The calibration process was initiated from a steady state condition of the hydraulic heads in the finite difference grids of the model domain. To achieve this condition, the simulation model was run for 80 years. The simulation was performed in stages with an interval of 10 years. An average value of pumping was used during this simulation period. Outputs at the end of the 10th year's simulation were used as initial conditions for the succeeding intervals of 10 years' period. The process was continued until a stable condition with respect to hydraulic head was achieved. These hydraulic head estimates at various grids of the model area were used as initial conditions of the calibration process. At this stage, the actual groundwater abstraction from the study area was used. The calibration was performed for the observed hydraulic heads in September 2018, and the hydraulic heads were monitored at the designated monitoring locations. Recharge and hydraulic conductivity estimates were fine-tuned to achieve the hydraulic heads closer to the actual hydraulic heads in the observation wells. Table 10.3 presents major parameter values used in the calibrated groundwater simulation models.

Table 10.3. Parameter values of the calibrated model

Parameters	Values	Units
Tanore upazila		
Hydraulic conductivity in X-direction for soil layer 1	2.5	m/day
Hydraulic conductivity in X-direction for soil layer 2	18	m/day
Hydraulic conductivity in X-direction for soil layer 3	25	m/day
Vertical anisotropy for the soil layers	4	-
Aquifer recharge applied on the top soil layer	0.0004	m/day
Conductance of the specified head boundaries	1.0	$(m^2/day)/m$
Specific yield of Aquifer layer 1	0.01	-
Specific yield of Aquifer layer 2	0.01	-
Specific yield of Aquifer layer 3	0.01	-
Godagari upazila		
Hydraulic conductivity in X-direction for soil layer 1	3.5	m/day
Hydraulic conductivity in X-direction for soil layer 2	15	m/day
Hydraulic conductivity in X-direction for soil layer 3	22	m/day
Vertical anisotropy for the soil layers	4	-
Aquifer recharge applied on the top soil layer	0.00038	m/day
Conductance of the specified head boundaries	1.0	$(m^2/day)/m$
Specific yield of Aquifer layer 1	0.01	-
Specific yield of Aquifer layer 2	0.01	-
Specific yield of Aquifer layer 3	0.01	-
Joypurhat sadar upazila		
Hydraulic conductivity in X-direction for soil layer 1	4.5	m/day
Hydraulic conductivity in X-direction for soil layer 2	18.8	m/day
Hydraulic conductivity in X-direction for soil layer 3	23	m/day
Vertical anisotropy for the soil layers	4	-
Aquifer recharge applied on the top soil layer	0.0007	m/day
Conductance of the specified head boundaries	1.0	$(m^2/day)/m$
Specific yield of Aquifer layer 1	0.01	-
Specific yield of Aquifer layer 2	0.01	-
Specific yield of Aquifer layer 3	0.01	-
Kalai upazila		
Hydraulic conductivity in X-direction for soil layer 1	2.5	m/day
Hydraulic conductivity in X-direction for soil layer 2	18	m/day
Hydraulic conductivity in X-direction for soil layer 3	23	m/day
Vertical anisotropy for the soil layers	4	-
Aquifer recharge applied on the top soil layer	0.00033	m/day
Conductance of the specified head boundaries	1.0	$(m^2/day)/m$
Specific yield of Aquifer layer 1	0.01	-
Specific yield of Aquifer layer 2	0.01	-
Specific yield of Aquifer layer 3	0.01	-

10.2.2 Component-2: BRRI

10.2.2.1 Groundwater abstraction pattern

Quantifying groundwater deficit and safe withdrawal

It is obvious that there is relationship between withdrawal and recharge of groundwater. If the amount of withdrawal of groundwater is greater than the amount of recharge, deficit in groundwater storage (aquifer) occurs. As a result, both maximum ground water table (MXGWT) and minimum ground water table (MNGWT) go down from its previous position. If this scenario happens every year, a declining trend both in MXGWT and MNGWT is shown after couples of years. So, care should be taken about withdrawal of groundwater so that the abstraction never exceeds annual recharge. A model has been developed in this project to quantify groundwater deficit and to solve the deficit problem and this model is named as Towfiqul Islam (TI) Model.

TI Model is a conceptual model. It can quantify (1) groundwater deficit compared to previous years, (2) how much groundwater to be withdrawn if minimum groundwater table is wanted to bring at a level (target water level) which remained in any previous years within targeted coming years, in other words recover the deficit recharge (3) how much area should be brought under water saving technology to recover the deficit recharge.

The schematic diagram of the model is shown in Fig. 10.16. In this Figure ABCDEFG is an aquifer. The present depth of MNGWT is y_2 and t years before that depth was y_1. Similarly, the present and t years before the MXGWT are x_2 and x_1, respectively. Again, considering area of the aquifer is "a" and the line ML is datum line in the aquifer.

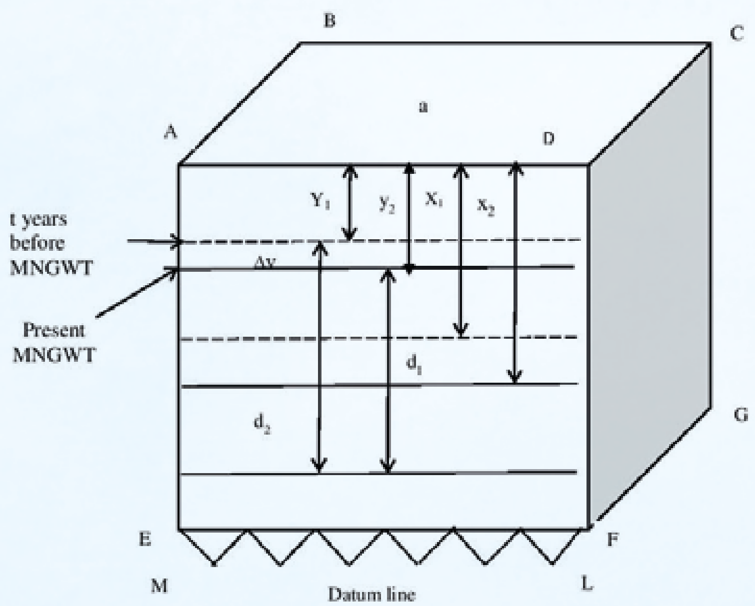


Fig. 10.16. Schematic diagram of groundwater table in the aquifer

From the figure:

$$\Delta y = \Delta d = (y_2 - y_1) = (d_2 - d_1) \quad (10.50)$$

If t years before volume of groundwater above datum line was V_2 i,e, $V_2 = a.d_2$ and after t years $V_1 = ad_1$. Then the change in volume i.e, deficit recharge volume will be: $\Delta V = (V_2 - V_1) = (ad_2 - ad_1)$; So, $\Delta V = a(d_2 - d_1)$;

$$\Delta V = a.\ \Delta d = a.\ \Delta y \tag{10.51}$$

Now percent of deficit recharge volume (DRV)

$$DRV(\%) = \frac{a.\Delta d \times 100}{ad_2} = \frac{\Delta d \times 100}{d_2} \tag{10.52}$$

If the ground surface is a datum line, then percent of DRV will be

$$DRV(\%) = \frac{\Delta y \times 100}{y_2} \tag{10.53}$$

Similarly, the percent of deficit volume at MXGWT which is recognize as deficit for excess withdrawal (DEW), so

$$DEW(\%) = \frac{dx \times 100}{x_2} \tag{10.54}$$

To bring the level of GWT from present to t years before position in other words to recover the deficit within coming t_1 years, then per year ground water withdrawal or utilization in terms of percentage should be reduced by total reduction percentage during t years divided by t_1 years i.e. reduced utilization percent (RUP) is

$$RUP\ (\%) = \frac{DRV}{t_1} = \alpha \tag{10.55}$$

It means per year reduced utilization percent would be α.

The model assumption is that all the equation has been developed considering constant recharge volume every year. All the stakeholder of groundwater should withdraw or utilize α percentage less water than regular withdraw or utilize to recover the deficit. But practically most of the stakeholders may not withdrawal or utilize α percentage less ground water per year. Since the biggest stakeholder of groundwater use is agriculture. So, suppose agriculture can take all responsibilities to use less water. If β percentage of total groundwater is being used by agriculture, then

$$\text{RUP for agriculture} = \alpha/\beta \tag{10.56}$$

Again, in agriculture, most of the groundwater is being used by Boro rice cultivation. Suppose, Boro cultivation use γ percentage of agriculture groundwater and if Boro cultivation takes all responsibilities to use less water, then

$$\text{RUP for Boro cultivation} = \left(\frac{\alpha}{\beta}\right)\Big/\gamma = \alpha/\beta\gamma \tag{10.57}$$

Now, it is known, any water saving technology used in Boro cultivation, can save certain percentage of water alone or if combined applied in the field. It is anticipated, water saved by the single or combined use of technologies is θ percentage. It means if water saving technology is applied in Boro cultivation, θ percent less water will be used. Now if θ is equal to RUP for Boro ($\alpha/\beta\gamma$) then hundred percent Boro area has to be brought under the water saving technology. But if θ is greater than $\alpha/_{\beta\gamma}$ then minimum area coverage in percentage by the technology can be calculated by following equation

$$\text{Minimum Area Coverage by Technology (MCT \%)} = \alpha/_{\beta\gamma\theta} \quad (10.58)$$

The total process of the model has been presented in the flowchart (Fig. 10.17). Long-term water table and rainfall data, irrigation coverage, number of DTW/STW, farmers' response data were collected for this model.

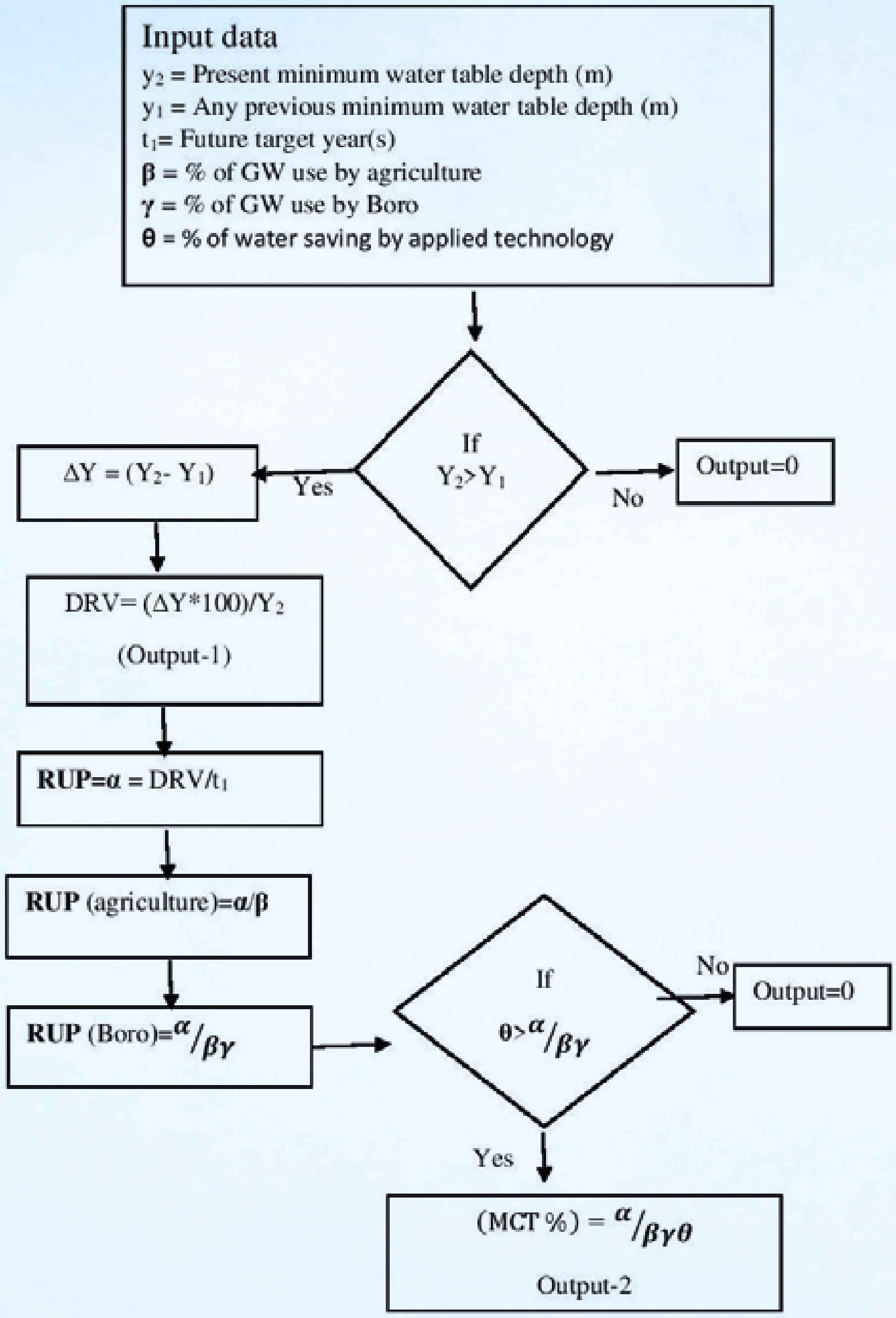


Fig. 10.17. Flowchart of the TI Model

10.2.3 Component-3: BINA

10.2.3.1 Groundwater abstraction pattern

Simulating water-table under different withdrawal rate using MODFLOW
Modular Finite-Difference Flow Model (MODFLOW) is a physical-based three-dimensional groundwater flow model (Harbaugh *et al.*, 2017 and McDonald and Harbaugh, 1988). It is the United States Geological Survey's (USGS's) modular hydrologic model and considered as the international standard for simulating and predicting groundwater conditions with the interaction between surface water and groundwater. MODFLOW was utilized for future groundwater level prediction in an unconfined aquifer (Fig. 10.18) of Nachole and Niamatpur upazil. Pumping rate under different cropping patterns and different recharge rates (measured recharge value, and also changing scenario of 80% and 90% of present recharge) were used for this modeling.

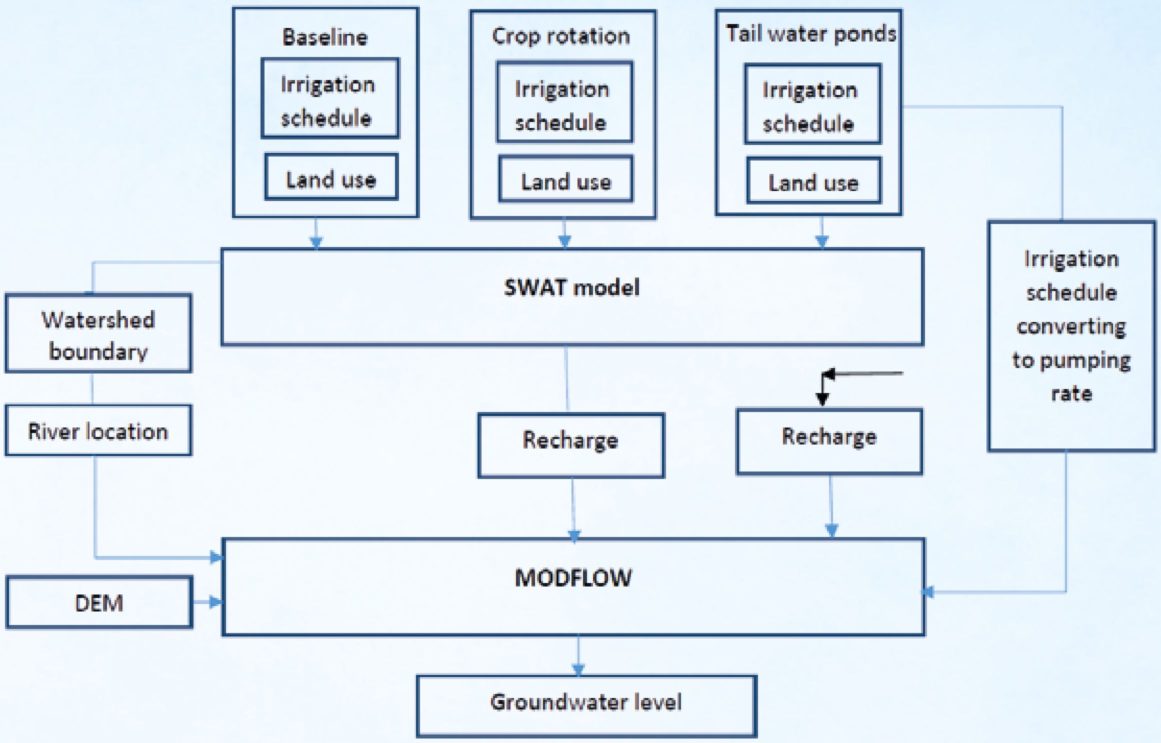


Fig. 10.18. Schematic of simulation modeling using MODFLOW

The description of scenario conditions (cropping patterns and/or recharge) is given in Table 10.4:

Table 10.4. Description of different scenario conditions

Sl.	Description of Conditions
Scenario-1 (S1)	With existing cropping pattern, and hence existing withdrawal rate of groundwater
Scenario-2 (S2)	Present Boro rice is replaced (100% replacement) by Aus rice
Scenario-3 (S3)	30% of present Boro rice is replaced by Aus rice
Scenario-4 (S3)	50% of present Boro rice is replaced by Aus rice
Scenario-5 (S5)	With existing cropping pattern, but recharge = 0.8 * present recharge
Scenario-6 (S6)	With existing cropping pattern, but recharge = 0.9 * present recharge

Model domain has been selected based on the coverage of GPS locations of field site (Fig.10.19). A rectangle is chosen in such a way that it covers all the field locations (Fig.10.20).

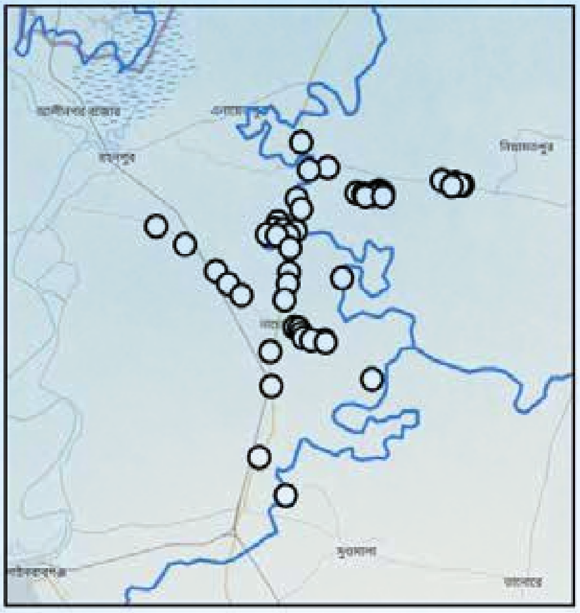


Fig. 10.19. Field site locations

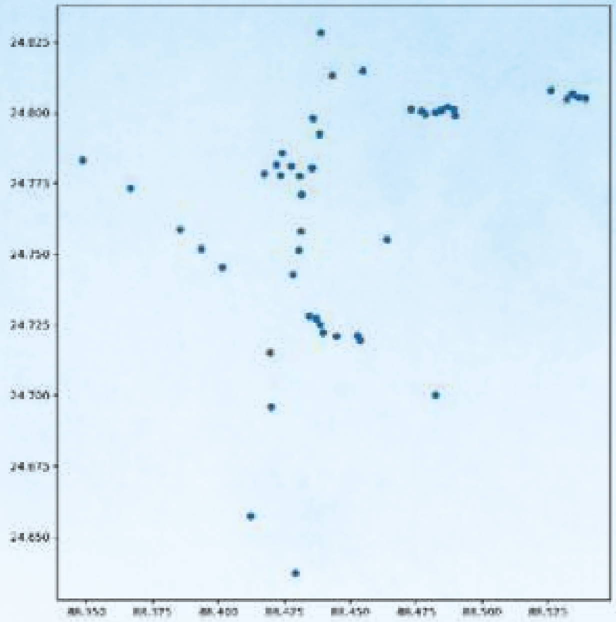


Fig. 10.20. Model domain rectangle

Total domain area is divided into 266 rows and 247 columns with 100m x 100m cell size. Daily evapotranspiration and recharge rate are calculated from monthly data.

The model parameters for Nachole and Niamatpur are given in Table 10.5. The simulations were done for the year 2030, 2040 and 2050.

Table 10.5. Model parameters for Nachole and Niamatpur

Model parameters	Nachole	Niamatpur
Aquifer depth	58 m	58m
Hydraulic conductivity	32.7 $m^3/m^2/d$	28.9 $m^3/m^2/d$
Initial Water table	34 m	29.56 m

10.2.4 Coordination Component: BARC

TI model is an analytical model developed by Dr. Md. Towfiqul Islam CSO & Head, IWM Division, BRRI. It can quantify (1) ground water deficit compared to previous years, (2) how much groundwater to be withdrawn if minimum ground water table is wanted to bring at a level (target water level), in other words recover the deficit recharge (3) how much area should be brought under water saving technology to recover the deficit recharge. It is used for optimizing groundwater abstraction for irrigation purpose. This model shows very good output. This is why the BARC component analyzed the BARI and BINA component data for optimizing groundwater abstraction pattern. The details about TI model have been given in Section 10.2.2.

10.3 Crop production and Cropping Patterns

10.3.1 Component-1: BARI

10.3.1.1 Cropping pattern based field trials with rice and non-rice crops

The study was initiated during the rabi season of 2018-2019 after harvesting of T.Aman rice in both Joypurhat and Rajshahi. The soil of the study area was loam - clay loam with an average field water-holding capacity of 28.5- 30.5 % and wilting point of 14.12-15.2%. Soil bulk density in the 0 to 60 cm depth ranged from 1.31 to 1.43 g/cc, with a weighted average of 1.39 g/cc. A typical dry climate with comparatively high temperature prevailed in Barind area. Temperature ranged from a minimum of 8^{o}C in the winter to a maximum of 44^{o}C in the summer. More than 85% of the total annual rainfall occurs from mid June to October and the magnitude of annual rainfall varied from 1300-1500 mm in Rajshahi and 1800 - 2000 mm in Joypurhat. Based on an extensive investigation on the existing cropping patterns in the study areas, two/three promising cropping patterns from each study area were selected for project works and the field experiments were conducted following the major cropping patterns of the respective study area. Three/four different cropping patterns with four/five principal crops of that region were selected for rotation of crops, including T.Aman, boro, wheat, mustard, and potato. Mungbean, a popular fallow crop, was included in T.Aman-Wheat-Fallow pattern after wheat cultivation. Irrigation schedule of different crops with their sowing/transplanting and harvesting date have been presented in Table 10.6. All crops were grown in the following sequences starting with rabi crops as: T.Aman-Potato-Boro, T.Aman-Mustard-Boro, T.Aman-Wheat-Fallow. Another pattern Boro-Fallow-T.Aman was tested as control treatment.

For each crop, the recommended doses of fertilizers were used and standard cultural practices were followed. Crops were sown immediately after harvesting of T. Aman with a view to save water for irrigation with effective utilization of residual soil moisture. Each crop was grown on a 100 m^2 plot with three replications. The growing period for wheat crop was Nov-March, for potato Nov-February, for mustard Oct/Nov-January/Feb and for boro rice December-April. At maturity, all crops were harvested manually to determine grain yield and aboveground biomass. Soil water content was monitored at 20 cm incremental depth up to 60 cm depth for wheat and mustard, and up to 40 cm depth for potato before and after irrigation. Soil moisture content at sowing and at harvest was monitored to find out the amount of profile soil moisture contributing to crops. All cultural practices were done as per recommendations. Important agronomic data and parameters were collected during the cropping season and at harvest time.

Yield was estimated by collecting samples from one square meter area of each replication. Harvested wheat/rice was threshed, cleaned and weighed and finally the yield was calculated at 14% moisture content. All weather data of the cropping period influencing crop water use were also collected. Depth of irrigation water applied in each irrigation was duly recorded. Total water use by the wheat, potato and other non-rice crops during the entire cropping period (sowing to harvesting) was calculated by using the field water balance equation as:

$$TWU= I + P+ - D - R \pm \Delta SWS \tag{10.59}$$

Where, TWU is the total water use (mm), P is the effective rainfall (mm), I is the irrigation water applied (mm), D is the deep percolation (mm), R the run-off and ΔSWS is the change in water storage in the soil profile. Deep percolation (D) was assumed negligible, since water was applied only to replenish soil moisture in the root zone. Run-off due to irrigation or rainfall was taken to be zero as irrigation/rainfall water was protected by levees of 15 cm height.

Table 10.6. Irrigation schedule of different crops with their sowing/transplanting and harvesting dates

Crops	Treatments	Sowing/ transplanting date	Harvesting date
Wheat (BARI Gom- 30)	T_1= Irrigation at CRI and pre-flowering stages T_2= Irrigation at CRI and grain formation stages T_3= Irrigation at CRI, pre-flowering and grain formation stages (20, 55 and 75 DAS)	20 November 2018	13-15 March 2019
Mustard (BARI Sarisha- 14)	T_1= One irrigation at vegetative stage T_2= One irrigation at pre-flowering stage T_3= Two irrigation at vegetative and pod formation stages	18-21 November 2018	11-13 February 2019
Potato (Diamant)	T_1= Farmers' practice (FP) T_2= Irrigation at stolonization, tuberization and bulking stages in furrow system (FI) T_3= Irrigation at stolonization, tuberization and bulking stages in alternate furrow system (AFI)	10-17 November 2018	11-15 February 2019
Boro (BRRI dhan- 28)	T_1= Farmers' practice (ponding up to 3-5 cm) T_2= Irrigation on 3rd day after disappearing of standing water T_3= Irrigation when water level fall 15 cm below ground surface	03-07 January 2018	27-30 April 2019
T.aman (BRRI dhan- 56)	T_1= Farmers' practice T_2= AWD with 20 cm depth T_3= AWD with 25 cm depth	21-28 July 2018	24-29 October 2019
T.Aus	T_1= Farmers' practice T_2= AWD with 20 cm depth T_3= AWD with 25 cm depth	03-09 June 2019	11-13 August 2019
Maize	T_1= Irrigation at vegetative and flowering stages (FP) T_2= Irrigation at seedling, vegetative and silking stages by furrow irrigation (FI) T_3= Irrigation at seedling, vegetative and silking stages by alternate furrow irrigation (AFI)	01 December 2018	05 May 2019
Tomato	T_1= Furrow irrigation T_2= Drip irrigation T_3= Alternate furrow irrigation	13-15 September 2019	14 November 2019-18 December 2019

Water productivity was determined as the ratio of yield to total water used by the crop as:

$$WP = Y/TWU \tag{10.60}$$

Where, WP is the water productivity (kg m^{-3}), Y is the crop yield (kg ha^{-1}) and TWU the total water use (m^3 ha^{-1}).
Total water use by rice crop during the entire cropping period (planting to harvesting) was calculated by using the following equation:

$$TWU = I + P - R - (S \& P) \tag{10.61}$$

where TWU is the total water use (mm), I is the irrigation water applied (mm), P is the effective rainfall (mm), R the run-off (mm) and S& P is the seepage and percolation (mm). Run-off was taken to be zero as irrigation water was protected by 30 cm height levees.

Water requirement (WR) for boro rice was determined as irrigation water applied (mm) plus effective rainfall (mm) during the cropping season.

Unlike non-rice crop, water productivity was determined as the ratio of water requirement to the yield as:

$$WP = WR/Y \qquad (10.62)$$

Where, WP is the water productivity (m^3/kg) and Y is the crop yield (kg/ha) and WR is the water requirement (m^3/ha).

Water use efficiency (WUE) was calculated by dividing the total water requirement by water supply during the cropping season as:

$$WUE = WR/WS \qquad (10.63)$$

Where, WUE is the water use efficiency (%), WR the total water requirement (mm) and WS is the water supply (mm).

10.3.2 Component-2: BRRI

10.3.2.1 Cropping pattern based field trials with rice and non-rice crops

Cropping pattern based experiments and demonstration of water saving technologies were conducted in four different locations of northwest hydrological region named Ishwardi and Santhia of Pabna and Mithapukur and Pirgonj of Rangpur during 2018-19 and 2019-20 to identify suitable cropping patterns which needed comparatively less irrigation with good yield and to popularize water saving technologies among the farmers'. Varieties and treatments used in different cropping patterns experiments and water saving technology demonstration is given in Table 10.7.

Cropping pattern based experiment was performed under 3 shallow tubewells (STW) and each STW was considered as the replication. For rice crop Bangladesh Rice Research Institute (BRRI) developed varieties and for non-rice crops and Bangladesh Agriculture Research Institute (BARI) developed modern high yielding varieties were used in the experiment. BARI and BRRI recommended fertilizer doses and agronomic management were were followed. For T. Aman rice supplemental irrigation was applied based on monitoring with a perforated AWD pipe of 25 cm long. BARI recommended irrigation scheduling were followed for Rabi crops. The amount of applied irrigation was recorded by taking the discharge of STW and time for each irrigation in the respective field. The grain yield, growth duration and biomass were recorded by taking crop cut sample from 10 m^2 area. During the whole growing period the total amount of rainfall received by each crop were recorded from nearby installed rain gauge. The total production cost involved in each operation was recorded regularly. During the harvesting of each crop the farm gate price of the crops was recorded to calculate the income from each crop. Finally, the gross margin of each cropping pattern was calculated. Data of grain yield and biomass, water requirement of different crops, rainfall, irrigation applied, crop yield, cost of production, cost of irrigation, value of crops, etc were collected.

Table 10.7. Variety and treatment used in different cropping patterns and water saving technology demonstration in the study areas during 2018-19 and 2019-20

<table>
<tr><th rowspan="2">Location</th><th colspan="2">Treatment</th><th colspan="4">Variety</th></tr>
<tr><th>For cropping pattern expt.</th><th>For water saving technology expt</th><th>T.Aman</th><th>Rabi</th><th>Boro</th><th>Aus</th></tr>
<tr><td>Mithapukur</td><td rowspan="4">T1= T. Aman-Mustard-Boro (CP1)

T2= T. Aman-Potato- Boro (CP2)

T3= T. Aman-Wheat- T. Aus (CP3)

T4= T. Aman-Lentil- T. Aus (CP4)

T5= T. Aman-Fallow-Boro (CP5) (existing cropping pattern)</td><td rowspan="4">T1= 5 cm irrigation applied when water level below 25 cm from soil surface in PVC pipe

T2=15 cm height levee mgt.

T3= 5 cm irrigation applied when water level below 15cm from soil surface in AWD method

T4=Farmers' practice in each treatment of T1, T2 & T3</td><td>BRRI dhan49</td><td>BARI Sarisha-14
BARI Alu-25
BARI Moshur-6
BARI Gom-26</td><td>BRRI dhan29
BRRI dhan58</td><td>BRRI dhan48</td></tr>
<tr><td>Pirgonj</td><td>BRRI dhan49</td><td>BARI Sarisha-14
BARI Alu-25
BARI Moshur-6
BARI Gom-26</td><td>BRRI dhan29
BRRI dhan58</td><td>BRRI dhan48</td></tr>
<tr><td>Ishwardi</td><td>BRRI dhan49</td><td>BARI Sarisha-14
BARI Alu-25
BARI Moshur-3
BARI Gom-26</td><td>BRRI dhan58</td><td>BRRI dhan48</td></tr>
<tr><td>Santhia</td><td>BRRI dhan39</td><td>BARI Sarisha-14
BARI Alu-25
BARI Moshur-3
BARI Gom-26</td><td>BRRI dhan58</td><td>BRRI dhan48</td></tr>
</table>

Supplemental irrigation was applied to mitigate terminal drought. Technology was demonstrated in the farmers' field at Mithapukur and Pirgonj of Rangpur and Ishwardi and Santhia of Pabna during T. Aman, 2018 to T. Aman, 2020. Three STWs were selected in each location and under each STW, the technology was demonstrated in a two bighas of land. Each land was divided into two parts one part was under research management (RM) and another was under farmer's management (FM). The trial under each STW was considered as replication. We used BRRI dhan49 as tested variety at farmers' field and recommended agronomic management was applied. To determine the agricultural drought and the suitable time for application of supplemental irrigation, BRRI has developed a method and that method was followed in this project. Following that method, a 35 cm long PVC perforated (top 10 cm blind and bottom 25 cm perforated) pipe was installed at one corner of the plot. Perforated part was placed below the soil surface and non-perforated part above the surface. When the perched water table went below 25 cm from the soil surface then agricultural drought started and 5 cm irrigation was applied. The other plot (FM) remained rainfed and no irrigation was applied. The amount of applied irrigation in supplemental irrigation was recorded by taking each irrigation time and discharge of the respective STWs. Daily rainfall was collected from rain gauge. Finally grain yield was recorded for each treatment.

Rainwater harvesting by 15 cm high levee management is useful to mitigate short term terminal drought during T. Aman rice. The experiment was conducted in four locations of the sub-project area and under the selected 3 STWs at each location during T. Aman, 2018 to T. Aman, 2020. Another two bighas of land were selected from each STW and each land was divided into two parts. One part was under RM ie 15 cm levee height and another part was under FM. BRRI dhan49 and BRRI dhan39 were the test varieties in Ishwardi and Santhia, respectively. A 25 cm perforated PVC pipe were installed in each rice field to monitor the perched water table movement and number of standing water days throughout the season. Finally grain yield was calculated taking samples from 10 m^2 in each plot.

Water saving technology was demonstrated during Boro, 2018-19 to Boro, 2019-20 seasons at four different locations of Rangpur (Mithapukur and Pirgonj) and Pabna (Ishwardi and Santhia). The selected STWs were used and AWD method was applied in RM plot and there was no AWD method in FM plot. Farmer irrigated in his own way. In AWD method a 25 cm long perforated PVC (top 10 cm blind and bottom 15 cm perforated) pipe was installed in each plot. Perforated part was placed below the soil surface and non-perforated part above the surface. When the perched water table disappeared from the PVC pipe a 5 cm irrigation was applied. The time required for one irrigation and discharge of STW were recorded. Yield in two plots were recorded taking samples from 10 m^2 area. Data of amount of water applied in each method, farmer's practice, cost of irrigation, yield and yield parameters were collected.

10.3.3 Component-3: BINA

10.3.3.1 Cropping pattern based field trials with rice and non-rice crops

Along with local existing cropping pattern, different 'low water demanding' cropping patterns (including technological intervention, such as new drought tolerant Aman variety, drought tolerant broadcast Aus variety) were selected to find out an economic and water-efficient cropping pattern/system based on the available resources.

Existing pattern

Existing pattern-1: Boro – Aman - Fallow
Existing pattern-2: Fallow – Aman – Rabi/Kharif

New patterns tested:

Aus – Aman – Rabi (Mustard/Lentil/Wheat)
Boro - Aman – Rabi (Mustard/Lentil)
Kharif-1 - Aman – Rabi

Details of crop-wise irrigation management and varieties used under new or existing practice are summarized in Table 10.8. The Irrigation management options under different crops were selected from the best option of trial treatments conducted in first year, considering optimum yield and water use.

Table 10.8. Details crop wise irrigation management or treatment and varieties used under new or existing practice based on optimum yield and water use

Cropping pattern	Crop	Practice	Treatment/Irrigation management	Variety (duration, days)
Pattern-1: Aus- Aman – Rabi (Mustard)	T. Aus	New	20 cm height levee around the plot and supplemental irrigation if ASM drops below 85%	Binadhan-19 (100) Binadhan-21 (102) BRRI dhan55 (105)
Pattern-2: Aus - Aman – Rabi (Lentil)	T. Aman	New	20 cm height levee around the plot, and supplemental irrigation during booting to soft-dough, if ASM drops below 85%	Binadhan-16 (115) Binadhan-17 (116) Binadhan-22 (116) BRRI dhan71 (117)
Pattern-3: Aus - Aman – Rabi (Wheat)	T. Aman	Existing	Farmer's practice (Rain feed and Supplemental irrigation to meet saturation or standing water in the field)	BRRI dhan51(155)

Cropping pattern	Crop	Practice	Treatment/Irrigation management	Variety (duration, days)
Pattern-4: Boro - Aman – Rabi (Mustard) Pattern-5 (control): Boro - Aman –Fallow	Mustard	New	Irrigation at early (15-17 DAS) and vegetative stage (28-30 DAS)	Binasarisha-9 (90) Binasarisha-10 (87) BARI Sarisha-14 (80)
	Lentil	New	No irrigation (only the use of profile soil moisture)	Binamasur-8 (115)
	Wheat	New	03 irrigation (at CRI, vegetative, booting-heading stage)	BARI Gom-26 (110) BARI Gom-33 (113)
	Boro Rice	New	3 days AWD (5 cm ponding)	Binadhan-14 (120)
	Boro Rice	Existing	Farmer's practice (Maintain saturation level or standing water at field)	Banglajira (160) (inbreed Indian variety)

Calculation of rice equivalent yield

Equivalent yield (in terms of a target crop, r) of non-rice crop (*i*) was calculated as:

$$Y_{eq-r}(t/ha) = \frac{Y_i(t/ha)\times P_i(\$/t)}{P_r(\$/t)} \quad (10.64)$$

Where,

$Y_{eq\text{-}r}$ = Equivalent yield (in terms of rice), t/ha

Y_i = Yield of a non-rice crop, t/ha

P_i = Price of a non-rice crop, Tk/t

P_r = Price of rice, Tk/t

Economic analysis

Economic analysis was performed considering full cost of production. Only the best performing treatment/cultivar was considered for economic analysis. Crops other than rice were transformed to equivalent rice. Market price of different crops for different years were taken by collecting information from nearest market and local farmers of the study area. The BCR was calculated for each pattern.

11. Results and Discussion

11.1. Benchmark evaluation

11.1.1. Component-1: BARI

11.1.1.1. Existing cropping patterns in the sub-project locations

Irrigated/non- irrigated area and major crops

The study areas of Rajshahi and Joypurhat sadar are fully dependent on irrigation in rabi seasons. Major crops of rabi seasons like boro, potato, wheat and maize are completely irrigation dependent at these sites. Besides all these crops, tomato is the main irrigated crop at Godagari site. In both sites of Rajshahi, a little percentage of T. Aman is still rainfed, though most of the T.Aman farmers apply supplemental irrigation to their fields. Based on irrigated area, maximum (96%) was observed at Godagari followed by Tanore (94%) and Joypurhat sadar (89%) while the minimum was observed at Kalai (87%). In Kalai and Joypurhat, a reasonable percentage of T. Aman and major portion of mustard are still rainfed (Table 11.1).

Table 11.1. Irrigated/non irrigated area and major crops

Study area	Irrigated area (%)	Non-irrigated area (%)	Irrigated crops	Non irrigated crops
Godagari	96	4	Boro, T. Aman, potato, wheat, maize, mustard, jute	T.Aman, jute
Tanore	94	6	Boro, T. Aman, potato, tomato, wheat, maize, mustard	T.Aman, pulses
Kalai	87	13	Boro, potato, T. Aman, maize, wheat	T.Aman, mustard
Joypurhat sadar	89	11	Boro, potato, T. Aman, maize	T. Aman, mustard

Major cropping patterns

A wide range of cropping patterns and diversified crops were recognized in the study areas and the important feature of the cropping pattern is that most of the patterns were rice dominated (Table 11.2). Even some patterns were composed of absolutely rice crops. Boro – Fallow – T.Aman was the most predominant cropping pattern in Godagari and Joypurhat sadar upzilas and about 30% of the net cropped area belonged to this pattern. In Tanore, this pattern occupied about 23% of the net cropped area while this pattern was absent in Kalai. In this area, predominant patterns were Potato – Boro – T. Aman and Mustard - Boro – T. Aman which belonged to 46% and 39%, respectively. In Tanore site, the cropping pattern Potato – Boro – T. Aman covered the highest area (32.5%) followed by the pattern of Boro – Fallow – T. Aman (23%). The cropping pattern Potato –T.Aus - T.Aman stood third and covered about 21.5% of the cultivated area followed by Mustard –Boro – T.Aman cropping pattern that covered on average 7% of the area.

Table 11.2. Major cropping patterns of the study areas with their area coverage

Location	Major cropping patterns in percentage	
	Cropping patterns	(%)
Godagari	1) Boro - Fallow –T.Aman	28
	2) Wheat – Fallow-Taman	12.5
	3) Lentil- Fallow- T.Aman	7.53
	4) Lentil - T.Aus– Fallow	7.4
	5) Guava-Guava-Guava	6.4
	6) Mustard–Fallow – T.Aman	5.27
	7) Permanent orchad	5.0
	8) Boro – T.Aus- Tomato	3
Tanore	1) Potato – Boro – T.Aman	32.5
	2) Boro – Fallow – T.Aman	23
	3) Potato - T.Aus – T. Aman	21.5
	4) Mustard – Boro – T.Aman	7
	5) Wheat – T.Aus – T.Aman	4.8

Location	Major cropping patterns in percentage	
	Cropping patterns	**(%)**
Kalai	1) Potato - Boro – T.Aman	46
	2) Mustard - Boro – T. Aman	39
	3)Wheat–T.Aus/Fallow-T.Aman	5
	4) T. Aman – Chili – Fallow	3
	5) T. Aman - Fallow – T. Aus	3
Joypurhat	1) Boro – Fallow – T.Aman	
	2) Potato – Boro – T.Aman	
	3) Mustard – Boro – T.Aman	
	4) Potato – Fallow – T.Aman	

Diversified crops were grown in the study area like rice (T. Aus, T. Aman, Boro), potato, tomato, wheat, pulses, mustard, spices, etc. Next to rice, potato was the dominant crop in the study areas, except in Godagari upazila where wheat was the second dominant crop.

Cropping intensity and land use

Among the three study sites, percentage of net cropped area ranged from 82% at Tanore to 85.24% at Joypurhat sadar. It was 84.58% at Kalai closely followed by 83.72% at Godagari (Table 11.3). In all sites, percent of triple crop was found higher than that of double cropped area except Godagari. However, percent of triple crop per year was recorded highest (89.90%) at Kalai followed by Tanore (79.64%) and Joypurhat sadar (66.43%) and the lowest (33.58%) was recorded at Godagari. But the percent double crop per year was recorded the highest at Godagari and the lowest (10.10%) was at Kalai. Percentage of single crop per year was found lower than double and triple crop with the highest value (11.67%) at Godagari and the lowest value (1.43%) at Tanore. At Kalai, single cropped area was nil. Based on all the cultivated crops in the area, the highest cropping intensity (290%) was found in Kalai followed by Tanore (278%) and Joypurhat sadar (265%) and the lowest (223%) in Godagari. Lower value of triple crop and higher value of single crop per year causes the lowest cropping intensity in Godagari while triple cropped area occupied the biggest share of net cropped area that caused higher cropping intensity in Kalai upazila. However, the quadruple cropped area also exists as a very negligible portion (0.95%) and is limited in only Godagari upazila. The cropping intensity is shown in Fig. 11.1.

Table 11.3. Single, double & triple cropped area and cropping intensity of the study areas

Area	Single cropped area (%)	Double cropped area (%)	Triple cropped area (%)	Quadruple cropped area (%)	Net cropped area (%)	Cropping intensity (%)
Godagari	11.67	53.79	33.58	0.95	83.72	223
Tanore	1.43	18.92	79.64	-	82.0	278
Kalai	-	10.10	89.90	-	84.58	290
Joypurhat sadar	3.57	29.99	66.43	-	85.24	265

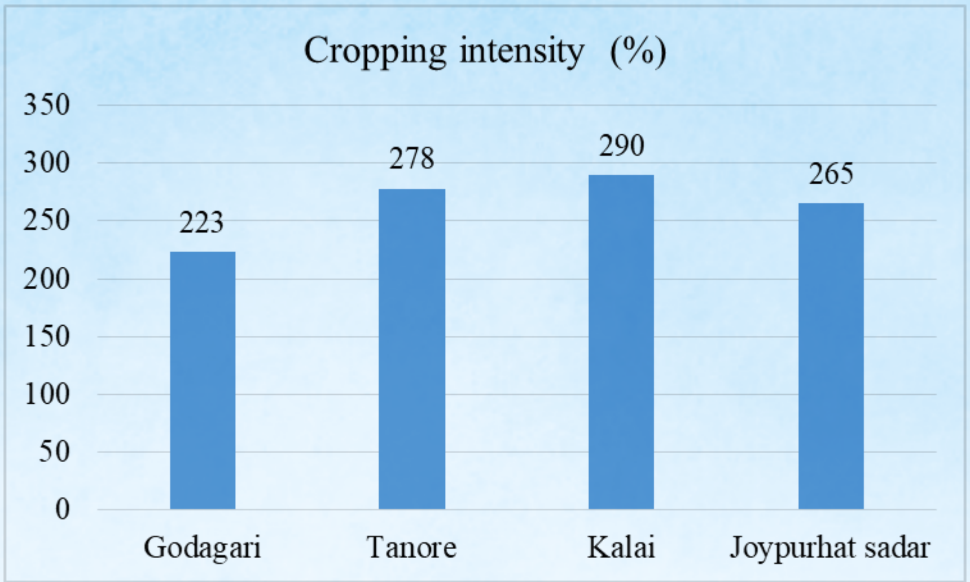


Fig. 11.1. Cropping intensity (%)

Crop-based irrigation status

Percent of irrigated area covered by major crops cultivated in the study areas is shown in Table 11.4. The study area had rice dominated agriculture with T. Aman as the main rice crop and its irrigation coverage was 97% at Godagari, 89% at Tanore, 68% at Kalai and 74% at Joypurhat sadar.

Table 11.4. Crop based irrigation percentage of study area

Crops	Irrigation in study area (%)			
	Godagari	Tanore	Kalai	Joypurhat sadar
Boro	100	100	100	100
T.Aman	97	89	68	74
T.Aus	100	96	87	95
Maize	100	100	100	100
Wheat	100	100	100	-
Potato	100	100	100	100
Tomato	100	100	100	100

11.1.1.2. Status of irrigation sources and pumping equipment

Irrigation equipment

DTW, STW and LLP were identified as the common irrigation devices used in the study areas. Most of the STWs were operated by diesel engine but all the DTWs were electric motor operated in Godagari and Tanore. While in study areas of Joypurhat, about one-fourth of DTWs were electric motor operated. Survey results showed that irrigation of the study areas mostly depend on groundwater and accomplished by DTW followed by STW. Of the total respondents, about 18% used STW irrigation and about 78% used DTW for irrigating their crop fields. DTW irrigation was recorded highest 93% in Kalai followed by 83% in Joypurhat sadar upazila, 78% in Tanore and the lowest 56% in Godagari upazila. Among the study areas, the highest 32% respondent was dependent on STW irrigation in Godagari followed by 17% in Joypurhat sadar, 15% in Tanore and the lowest 7% in Kalai. Few farmers (7-8%) at Godagari and Tanore reported that they occasionally use pond water for irrigation. However, there is no scope for surface irrigation at Kalai and Joypurhat sadar (Table 11.5).

Table 11.5. Mode of irrigation, power used and area coverage by equipment in the study area

Location	STW		DTW		LLP		Respondent (%) by equipments		
	Diesel	Electricity	Diesel	Electricity	Diesel	Electricity	STW	DTW	LLP
Godagari	1850	280	-	719	480	46	32	56	8
Tanore	56	411	-	542	350	9	15	78	7
Kalai	147	213	142	383	-	-	7	93	-
Joypurhat sadar	488	598	108	440	-	-	17	83	-

Crop yield and their irrigation practices

Since diversified crops were cultivated in the study areas, a variable yield pattern was also observed. However, yield of the same crop did not change very much with locations. The yield pattern of some major crops of the four study areas are presented in the Table 11.6. In Godagari, almost all crops were irrigated obviously the highest irrigation consumer like other study sites was boro rice. Over the study areas, number of irrigations for boro rice ranged from 12 to 18. Next to boro rice, potato was the second highest irrigation consumer with 3 to 6 irrigations per season followed by T.Aus. In kalai and Joypurhat sadar, mustard was non-irrigated, but in Godagari, it was irrigated with one or two irrigations. So, it showed a clear evidence of huge yield difference of mustard between irrigated and non-irrigated condition.

Table 11.6. Yield of crops and their irrigation practices in study areas

Location	Crop	Yield (t/ha)	No. irrigation
Godagari	T. Aman	3.24	2 to 4
	T.Aus	2.56	3 to 5
	Boro	5.12	12 to 18
	Potato	16.0	4 to 5
	Mustard	1.42	1 to 2
	Maize	8.2	3 to 4
	Lentil	0.94	0-1
	Tomato	32	5 to 8
Tanore	T.Aman	2.91	1-2
	T. Aus	2.58	3 to 4
	Boro	5.03	15 to 18
	Potato	26.5	5 to 6
	Mustard	1.12	1
	Maize	7.6	2 -3
Kalai	T.Aman	3.31	0-2
	Boro	4.79	14-16
	Potato	19.5	3 to 5
	Mustard	0.80	0
Joypurhat sadar	T.Aman	3.07	1-2
	Boro	5.06	14-18
	Potato	20.0	3 to 5
	Mustard	0.89	0

Features of irrigation schemes

Information of irrigation schemes of the study areas has been presented in Table 11.7. A different type of ownerships exists in the study areas. In Joypurhat, farmers owned DTWs on cooperative basis and used water for themselves and also sold water to their neighboring farmers on rental basis. On the other hand, the irrigation system of Godagari and Tanore was controlled totally by the BMDA. Farmers irrigated their field on a rotational basis using a card. Average depth of wells was between 38m and 44m with 12 to 27m filter and 15-20cm pipe diameter. Most of the tubewells capacity was 56 lit/sec and few numbers was of 42 lit/sec capacity. There was a variation in command area under DTW irrigation scheme with the highest command area of 26 ha in Kalai and the lowest was 17 ha in Joypurhat sadar. Number of water users under a DTW varied greatly from 55 in Godagari to 169 in Kalai upazila.

Table 11.7. Some salient features of DTW irrigation schemes in the study areas

Description	Godagari	Tanore	Kalai	Joypurhat sadar
Pump ownership	Public	Public	Cooperative	Cooperative
Installation year	1980-2002	1980-2002	1980-1989-2000	1980-1989
Depth of well, m	43	40	44	38
Tubewell dia, cm	15	15	20	20
Length of filter, m	24	12	27	27
Pump type	Submersible	Submersible	Submersible	Submersible
Pump capacity, lit/sec	56, 42	56, 42	56	56
Power source	Electricity	Electricity	Electricity	Electricity
Command area, ha	20	24	26	17
Pump owner land, ha	0.60	0.80	2.14	1.33
Water users, no.	55	90	169	120
Average pumping time/season (days)				
Rabi (boro)	83	89	92	87
Kharif I	15	17	13	12
Kharif 2	32	36	27	25
Average pumping time, hr/day				
Rabi (boro)	13.5	14	15.5	13
Kharif I	7	6	8	8.5
Kharif 2	8	10.5	9	7
Conveyance system*	BP, EC	BP, EC	EC, LC	EC, LC

*BP: Buried pipe, EC: Earthen canal, LC: Lined canal

It was 90 at Tanore and 120 at Joypurhat sadar. Average pumping time was more or less 90 days in rabi season, 15 days in Kharif I and about 30 days in Kharif II season. Pump operating time per day was also higher in rabi season and it ranged from 13 to 15.5 hr. In Kharif I and Kharif II seasons pump operating time were 6-8.5 and 7-10.5 hr/day, respectively. Pumping time in both per season and per day was higher in Boro season due to high water consuming boro rice. In Rajshahi, buried pipes are predominantly used for conveying water from pump to field. Some earthen canal also used to deliver water from riser to individual field to be irrigated. But in Joypurhat, conveyance systems were comprised of mainly earthen canals with some lined canals. So, operating days and hours were more in Joypurhat than that in Rajshahi due to more conveyance loss of water in earthen canal that mostly used for water distribution in Joypurhat district.

11.1.1.3. Irrigation pricing systems and cost

Two types of water pricing system exist in the study areas: area-based and time-based. Under area-based pricing system, which is most commonly used in the study areas, farmers paid a fixed fee for a unit area. Area-based pricing system can be fixed either by season basis or by irrigation event basis (Table 11.8). In Godagari, pricing of irrigation was entirely determined by per hour of pumping (time basis). In Tanore, farmers paid the irrigation charge in all systems. They paid fixed fee per unit of land/season for boro rice and potato, fixed fee per irrigation for T.Aman rice and per hour of pumping for mustard, wheat and maize. Fixed rate per cropping season was the only system in Kalai and Joypurhat sadar for all crops.

Table 11.8. Water charging in Taka

Location	Charging basis	Boro	T. Aman	Potato	Wheat/mustard/ Maize
Godagari	Fixed rate per cropping season/area				
	Per hour of pumping	860/ha	860/ha	860/ha	860/ha
Tanore	Fixed rate per cropping season/area	14970/ha or 900 kg paddy/ha		8980-10480/ha	
	Per hour of pumping				130/hr
	Fixed rate per irrigation/area		1500-2250/ha		
Kalai	Fixed rate per cropping season/area	60/decimal	8-10/ decimal	20/decimal	20/decimal for wheat only
Joypurhat sadar	Fixed rate per cropping season/area	7480-8230/ha	1230-3750/ha	20/decimal	5/decimal

The cost of irrigation per hectare differed with the locations and crops (Table 11.9). Irrigation cost was higher for boro rice than all other crops. The cost was almost same at Godagari, Tanore and Kalai for boro rice. Farmers of Godagari reported that they had to pay Tk. 13500 to Tk. 15000 per hectare as irrigation charge for boro rice. It was Tk.15000/ha for both Tanore and Kalai while the charge was almost half (Tk. 7500 – 8250/ha) in Joypurhat sadar. The irrigation charge for T.Aus and T.Aman rice was Tk. 5000 – 6500/ha and Tk. 3750 – 4200/ha respectively in Godagari. At Tanore, this charge was Tk. 4500 – 6750/ha for T. Aus and Tk. 2250 – 4500/ha for T.Aman rice cultivation. This charge for T.Aman rice was lowest in Joypurhat sadar that ranged from Tk. 1250 to Tk. 3750/ha depending on number of irrigation per season. There existed a great difference in irrigation charge for potato cultivation with the highest cost of Tk. 9000 – 10500/ha in Tanore followed by Tk.5000/ha for Kalai and Joypurhat sadar. The cost was much lower (Tk.1200 – 1400/ha) in Godagari than other sites due to time-based irrigation charge system. Among the rabi crops, mustard had the lowest irrigation cost ranged from Tk 1250/ha in Joypurhat sadar to as high as Tk. 1950/ha in Tanore. The irrigation cost for wheat ranged from Tk.2000/ha in Joypurhat sadar to Tk.5000/ha in Kalai.

Table 11.9. Irrigation cost in different study areas

Location	Crop						
	T. Aman	T.Aus	Boro	Mustard	Potato	Wheat	Maize
Godagari	3750-4200	5000-6500	13500-15000	1400-1875	1200-1400	3000	4000-5000
Tanore	2250-4500	4500-6750	15000	1460-1950	9000-10500	3500	2000-3000
Kalai	2000-	3750	15000	NI	5000	5000	-

Location	Crop						
	T. Aman	T.Aus	Boro	Mustard	Potato	Wheat	Maize
	4000						
Joypurhat sadar	1250-3750	3750	7500-8250	1250	5000	2000	-

11.1.1.4. Common problems in irrigation

Various problems of irrigation were identified and presented in Table 11.10. Predominant problem regarding irrigated agriculture was declination of groundwater table in rabi season and it was a common problem in all the study areas. Some other problems in rabi season were lack of rainfall, load shedding, low discharge of pump, conflicts among water users, etc. In Kharif I and Kharif II seasons, farmers wanted to depend on rainfall for T.Aus and T.Aman cultivation but insufficient rainfall compelled them to apply supplemental irrigation. Most of the earthen canals were damaged in T.Aman season, so farmers often faced problems in irrigating their lands. All respondents in Rajshahi district complained about the low discharge while 69 to 76% respondents of Joypurhat were complaining about low discharge in rabi season. Few percentages of respondents in study areas also reported about the pump breakage and burning of motors.

Table 11.10. Common problems of irrigation in different crop seasons in the study areas

Crop seasons	Problems	Respondents (%)			
		Godagari	Tanore	Kalai	Joypurhat sadar
Kharif I & II	Insufficient rainfall	86	90	62	66
	Damaged irrigation canal	52	48	87	91
Rabi (boro) season	Declining of GW table	100	100	100	100
	Lack of rainfall	100	100	100	100
	Load shedding	56	47	29	21
	Voltage up down	26	20	15	18
	Conflicts among water users	17	22	36	27
	Low discharge	100	100	76	69
	Brekage of pump	11	9	4	6
	Burning of motor	16	13	9	11

11.1.2. Component-2: BRRI

11.1.2.1. Existing cropping patterns in the sub-project locations

Pabna had diversified cropping patterns than that of Rangpur. Farmers cultivated vegetable round the year in their high land. However, Boro rice based cropping patterns were found the most dominating pattern in all the four locations of Rangpur and Pabna district. Boro rice covered most of the area during dry season although it consumed more irrigation water than Rabi crops. The respondents replied that family consumption, land topography, soil moisture content above saturation during Rabi period, climatic vulnerability, social issues regarding community crop cultivation approaches, etc. led to Boro rice cultivation despite less benefit from the crop. Rangpur area was covered with more Boro rice than Pabna (Fig. 11.2). Among the cropping pattern, T. Aman-Fallow-Boro covered the maximum area in all the locations (Fig. 11.3). The most common cropping patterns have been given in Table 11.11.

Table 11.11. Widely cultivated existing cropping patterns in the sub-project areas

Rangpur		Pabna	
Mithapukur	**Pirgonj**	**Ishwardi**	**Santhia**
Boro−Fallow−T.Aman Potato−Boro−T.Aman Potato−Fallow−T.Aman Maize−Jute−T.Aman Boro−Fallow−Fallow Mustard−Boro−T.Aman Wheat−Jute−T.Aman	Boro−Fallow−T.Aman Potato−Boro−T.Aman Potato−Fallow−T.Aman Maize−Jute−T.Aman Boro−Fallow−Fallow Mustard−Boro−T.Aman Wheat−Jute−T.Aman	Boro−Fallow−T.Aman Vege. −Vege. −Vege. Mustard−Aus−T.Aman Y_Annual crops Boro−Aus−T.Aman Wheat−Mungbean−T.Aman Wheat−Vegetab−Vegetab	Boro−Fallow−T. Aman Wheat−Jute−T.Aman Onion – Sesame+B.Aman Grasspea−Sesame−T.Aman Mustard−B.Aus+B.Aman Vege. −Vege. −Vege.

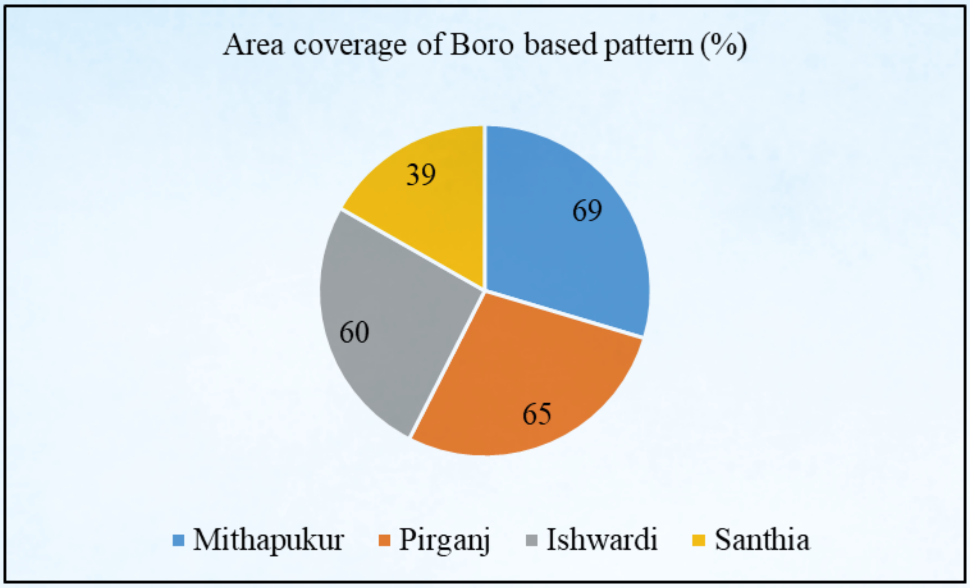


Fig. 11.2. Boro area coverage during dry season

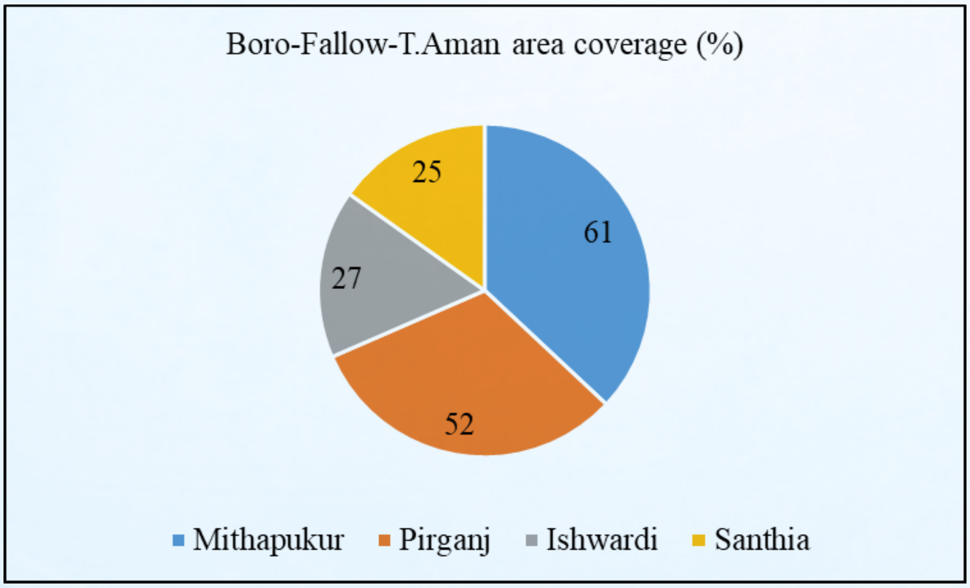


Fig. 11.3. Area coverage by Boro-Fallow-T. Aman cropping pattern

11.1.2.2. Status of irrigation sources and pumping equipment

All farmers opined that they used groundwater for irrigation to their crop field in all four locations of Pabna and Rangpur. Occasionally they used pond water for seed bed preparation. In the surveyed area, no deep tubewell (DTW) was found except shallow tubewell (STW). All STW belongs to private ownership and no STW were under farmer's group or co-operative. The highest 92% STW was operated by electricity at Mithapukur followed by 80% in Pirgonj and 50% in Ishwardi (Fig. 11.4). The lowest 40% electricity operated STW was found in Santhia of Pabna and the rest STWs were diesel operated. The highest average STW depth 47 m was found in Santhia and the lowest (30 m) STW depth was found in Mithapukur, Rangpur (Fig. 11.5). The strainer size of STWs varied from 12 m to 18 m at each location. The highest pump discharge was found 9 l/s and the lowest 4 l/s was found at Pirgonj, Rangpur and Santhia, Pabna, respectively during dry season (Fig. 11.7). All the STWs had less command than its capacity. The highest average (2.5 ha) command area was found in Pirgonj and the lowest (1.2 ha) found in Mithapukur (Fig. 11.6). The farmers orated that this might be due to less withdrawal rate of pumps, excess number of STW installation and highest irrigation application than requirement.

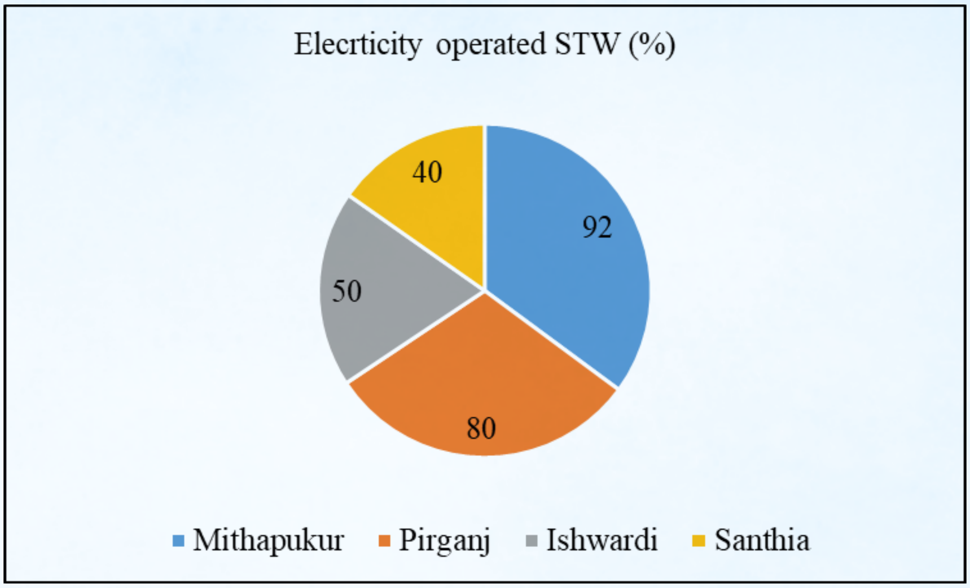


Fig. 11.4. Percent of electricity operated STWs in the project locations

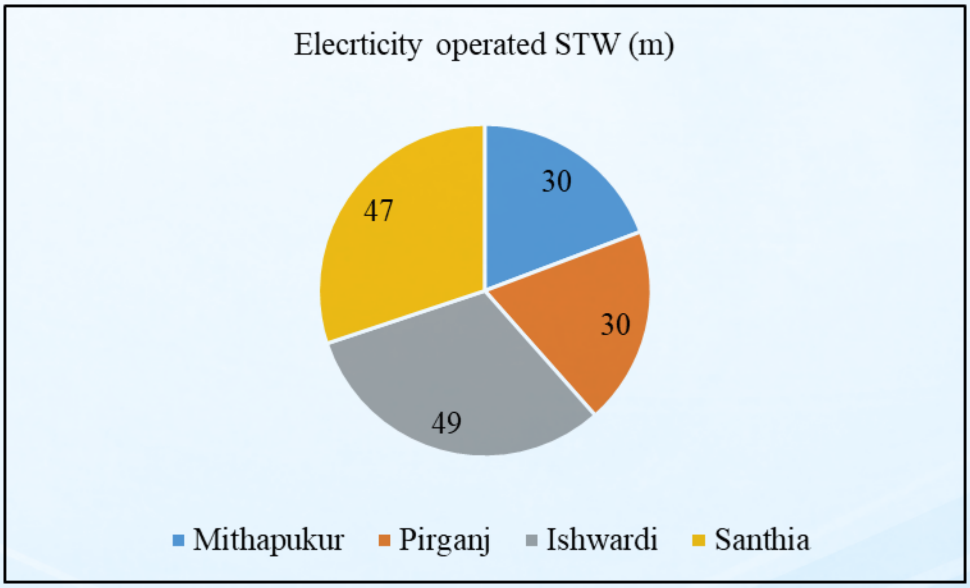


Fig. 11.5. Status of STW depth in the project locations

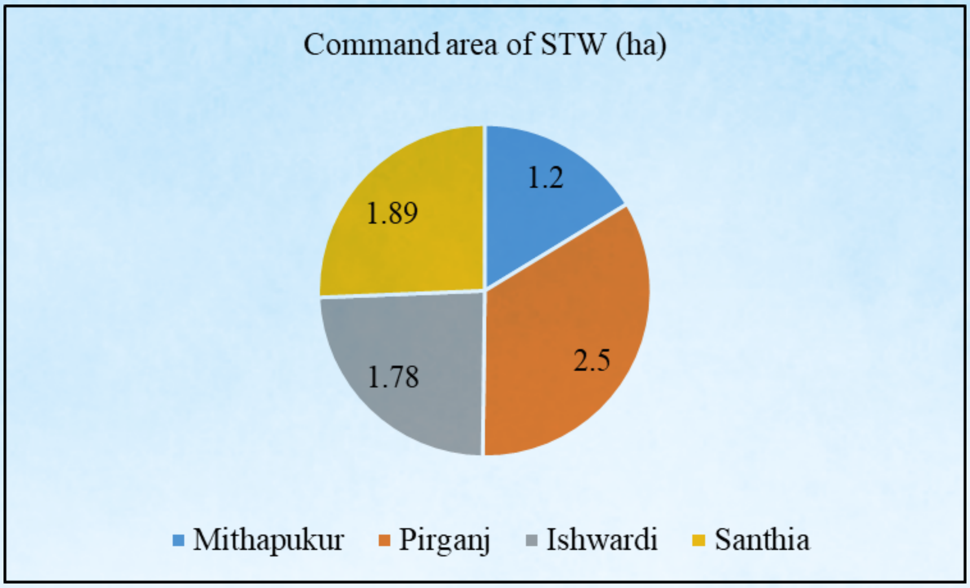


Fig. 11.6. Command area of STWs in the project locations

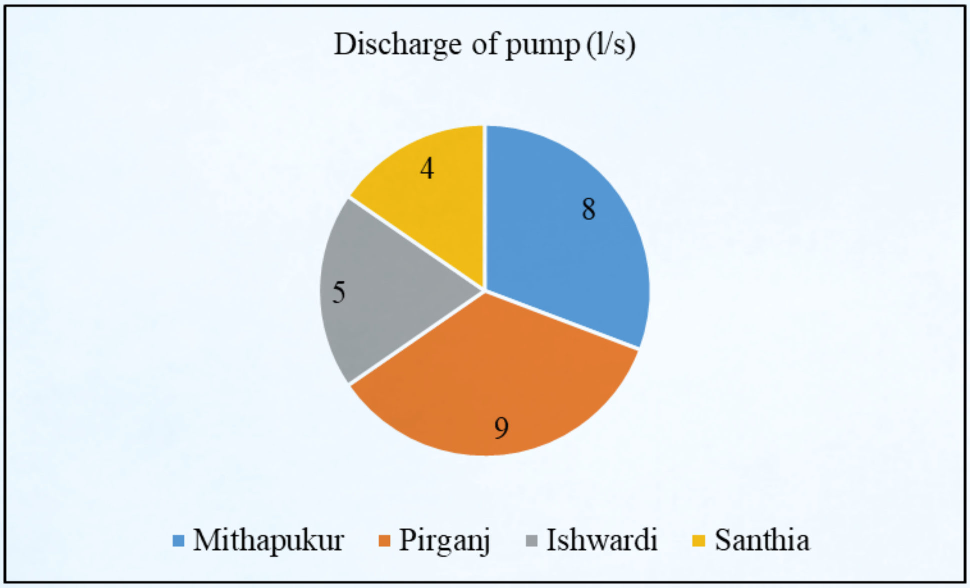


Fig. 11.7. Average discharge of STWs in the project locations

Conveyance loss and irrigation management

No improved water distribution system such as lined canal, buried pipe water distribution, PVC pipe distribution etc. were found in the four study locations. Farmers usually used earthen canal distribution system for irrigation. Thus, the average conveyance loss of water was found the maximum 25% at Ishwardi, Pabna and the minimum 20% at Pirgonj (Fig. 11.8). This was the results of broken distribution channel, poor maintenance, rat damage, severe weed infestation etc. Farmer rarely maintained their distribution canals. It was found that the highest 28 number of irrigations was applied in Pirgonjwhereas; the lowest average 21 irrigation was applied at Mithapukur (Fig. 11.9).

Regarding T. Aman rice farmers followed rainfed rice cultivation method in Rangpur. They have opined that sometimes they faced drought at the later part of the growing period but could not apply supplemental irrigation to mitigate it. Lack of irrigation facilities including nonoperation of pump, farmers' reluctance to irrigation and additional cost involvement led to rainfed rice cultivation. However, they have agreed about moderate to severe yield loss due to water stress. Besides, all farmers in Pabna agreed that they know about the T. Aman drought and faced it almost every year. But few farmers responded that they applied supplemental irrigation where facilities are available. Most of the farmers do not apply irrigations due to lack of facilities and knowledge.

In both the Pabna and Rangpur, farmers opined that they do not maintain levee management around their rice fields.

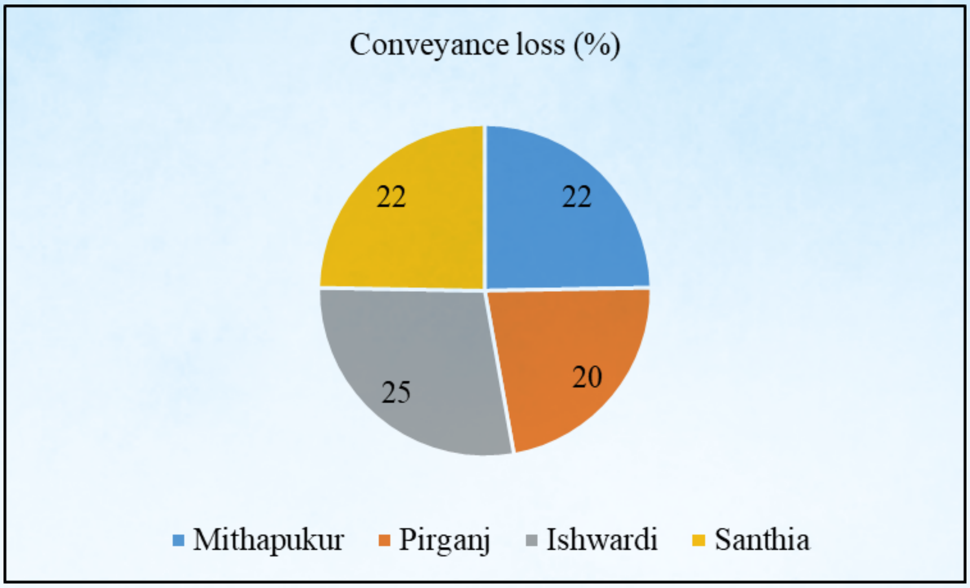


Fig. 11.8. Conveyance loss of water in the project locations

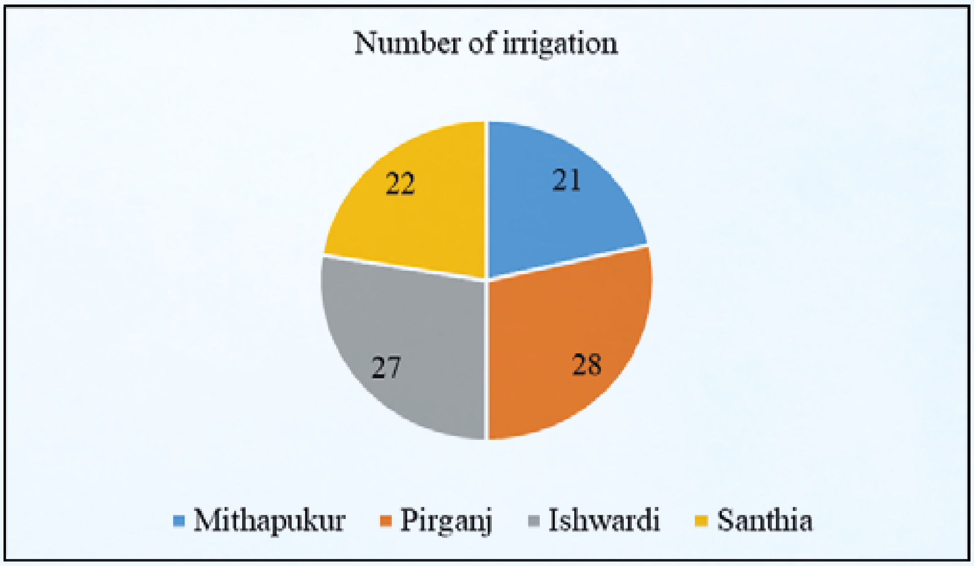


Fig. 11.9. Average number of irrigation in the project locations

Farmers' knowledge about groundwater status

Farmers opined, they didn't face any groundwater shortage during dry season irrigation at both the locations of Rangpur (Mithapukur and Pirgonj). However, less pump discharge was experienced during dry season irrigation at Ishwardi and Santhia of Pabna. Farmers in both the locations of Pabna responded that they had to lower the STW set at 2 to 3 m below the ground surface during dry period (March to May) as groundwater table declined below suction limit. Seventy percent farmers of Rangpur responded that they don't have any idea about groundwater level depletion however the rest

30% said that groundwater level depletion is occurring. All the respondents in Pabna told that they have experienced groundwater level depletion in their area.

Farmers' awareness about water saving technologies

Farmers in both the locations responded that they don't have sufficient knowledge about water management technologies. While, some other farmers opined that they came to know about alternate wetting and drying water management technology from their neighbor farmers and extension workers, but did not apply it to their fields. In Rangpur, the highest 13% and 9% of the respondents in Mithapukur and Pirgonj respectively said that they knew about water saving alternate wetting and drying technology from Department of Agricultural Extension (DAE) through field demonstrations and training. In Pabna, only 33% and 23% of the respondents knew about the AWD technology at Ishwardi and Santhia, respectively (Fig. 11.10).

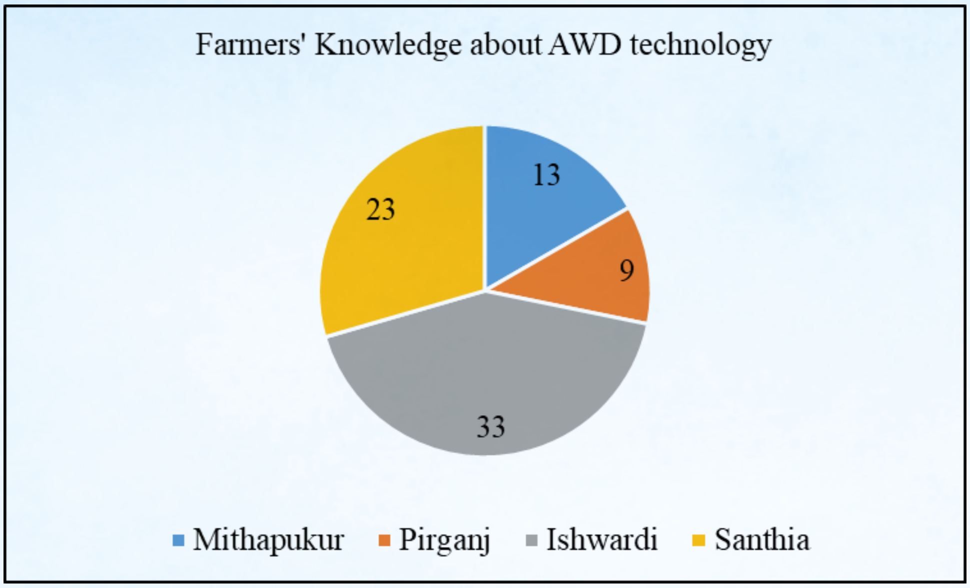


Fig. 11.10. Farmers' perception about AWD tecjnology (% respondent) in the project locations

11.1.2.3. Irrigation pricing system

Irrigation pricing was found on seasonal basis in each location. Farmers had to pay in hand cash for irrigation in Rangpur whereas, both in hand cash and crop sharing pricing were found in Pabna. A large variation of irrigation pricing was observed for rice cultivation. It varied from location to location and pump owner to pump owner. Higher irrigation pricing was observed in Pabna than that of Rangpur (Fig. 11.11). Among the locations, the highest irrigation cost was found in Santhia, Pabna whereas, the lowest cost was found in Mithapukur, Rangpur. Most of the farmers opined that irrigation cost was reasonable in Rangpur. However, all farmers in Pabna said that they had to pay higher cost for irrigation to the pump owner. Other than Boro rice, farmers paid a fixed rate per hour for irrigating Rabi crops.

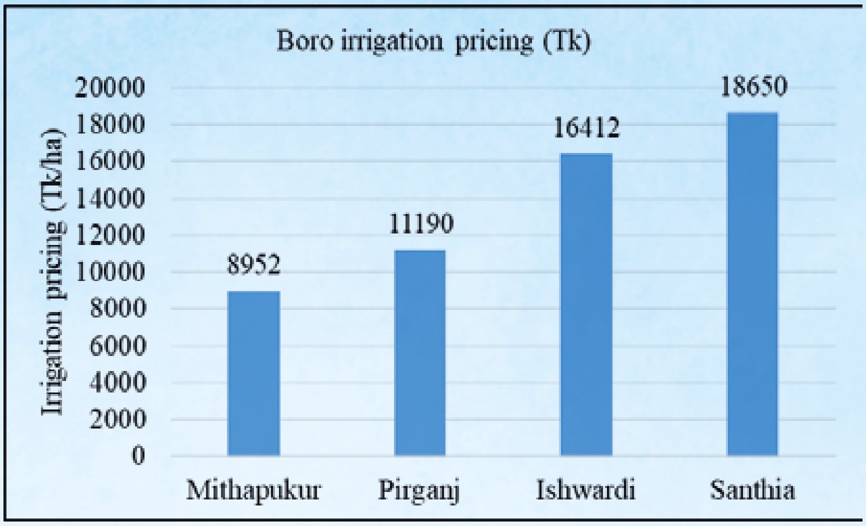


Fig. 11.11. Irrigation cost for Boro rice cultivation in the study region

11.1.2.4. Common problems in irrigation system

Sometimes older rice seedlings were transplanted due to late operation of pump. Farmers could not irrigate Rabi crops and T. Aman rice due to the absence of pumps. Pump operation often remained suspended due to loadsheding. Higher irrigation pricing also increased the production costs. Farmers suffered due to less discharge in April and May due to water level declination in Pabna.

11.1.3. Component-3: BINA

11.1.3.1. Existing cropping patterns in the project areas

Irrigated Cropping Patterns (CP)

There were various types of cropping pattern in the surveyed area of Nachole upazila (Fig 11.12). The most prominent cropping pattern in this area was Aman-Boro-Fallow which wasd about 37.80%. Coverage of Aman-Lentil-Boro cropping pattern was also higher which around 28.9%. Aman-Wheat-Fallow, Aman-Mustard-Fallow, Aman-Lentil-Fallow were also found in the area. The farmers used local as well as modern/high-yielding varieties.

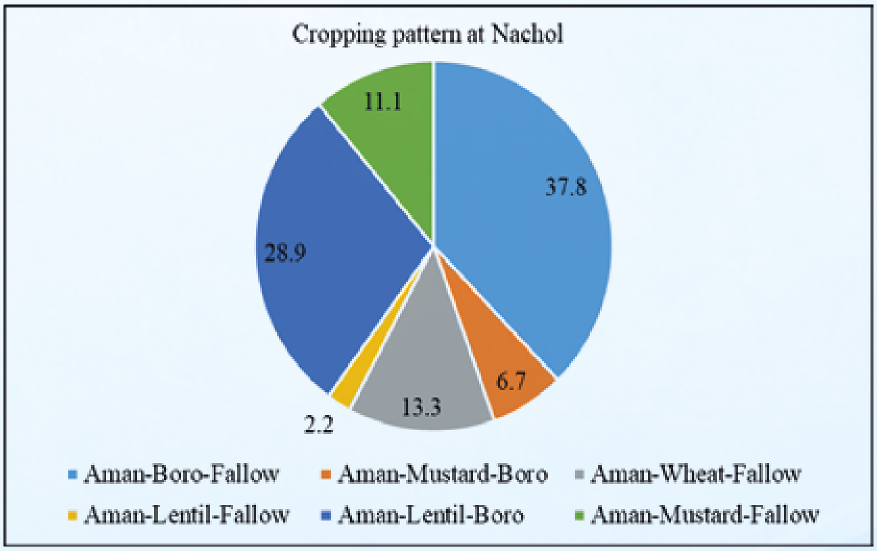


Fig. 11.12. Cropping patterns at Nachole upazila

Among the existing cropping patterns, the major cropping pattern of Niamatpur upazila was Aman-Wheat-Fallow, which was about 41.50%. Coverage of Aman-Boro-Fallow cropping pattern was also higher which around 34.3% (Fig.11.13). Aman-Mustard-Boro, Aman-Mustard-Fallow, Aman-Pea-Fallow, Aman-Lentil-Fallow, Aman-Mustard-Pea were also found in the area. The farmers used local as well as modern/high-yielding varieties.

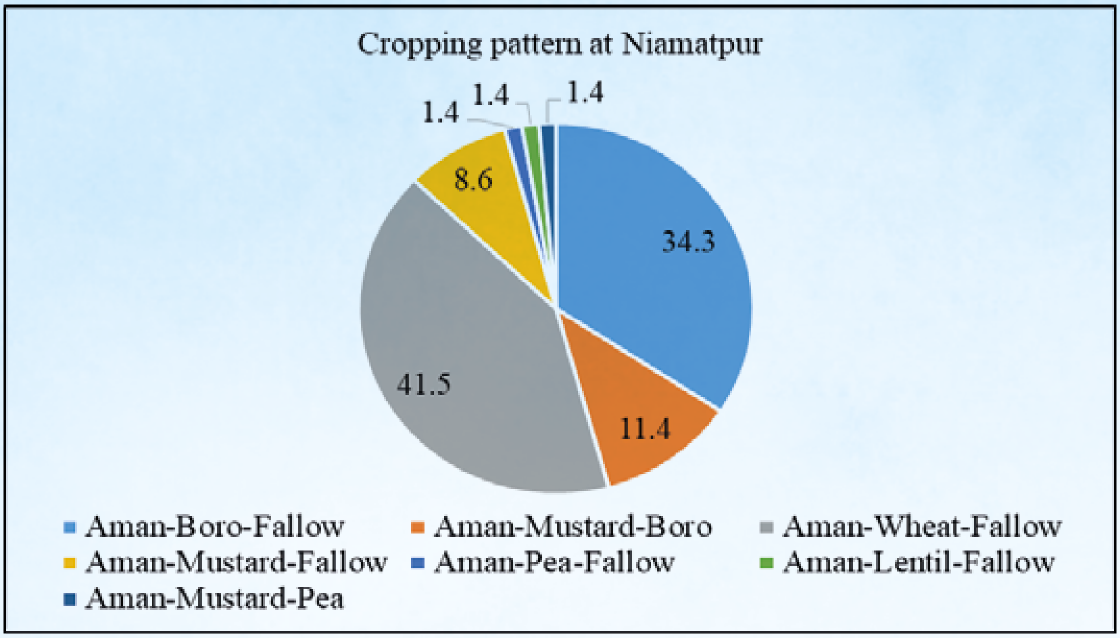


Fig. 11.13. Area coverage (%) under different cropping patterns at Niamatpur upazila

Rainfed Cropping Pattern

The area coverage of rainfed cropping patterns at Nachole was only 27% and that of irrigated cropping patterns was 73% (Fig. 11.14).

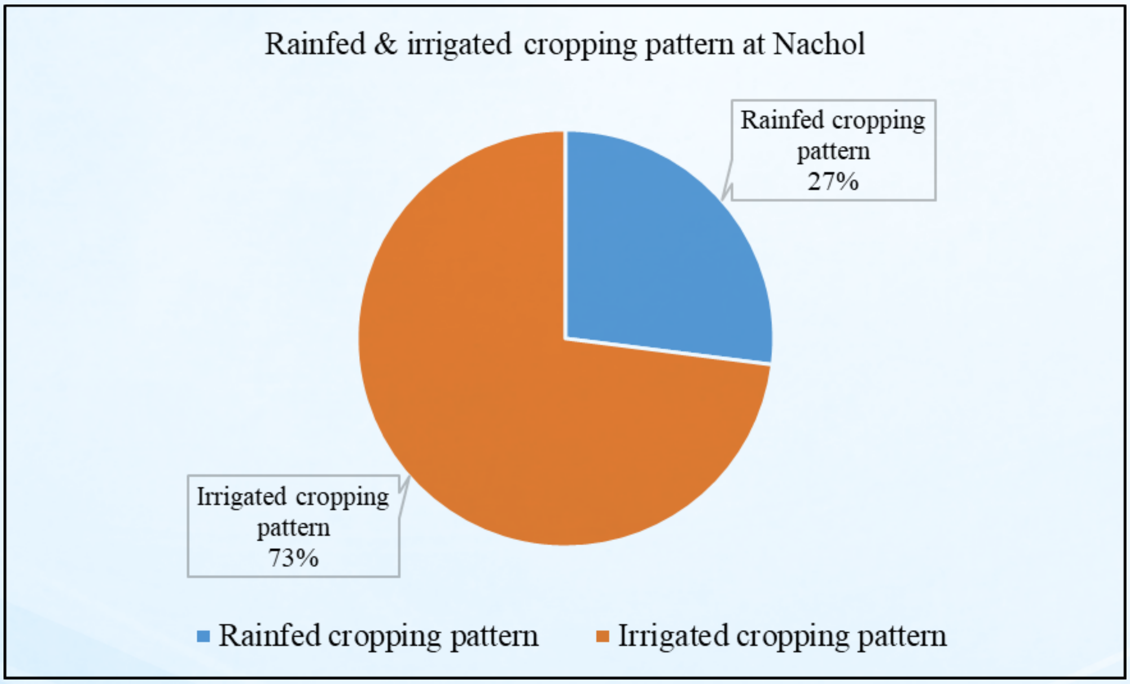


Fig. 11.14. Rainfed and irrigated cropping patterns at Nachole upazila

The area under rainfed cropping pattern at Niamatpur was 54.3% and that of irrigated cropping pattern was 45.7% (Fig. 11.15).

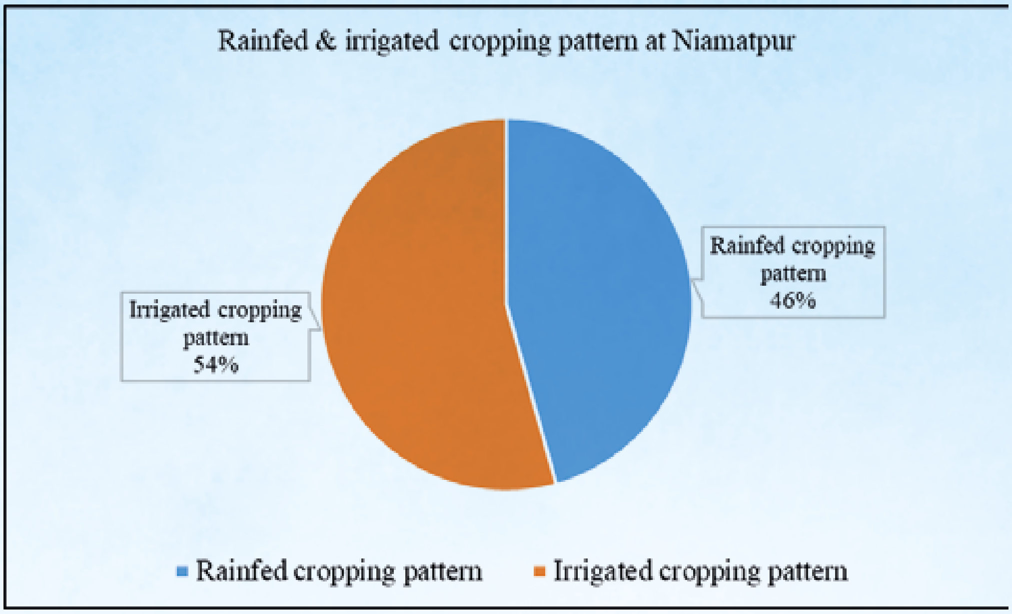


Fig. 11.15. Rainfed and irrigated cropping pattern at Niamatpur upazila

11.1.3.2. Status of irrigation with pumping equipment

Irrigated area under each Pump

On an average, in Nachole area each pump covered around 50 acres (20 ha) land in Rabi season, 1.10 acre (0.44 ha) in Kharif-1 and 55 acre (22.2 ha) in Kharif-2 (Fig. 11.16). The pumps were operated on contract basis using rechargeable card provided by BMDA, with the cost of around Tk. 100-110 per hour.

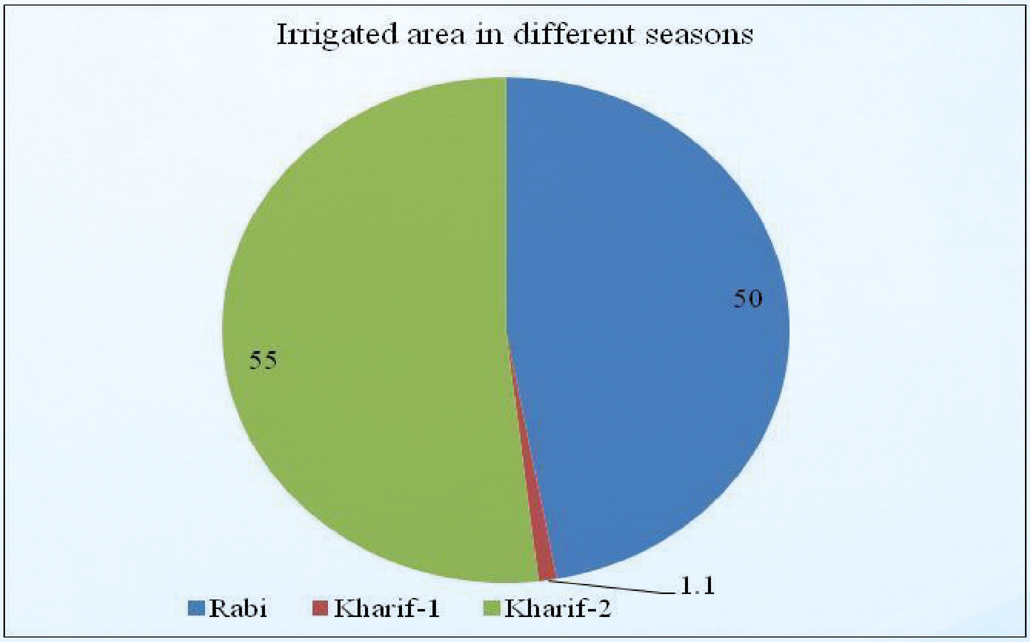


Fig. 11.16. Irrigated area in different seasons under each pump at Nachole upazila

On an average, in Niamatpur area each pump covered around 78 acres of lands in Rabi season, 15 acre in Kharif 1 and 83 acre in Kharif 2 (Fig 11.17). The pumps are operated on contract basis using rechargeable card provided by BMDA, with the cost of around Tk. 100-110 per hour.

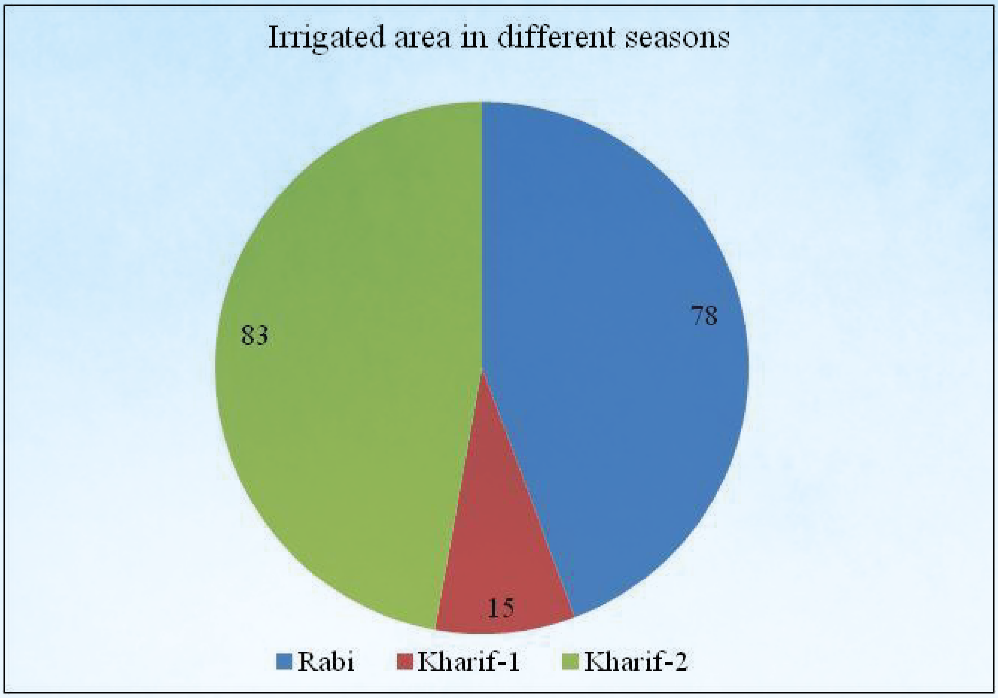


Fig. 11.17. Irrigated area in different season under each pump at Niamatpur

Percent of farmer using pump for irrigation

In Kharif-2 season, about 50.81% farmers and in kharif-1 about 1.32% farmers used pumps in Nachole area. Mostly these pumps were used for irrigating rice field. On the other side in Rabi season, about 47.87 % farmers used pumps for irrigating in Boro rice and other Rabi crops (Fig 11.18).

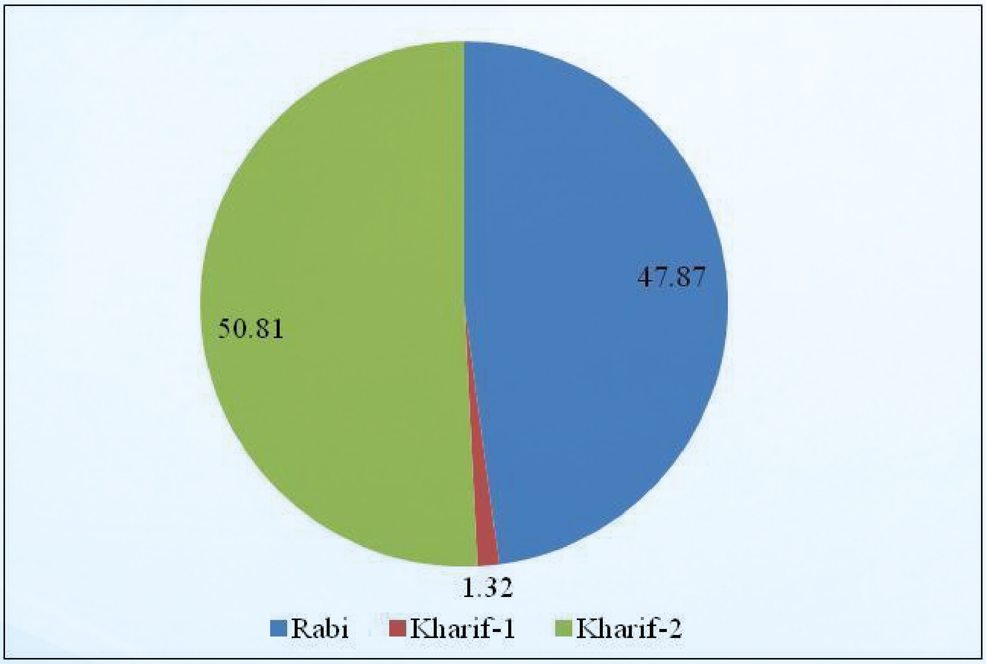


Fig. 11.18. Percent of farmer's using pump for irrigation in different seasons in Nachole

In Kharif-2 season, about 46.32% farmers and in Kharif-1 season, about 9.75% farmers used pump in Niamatpur area. Mostly these pumps were used for irrigating rice field. On the other side in Rabi season, about 43.92 % farmers used pump for irrigating Boro rice and other Rabi crops (Fig.11.19).

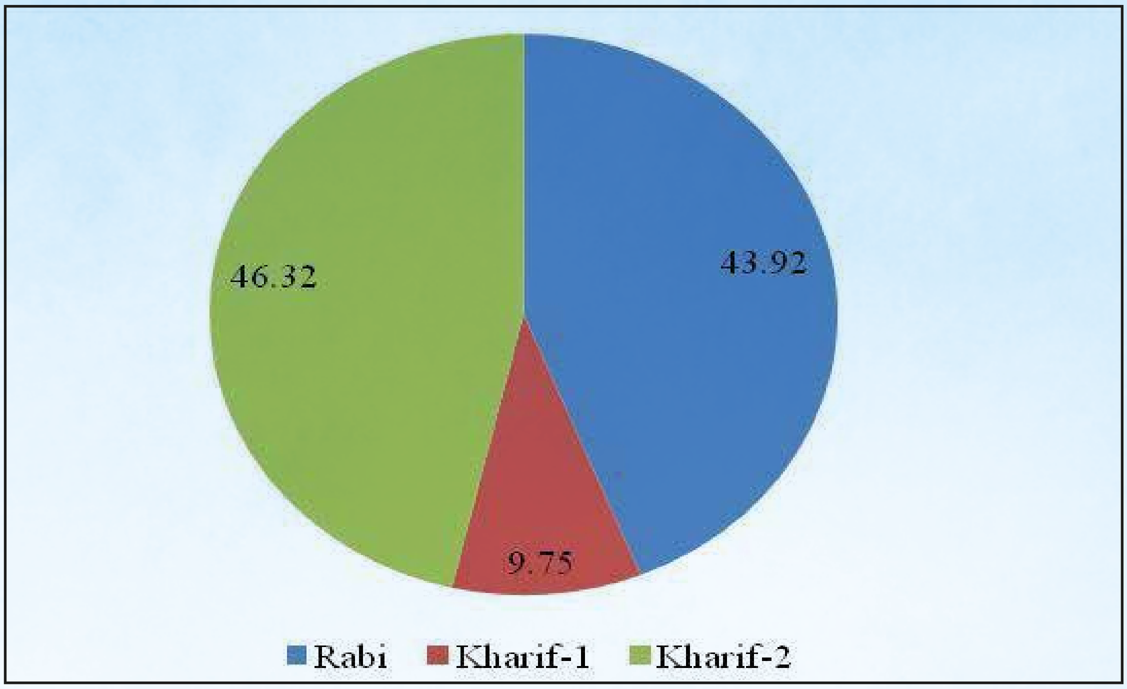


Fig. 11.19. Percent of farmers using pump for irrigation in different seasons in Niamatpur

11.1.3.3. Irrigation pricing systems

Farmers had to pay huge amount of money for irrigating the crop (Fig.11.20). Cost was very high for Boro rice due to higher irrigation requirement

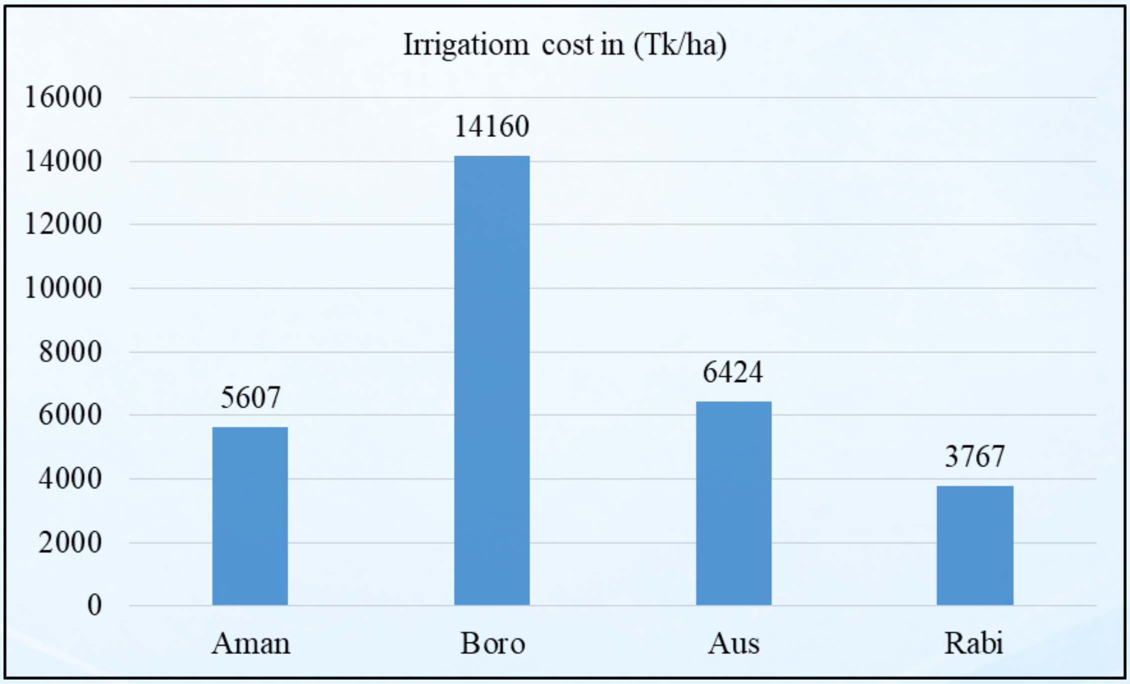


Fig. 11.20. Graphical representation of irrigation cost in the study area

11.1.3.4. Common problems in irrigation

There were various common problems, faced by the farmers during crop cultivation. It as found that groundwater layer depleted downward in Boro season. Irrigation water supply was not sufficient in Boro season and irrigation cost was also high. As demand of irrigation was high, so, getting water in time was very difficult. DTWs were not sufficient to irrigate all the crop land. In addition, most of the irrigation channels were earthen.

11.2. Groundwater availability and recharge assessment

11.2.1. Component-1: BARI

11.2.1.1. Trend of groundwater level fluctuation

Predicted response over the validation data's time span at the observation wells of Tanore, Godagari, Joypurhat sadar, andKalai upazilas were illustrated in Figures 11.21, 11.22, 11.23, and 11.24, respectively.

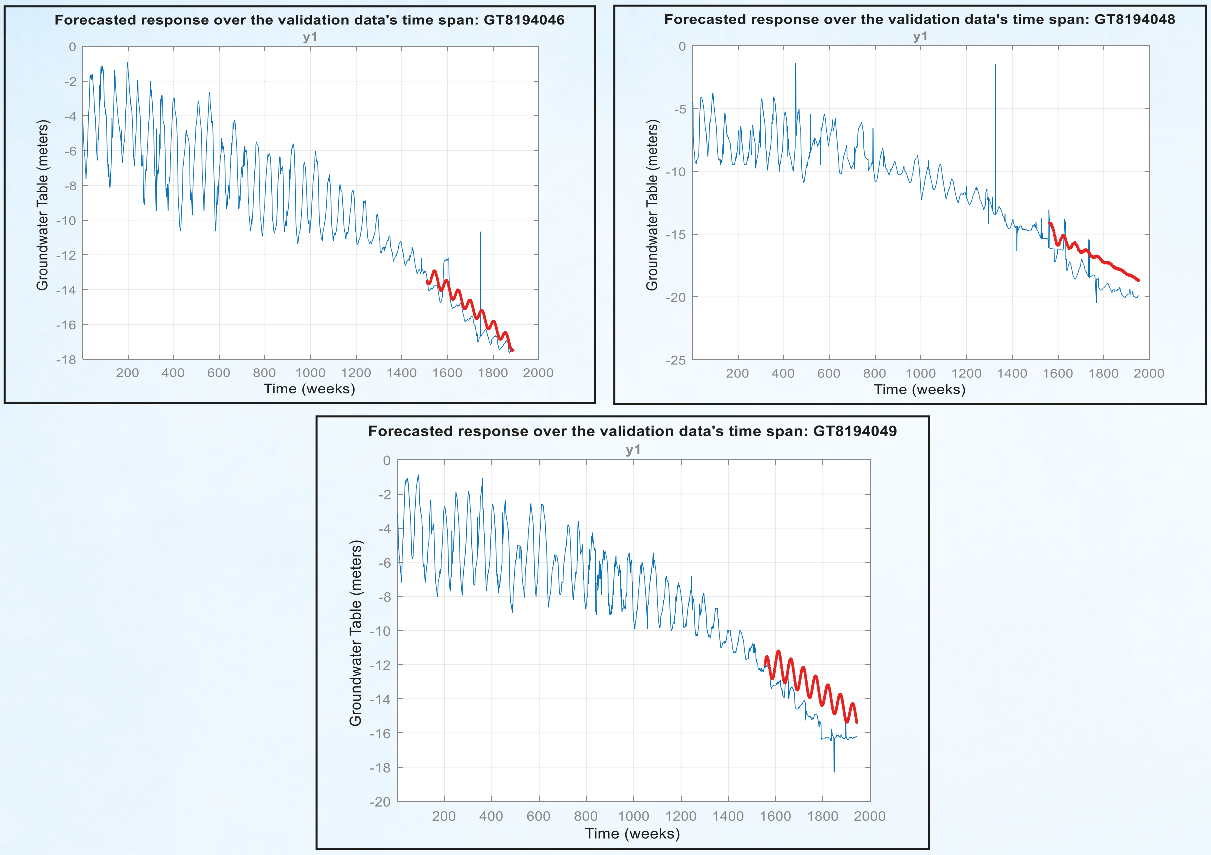


Fig. 11.21. Predicted response over the validation data's time span at observation wells GT8194046, GT8194048, and GT8194049 of Tanore upazila

The plot showed that the model response overlaps the measured value for the validation data. The combined prediction and forecasting results indicated that the model represented the measured water level data. Figure 11.21, 11.22, 11.23 and 11.24 showed that there were relatively good agreements between the simulated and observed groundwater levels for all the developed models at the selected observation wells in the four upazilas. Thus, it was practically possible to develop groundwater forecasting models using this data-driven approach. However, there were discrepancies in matching some of the peak events, where the events may be under predicted or over predicted values. The forecasting results also showed that over large horizons the model variance is large and for practical purposes future forecasts should be limited to short horizons. For the water level prediction model, a horizon of 22 years is appropriate given the previous data available is only for 38 years.

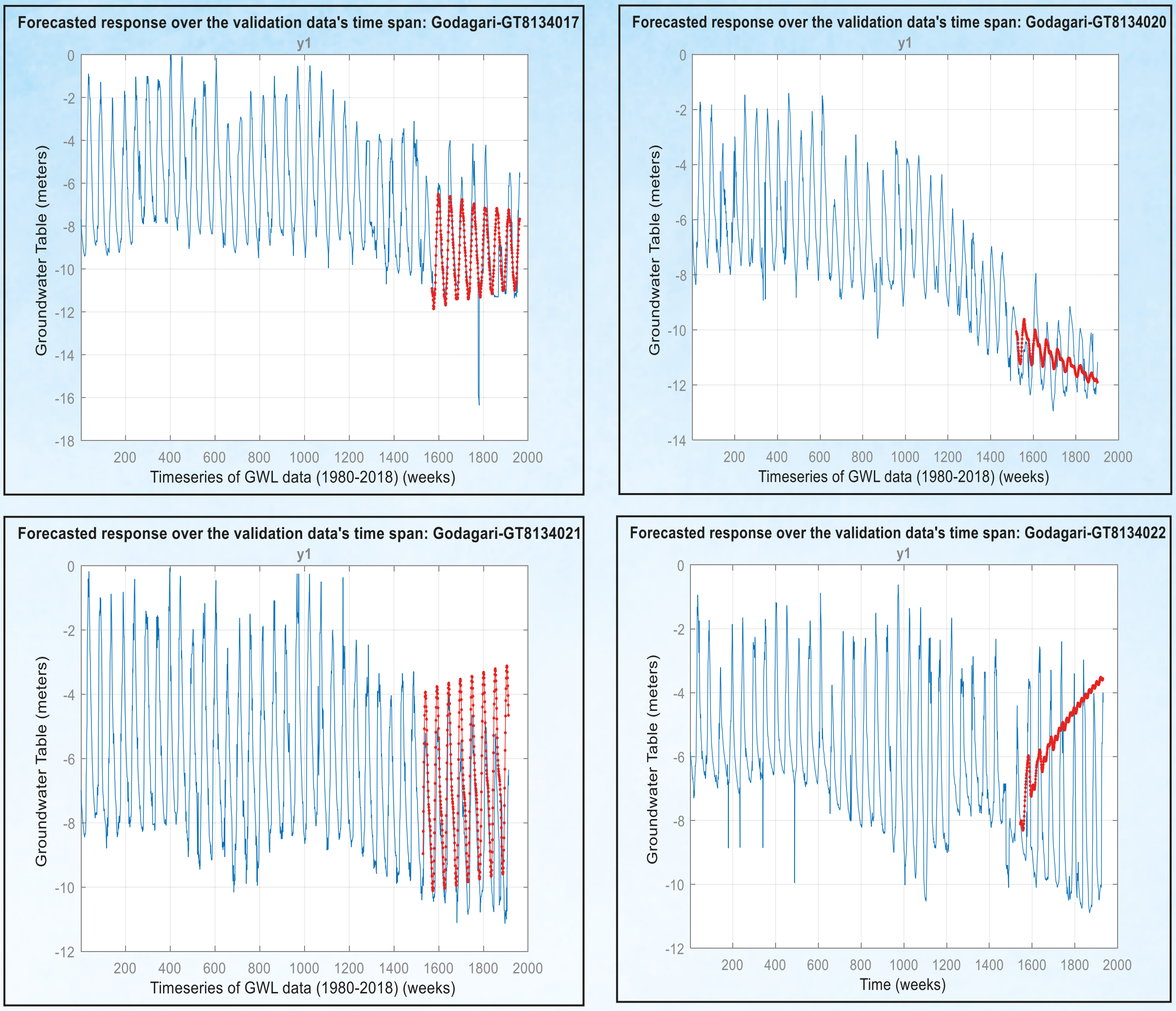


Fig. 11.22. Predicted response over the validation data's time span at observation wells GT8134017, GT8134020, GT8134021, GT8134022 of Godagari upazila

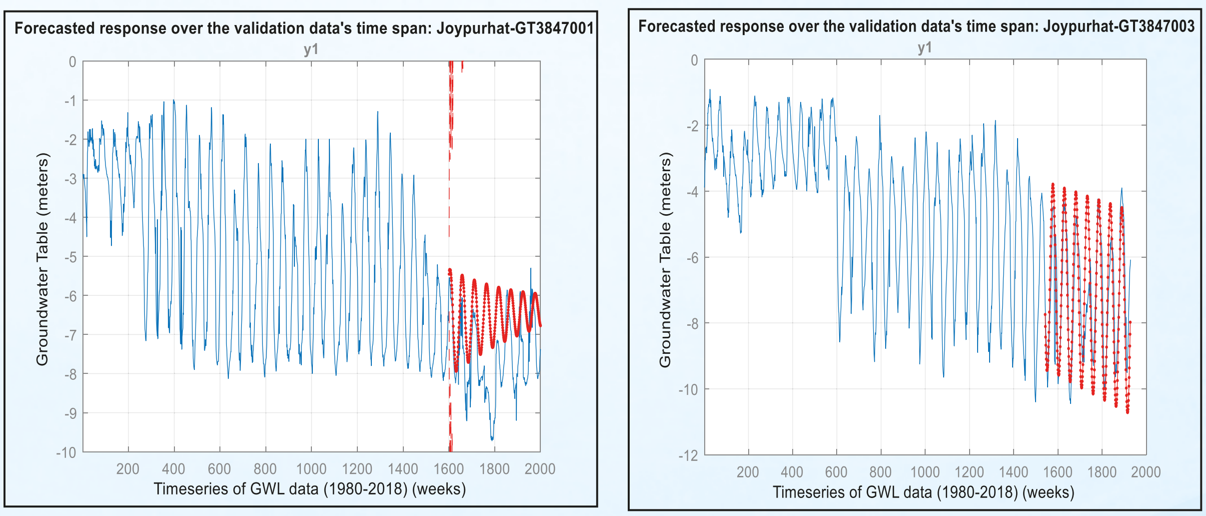


Fig. 11.23. Predicted response over the validation data's time span at observation wells GT3847001 and GT3847003 of Joypurhat sadar upazila

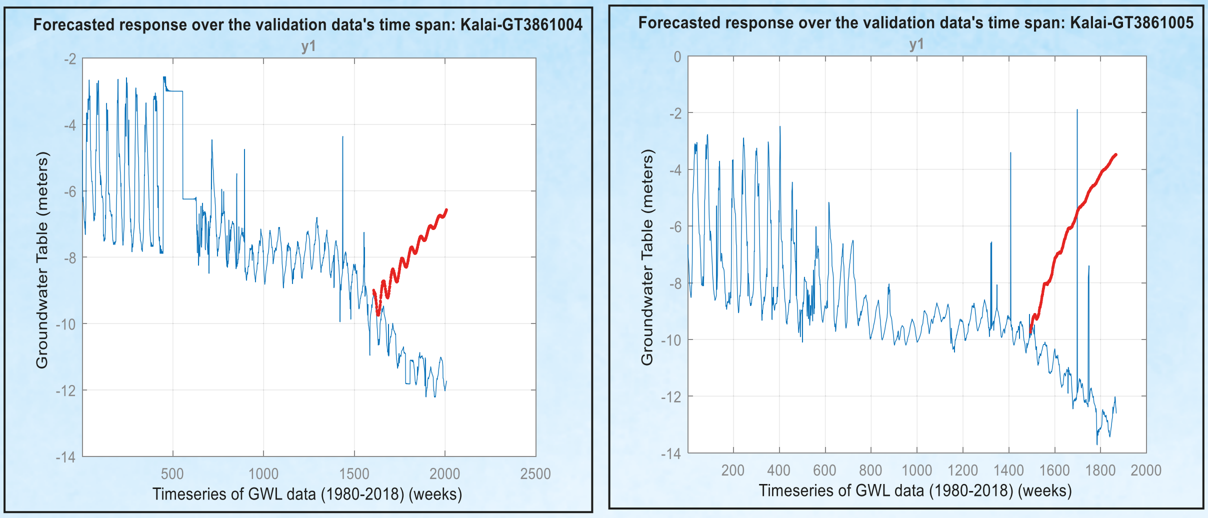


Fig.11.24. Predicted response over the validation data's time span at observation wells GT3861004 and GT3861005 of Kalai upazila

The properly trained and validated models were then used to forecast the response 1105 steps into future for the time span of 22 years (From 25/09/2018 to 24/09/2040). The forecasted results were presented in Figures 11.25, 11.26, 11.27 and 11.28 respectively for Tanore, Godagari, Joypurhat sadar, and Kalai upazilas. In these figures, the green curve showed the measured identification data whereas the blue curve showed the measured validation data that spans over 1-1900 weeks. The red curve is the forecasted response for 1105 weeks beyond the measured data's time range.

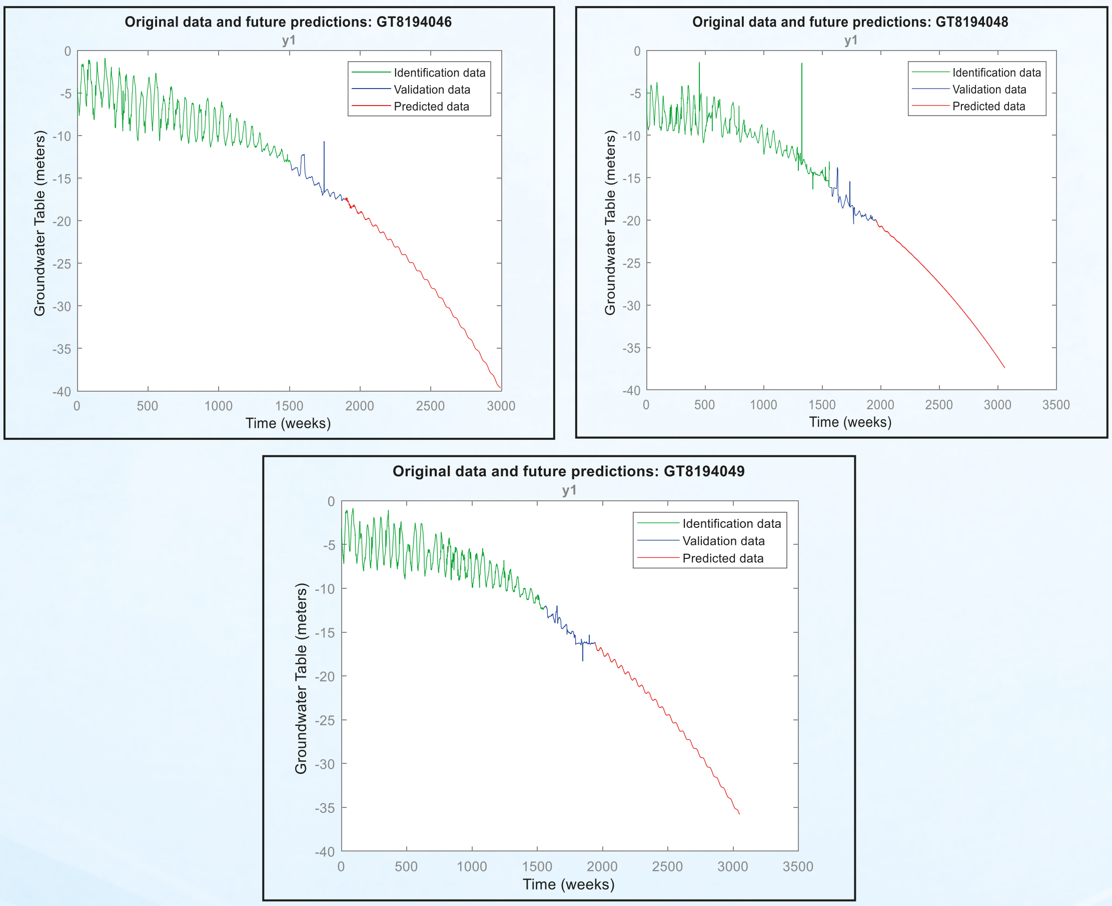


Fig. 11.25. Original and future predicted data at observation wells GT8194046, GT8194048, and GT8194049 of Tanore upazila

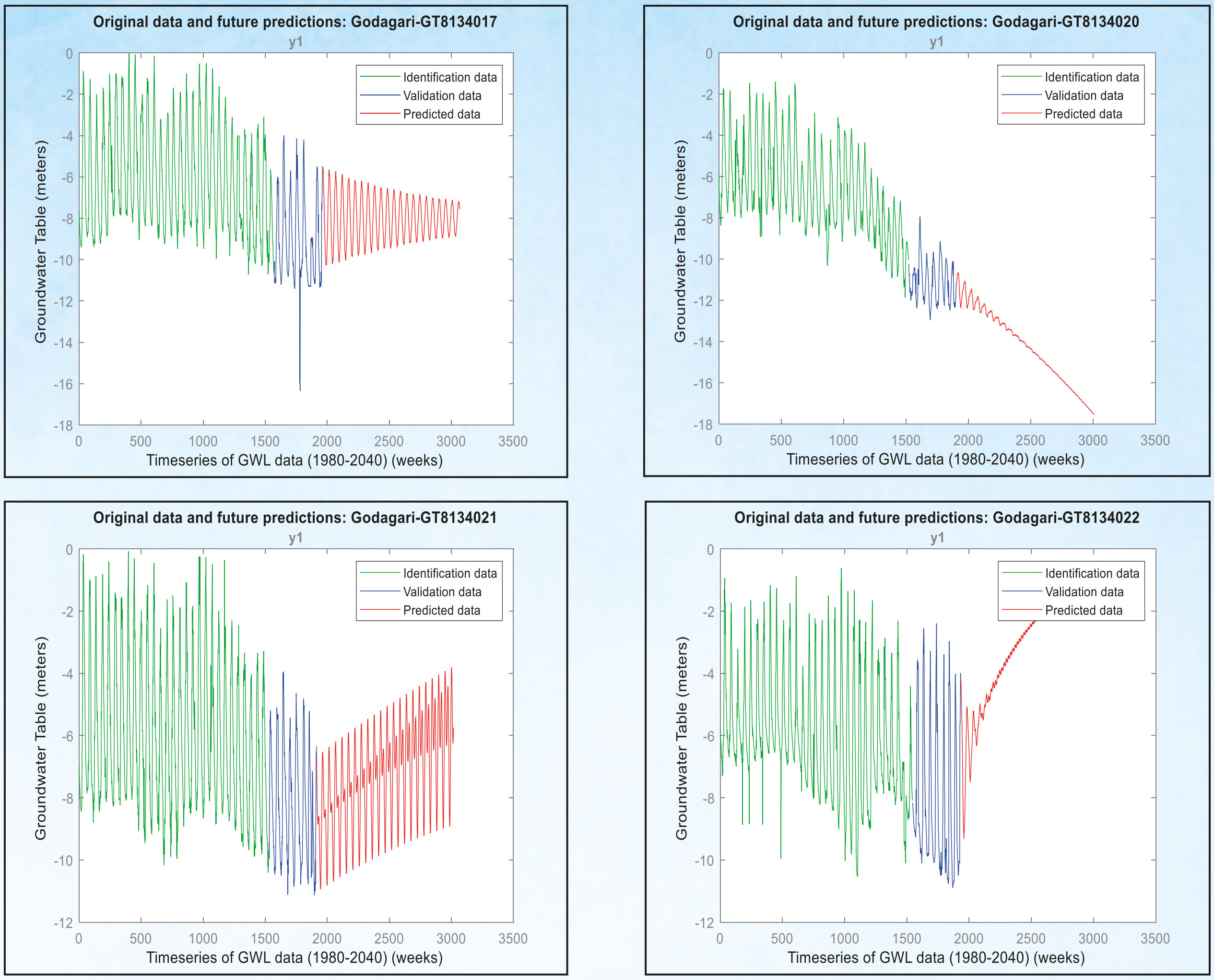


Fig. 11.26. Original and future predicted data at observation wells GT8134017, GT8134020, GT8134021, GT8134022 of Godagari upazila

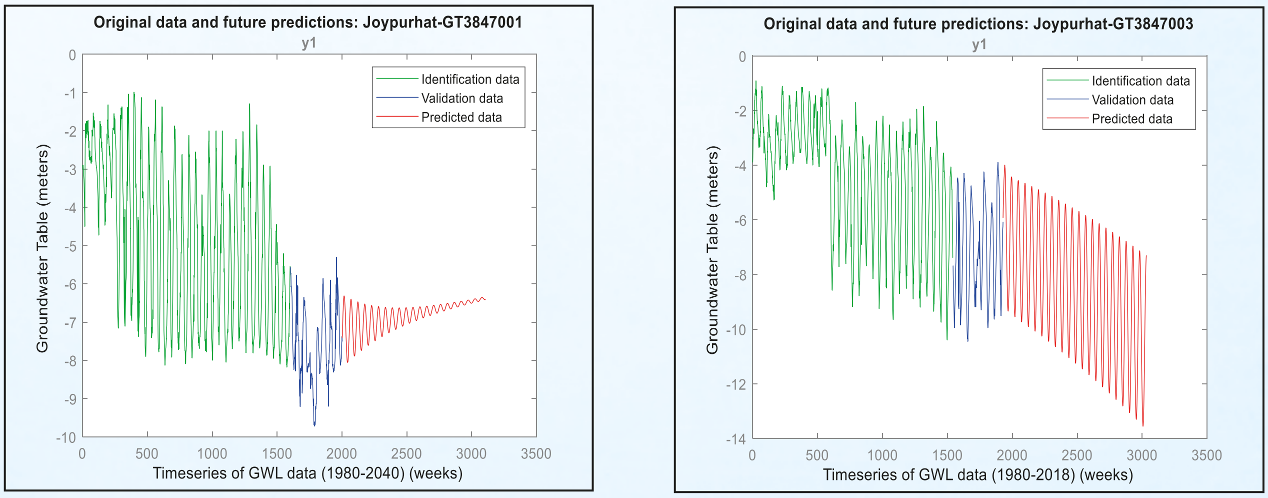
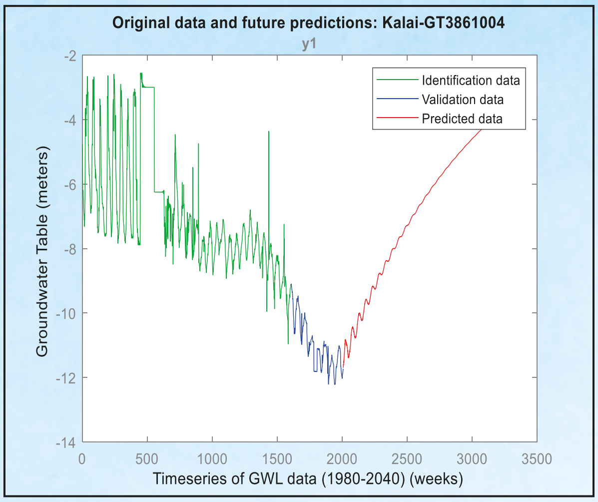


Fig. 11.27. Original and future predicted data at observation wells GT3847001 and GT3847003 of Joypurhat sadar upazila



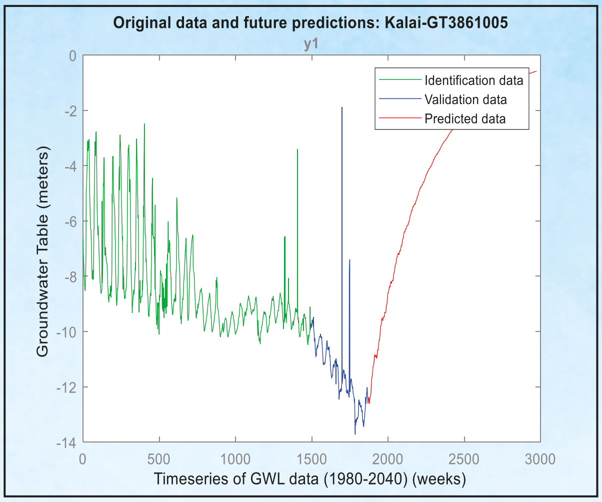


Fig. 11.28. Original and future predicted data at observation wells GT3861004 and GT3861005 of Kalai upazila

Figures 11.29, 11.30, 11.31 and 11.32 illustrated groundwater level at the selected observation wells on 24/09/2018 and the projected (model predictions) groundwater table on 24/09/2040. It is perceived from Figure 11.29 that groundwater level declination will be almost double at all the three observation wells of Tanore upazila for the next 22 years if the present rate of abstraction is continued. In Godagari, Joypurhat sadar, and Kalai upazila, the future trends of groundwater level fluctuations were quite interesting as obtained by the modelling results. While the groundwater level declination was found obvious in few observation wells, the groundwater levels showed rising trends in some observation wells. The rising trend in groundwater levels in some observation wells indicated the recent initiatives adopted by the authority in imposing the constraints of the maximum withdrawal limits. It was concluded that the proposed modeling framework can serve as an alternative approach to simulating groundwater level change and water availability, especially in regions where subsurface properties are unknown.

Of note, the forecasting results were entirely based on the historical groundwater level data based on the previous abstraction and recharge rates. As the increasing demand of water is triggering more and more groundwater abstraction from the aquifer and the recharge rate is decreasing due to scanty rainfall in that area, the groundwater level declination might be even more dangerous than the projected ones if corrective measures are not taken. Moreover, the sticky clay subsurface of the study area slows down the natural recharge to the aquifer. Therefore, groundwater abstraction should be judiciously optimized in the study area to protect the already vulnerable groundwater resources.

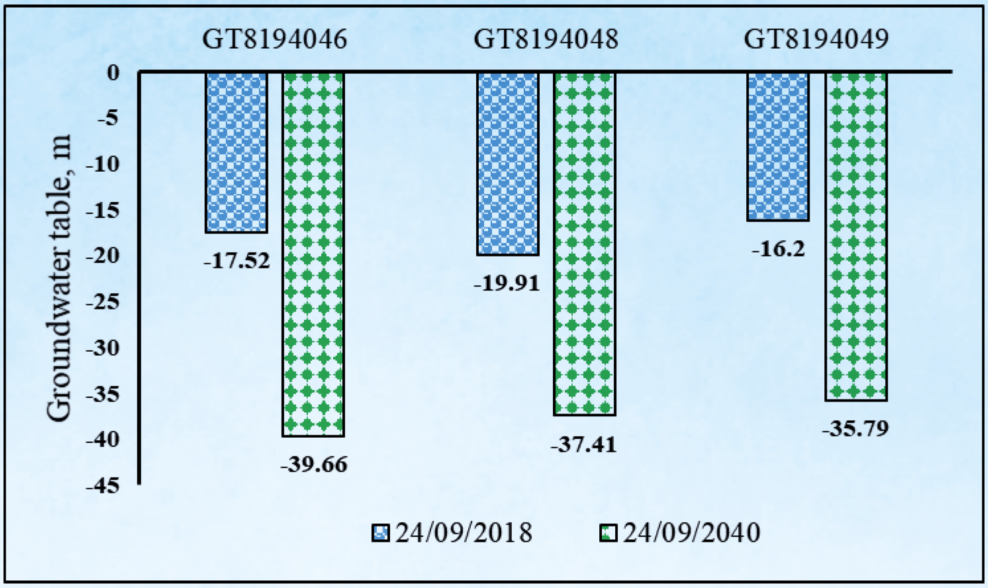


Fig. 11.29. Present and future scenarios of groundwater table at three observation wells of Tanore upazila

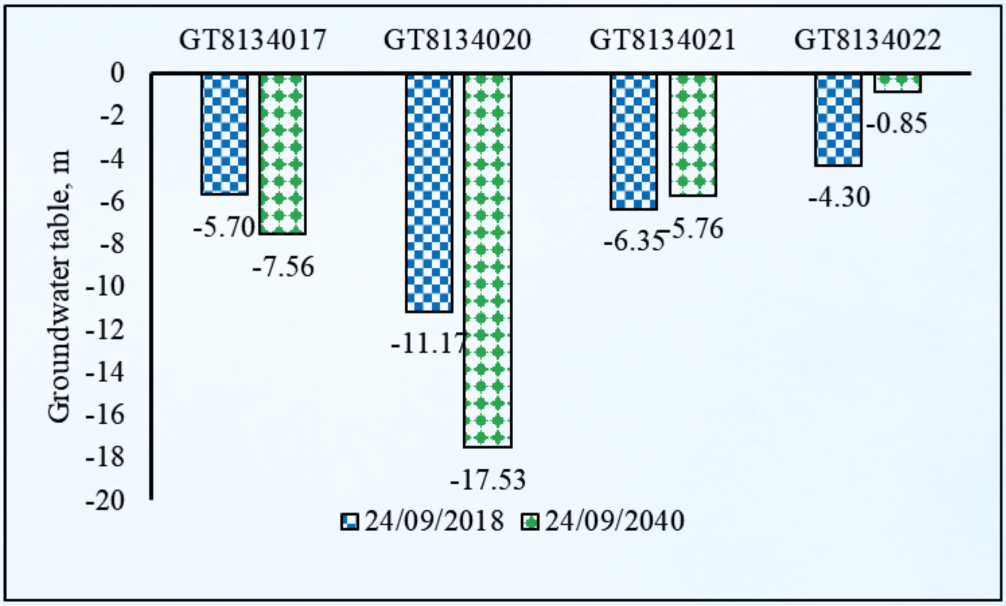


Fig. 11.30. Present and future scenarios of groundwater table at four observation wells of Godagari upazila

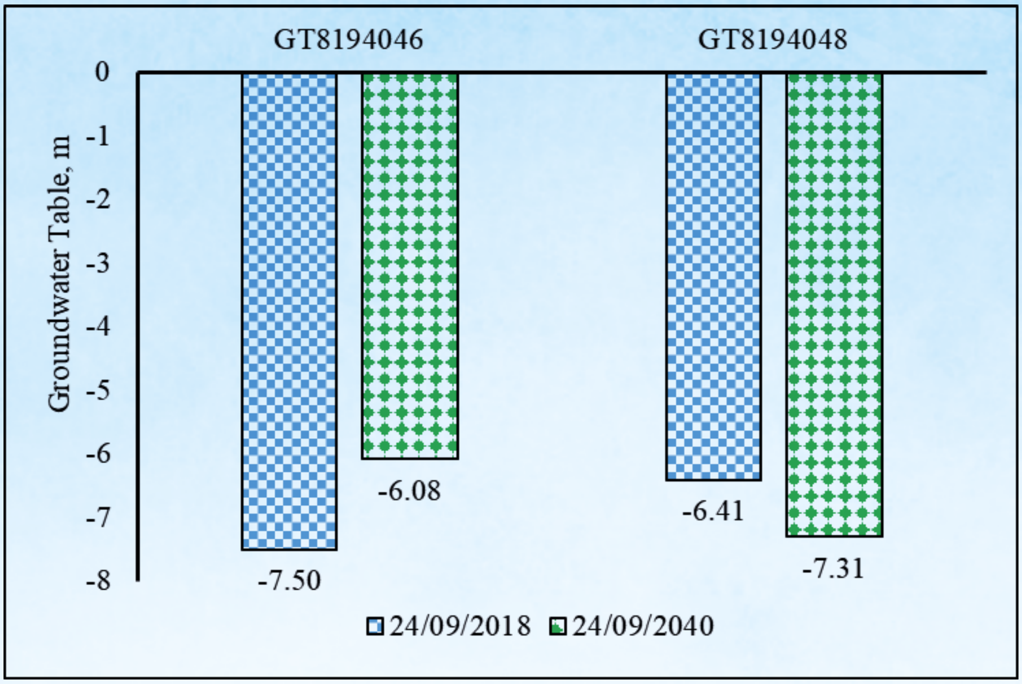


Fig. 11.31. Present and future scenarios of groundwater table at two observation wells of Joypurhat sadar upazila

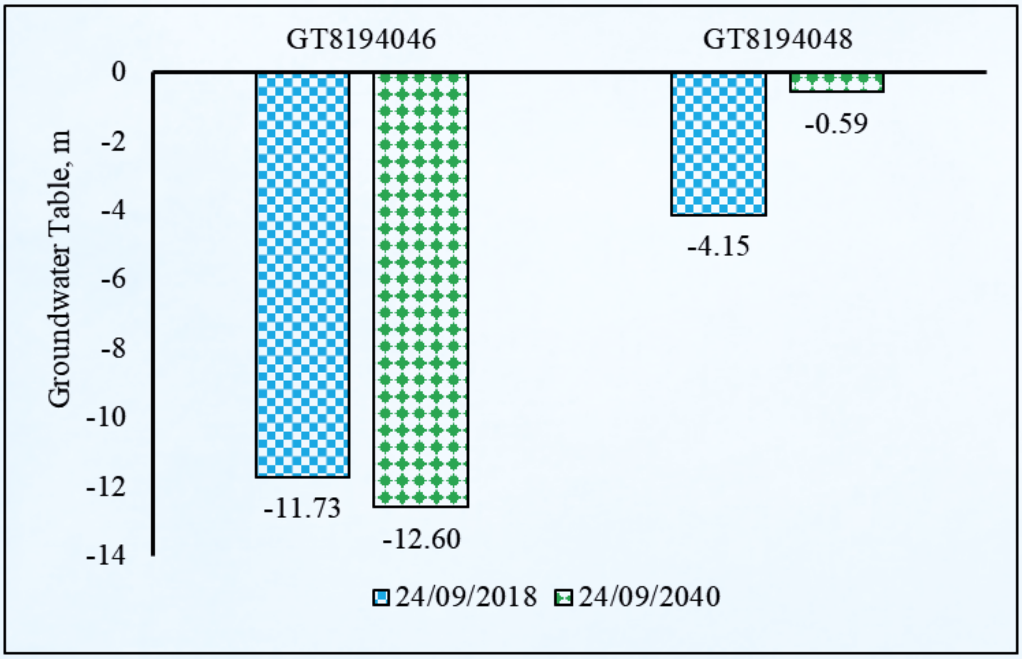


Fig. 11.32. Present and future scenarios of groundwater table at two observation wells of Kalai upazila

The present study investigated the accuracy of the discrete Space-State modelling approach for forecasting weekly groundwater levels. The core idea was to develop a dynamic prediction model using the prediction focused approach to accurately forecast future groundwater levels at specified observation wells. The models were developed using the historical groundwater level data of the study area. The combined training, validation and forecasting results indicated that the model represented the measured water level data quite accurately. Therefore, the modelling approach presented in this report can be used as an alternative to the complex numerical simulation models in data scarce situations. A univariate time series of groundwater level analysis has been performed and presented in this report. Future studies may aim to consider a multivariate time series analysis that considers the effects of other hydrogeological parameters for groundwater level predictions.

11.2.1.2. Anaslysis of groundwater level analyzed by MAKESENS model

Trend in GWL fluctuation analysis was conducted following MAKESENS Model as presented in Table 11.12. The analysis was not continued for other locations due to difficulties as outlined in foot note below the table 11.12.

Table 11.12. Rate of change of maximum water table depth (myear^{-1}) and prediction of maximum water table depth (m) at Tanore, Rajshahi

Observation well	Rate of change of maximum water table (myear^{-1})	Maximum WT (m) deplition from 1980 to 2018	Maximum WT depth (m) in 2018	Prediction of maximum water table (WT) depth (m) in different year			
				2025	2030	2035	2040
GT8194046	0.300 ***	11.40	17.25	19.35	20.85	22.35	23.85
GT8194048	0.390 ***	14.82	20.83	22.93	24.88	26.83	28.78
GT8194049	0.298 ***	11.32	16.54	18.64	20.13	21.62	23.11

Foot note:

- 3*38 = 11.4, 17.25 + (7*0.3) = 19.35, 17.25 + (12*0.3) = 20.85 and so on…
- Linear interpolation based on the rate of change of maximum water table
- Real systems are not that much straightforward
- Cannot act as an alternative to Numerical simulation in data scarce situations

11.2.1.3. Groundwater quality assessment

The chemical compositions of the groundwater samples collected in pre-irrigation and post-irrigation season were presented in Tables 11.13 and 11.14, respectively. The pH value was found slightly higher in post-irrigation season than pre-irrigation season. The pH values of groundwater samples in the study area ranged from 7.11 to 7.36, and 7.22–7.54 for pre- and post-season irrigation periods respectively. The high pH value indicated the slight alkalinity of water, possibly due to the presence of appreciable amounts of sodium, calcium, magnesium, and carbonate ions (Rao *et al*., 1982). All the samples conform to FAO standard of pH value of 6.5 – 8.4 for irrigation use. The range of electrical conductivity (EC) was 0.36 – 0.58 dS/m in pre-irrigation season and 0.48 – 0.66 dS/m in post-irrigation season. Over the seasons, EC value of groundwater of the study area ranged from 0.36 to 0.66 dS/m with an average value range 0.47 – 0.57 dS/m, which according to Wilcox (1955) falls within the irrigation water quality classification stand 'excellent to good'. In terms of the 'degree of restriction on use', EC value of < 700 μS/cm refers the water to 'none'; 700-3000 μS/cm 'slight to moderate' and 3000 μS/cm 'severe' (UCCC, 1974). It was easily presumable from the EC values in Table 11.13 and 11.14, that all water samples of the study area were suitable for irrigation purpose as it falls under category 'none' (UCCC, 1974).

The concentrations of Na^+, Ca^{++}, Mg^{++}, and K^+ in water samples varied respectively in the ranges of 9.44-17.67, 18.34-21.27, 2.10-3.20 and 2.12-2.70 mg/L in pre-irrigation season and in the ranges of 11.02-18.86, 18.34-21.27, 3.46-5.52 and 2.22-2.74 mg/L in post-irrigation season. Recommended maximum concentrations of Na^+, Ca^{++}, Mg^+ and K^+ for long-term irrigation use on all soils were 200, 200, 100 and 10 mg/L, respectively (Ayers and Westcot, 1985). Therefore, all the samples in the study area can be used safely for long-term irrigation.

One of the toxic major ions in irrigation water is chloride (Bouderbala 2015). Chlorides are not absorbed or held back by soils; therefore, it moves readily with the soil-water, and is taken up by the crops, moves in the transpiration stream and accumulates in the leaves.

Table 11.13. Mean quality parameters of groundwater at different study sites during November -December 2018 (pre-irrigation season)

Location	Parameters, mg/L except pH											
	Source	pH	EC (dS/m)	PO_4-	K	NO_3-	Cl-	Na	Ca	Mg	HCO_3-	SO_4-
Godagari	DTW (n=6)	7.24	0.42	0.72	2.20	0.64	1.57	14.14	31.27	2.12	191.23	7.48
	STW (n=4)	7.33	0.46	0.80	2.34	0.68	1.38	16.12	34.78	3.20	202.54	8.12
Tanore	DTW(n=5)	7.11	0.36	0.63	2.14	0.76	1.47	15.06	36.42	2.66	205.39	7.66
	STW (n=3)	7.22	0.48	0.82	2.16	0.72	1.49	17.67	19.36	2.72	229.56	7.92
Kalai	DTW n=8)	7.15	0.54	0.54	2.54	0.68	1.63	11.32	37.07	2.54	200.56	8.07
	STW (n=2)	7.23	0.58	0.62	2.70	0.66	1.67	13.46	28.68	2.58	205.39	8.84
Joypurhat sadar	DTW(n=6)	7.17	0.49	0.65	2.12	0.74	1.42	9.44	39.34	2.10	198.66	9.28
	STW (n=2)	7.36	0.48	0.74	2.32	0.82	1.32	10.36	32.64	2.88	222.38	9.74
Range		7.11-7.36	0.36-0.58	0.54-0.82	2.12-2.70	0.64-0.82	1.32-1.67	9.44-17.67	18.34-21.27	2.10-3.20	191.23-229.56	7.66-9.74
Average		7.23	0.48	0.69	2.32	0.71	1.49	13.45	32.45	2.60	206.96	8.39

If the chloride concentration in the leaves exceeds the tolerance of the crop, injury symptoms develop, such as leaf burn or drying of the leaf tissue, yellowing of leaf and spotting on the leaf. High content of Cl- in water also limits its use in sprinkler irrigation. In the present study, chloride concentration varied from 1.32-1.67 in pre-irrigation season and 1.58-1.81 mg/L in post-irrigation irrigation, respectively which fall under excellent category according to Ayre and Westcot (1985). The upper limit of NO_3^- , SO_4^{--} and HCO_3^- was 0.84, 9.94 and 222.06 mg/L respectively which were far below their corresponding recommended levels of 50, 250 and 400 mg/L. So, the evaluated water might not be problematic for irrigation use.

Table 11.14. Mean quality parameters of groundwater at different study sites during March – April 2019 (post-irrigation season)

Location	Parameters, mg/L except pH											
	Source	pH	EC (dS/m)	$PO4^-$	K	$NO3^-$	Cl^-	Na	Ca	Mg	$HCO3^-$	$SO4^-$
Godagari	DTW (n=6)	7.32	0.54	0.80	2.28	0.72	1.76	14.68	21.27	3.46	208.62	6.98
	STW (n=4)	7.43	0.66	0.82	2.40	0.78	1.60	17.22	20.78	4.12	222.06	7.58
Tanore	DTW (n=5)	7.22	0.48	0.72	2.46	0.82	1.62	15.86	19.42	4.62	203.86	8.04
	STW (n=3)	7.42	0.57	0.88	2.54	0.76	1.72	18.12	19.36	4.84	216.66	8.18
Kalai	DTW (n=8)	7.28	0.62	0.62	2.62	0.70	1.81	13.81	21.07	5.52	196.86	8.36
	STW (n=2)	7.36	0.64	0.68	2.74	0.74	1.85	15.52	20.68	4.58	211.94	8.56
Joypurhat sadar	DTW (n=6)	7.25	0.52	0.74	2.22	0.78	1.66	11.02	18.34	3.54	178.16	9.52
	STW (n=2)	7.44	0.58	0.76	2.40	0.86	1.58	13.32	18.44	3.82	202.08	9.94
Range		7.22-7.54	0.48-0.66	0.62-0.88	2.22-2.74	0.70-0.84	1.58-1.81	11.02-18.86	18.34-21.27	3.46-5.52	178.16-222.06	7.58-9.94
Average		.7 35	0.58	0.75	2.46	0.77	1.49	14.94	19.92	4.31	205.03	8.40

The suitability of groundwater for irrigation is dependent on the effects of the mineral constituents of the water on both the plant and the soil. In this study, SAR, SSP, RSC and KR were used to carry out the assessment of the suitability of water for irrigation purposes (Table 11.15). Irrigation water that has high sodium (Na^+) content can bring about a displacement of exchangeable cations Ca^{2+} and Mg^{2+} from the clay minerals of the soil, followed by the replacement of the cations by sodium. SAR (Sodium Adsorption Ratio) is a measure of suitability of water for irrigation with respect to the sodium hazard. As higher deposition of sodium may cause damage to soil, soil irrigation with high sodium depositing waters is not suitable. SAR is directly related to adsorption of sodium by soil; therefore, it is a better measure of sodium (alkali) hazard in irrigation water. High SAR in any irrigation water implies hazard of sodium (Alkali) replacing Ca and Mg of the soil through cation exchange process, a situation eventually damaging to soil structure, namely permeability which ultimately affects the fertility status of the soil and reduce crop yield (Gupta, 2005). SAR gives the clear idea about the adsorption of sodium by soil. Based on the grading criteria of water for irrigation, SAR is classified into excellent (<10), good (10-18), permissible (18-26), unsuitable (>26) (Khodapanah *et al.* 2009). The assessment results with these methods were listed in Table 11.15. As per SAR value, all samples collected either from STW or from DTW in both seasons fall into excellent category. During pre-irrigation season the values of SAR of the collected water samples ranged from 0.40 to 0.99 with an average value of 0.62 and it ranged from 0.69 to 0.95 during post-irrigation season with an average value of 0.79.

The residual sodium carbonate (RSC) is a measure of the hazard involved in the use of high carbonate waters. Water quality for irrigation is influenced when concentration of carbonates and bicarbonates is higher than calcium and Magnesium. Waters containing high concentrations of these ions, calcium and possibly magnesium (Mg^{+2}) may precipitate as carbonates when water is concentrated by transpiration and evaporation. With the removal of calcium and magnesium from soil solution, the relative proportion of sodium is increased with attendant increase in alkali hazard. A high range of RSC in irrigation water means an increase in the adsorption of sodium on the soil. Water having RSC > 5 has not been recommended for irrigation because of damaging effects on plant growth. According to USDA (United State Department of Agriculture) any source of water in which RSC is higher than 2.5 is not considered suitable for agricultural purpose, and water < 1.25 is recommended as safe for irrigation purpose. A negative value of RSC reveals that concentration of Ca^{2+} and Mg^{2+} is in excess. A positive RSC denotes that Na^+ existences in the soil are possible. RSC calculation is also important in context to calculate the required amount of gypsum or sulfuric acid per acre-foot of irrigation water to neutralize residual carbonates effect. RSC values for pre-irrigation season varied from 1.11 to 2.57 with an average value of 1.55 while for post-irrigation season RSC values varied from 1.71 to 2.26 with an average value of 2.01. In both the seasons, KR values were found less than 1, indicating that all groundwater samples were suitable for irrigation use.

Soluble Sodium Percent (SSP) is also used to evaluate sodium hazard. Water with a SSP greater than 60% may result in sodium accumulations that will cause a breakdown in the soil's physical properties (Khodapanah *et al.* 2009). The values for the soluble sodium percent (SSP) in the study areas were found to vary from 15.74 to 38.06% with an average value of 23.94 % in pre-irrigation season and from 27.41 to 35.42 with an average value of 31.30 in post-irrigation season (Table 11.15). This result corroborates the findings of Khan *et al.* (1989) who found SSP ranging from 14.50 to 37.55 in the North-West region of Bangladesh. Based on the classification after Wilcox (1955) for SSP, all samples fall under excellent and good classes, so it can be used safely for irrigation.

Table 11.15. Water quality indices for suitability assessment of different water sources for irrigation

Location	Source	Pre-irrigation season				Post-irrigation season			
		SAR	RSC	SSP (%)	KR	SAR	RSC	SSP (%)	KR
Godagari	DTW	0.66	1.39	25.50	.353	0.78	2.07	1.16	0.472
	STW	0.70	1.31	25.33	0.349	0.90	2.26	34.15	0.542
Tanore	DTW	0.65	1.32	23.79	0.321	0.84	1.99	32.70	0.509
	STW	0.99	2.57	38.06	0.643	0.95	2.18	35.42	0.574
Kalai	DTW	0.48	1.22	18.77	0.238	0.69	1.71	27.53	0.397
	STW	0.64	1.72	25.41	0.355	0.80	2.06	31.23	0.477
Joypurhat sadar	DTW	0.40	1.11	15.74	0.192	0.62	1.71	27.41	0.395
	STW	0.47	1.77	18.91	0.241	0.74	2.07	30.79	0.467
Average		0.62	1.55	23.94	0.34	0.79	2.01	31.30	0.48
Range	DTW	0.40-0.66	1.11-1.39	15.74-25.50	0.192-0.353	0.62-0.84	1.71-2.07	27.41-32.70	0.39-0.509
	STW	0.47-0.99	1.31-1.77	18.77-38.06	0.241-0.643	0.74-0.95	2.07-2.26	30.79-35.42	0.467-0.574

In the study area, the assessment of groundwater quality for irrigation was also carried out through the estimation of Water Quality Index (WQI) to identify its suitability for irrigation purpose (Fig. 11.33). This index is an important parameter for assessing groundwater quality and its suitability (Avvannavar and Shrihari, 2008). The advantage of water quality index is based on the relative importance of essential parameters with respect to standards of irrigation purposes.

The WQI ranged from 50.45 to 60.1 for DTW and from 55.15 to 90.24 for STW in pre-irrigation season while it ranged from 53.26 to 67.21 and 60.04 to 101.12 for STW and DTW water, respectively, in post-irrigation season. According to the WQI values, all the samples were found to be "good" in pre-irrigation season whereas in post-irrigation season, all samples were found also "good" except STW's water of Tanore was found poor with WQI value of 101.12 (Table 11.16). Dissolved ions such as Na, K, Mg, HCO_3, Cl, NO_3, and SO_4, affected WQI values during post-monsoon period. High iron concentration in groundwater caused high WQI values; high chloride concentrations also contributed to high WQI values typically during the post-monsoon period.

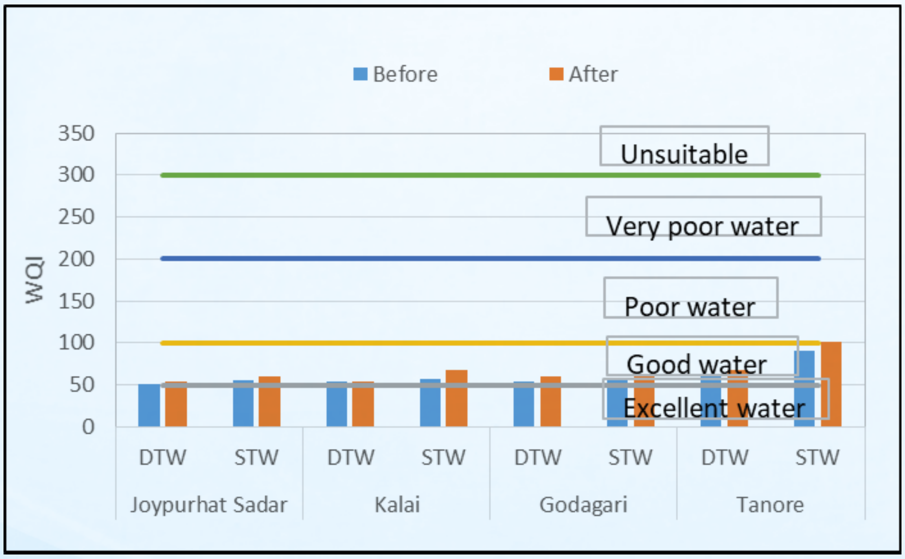


Fig. 11.33. Water quality index (WQI) of groundwater at different locations of the study area (solid line represents the range of different categories of water quality)

Table 11.16. Classification of groundwater quality in the study area

Quality index	Categories	Ranges	Sources of water	
			Pre-irrigation	Post-irrigation
SAR	Excellent	<10	STW, DTW	STW, DTW
	Good	10 – 18		
	Permissible	18 – 26		
	Unsuitable	>26		
RSC	Excellent	<1.25	STW, DTW	-
	Permissible	1.25-2.5	-	STW, DTW
	Unsuitable	>2.5	STW (Tanore)	-
SSP	Excellent	0 – 20	DTW(K), STW/DTW(Joyp)	-
	Good	20 – 40	STW, DTW	STW, DTW
	Permissible	40 – 60	-	-
	Doubtful	60 – 80	-	-
	Unsuitable	>80	-	-
KR	Suitable	<1	STW, DTW	STW, DTW
	Unsuitable	≥ 1	-	-
WQI	Excellent	<50	DTW (Joypur)	-
	Good	50 – 100	STW, DTW	STW, DTW
	Poor	100 – 200	-	STW (Tanore)
	Very poor	200 – 300	-	-
	Unsuitable	>300	-	-

The groundwater quality in two districts (Rajshahi and Joypurhat) of north-west region has been evaluated for agricultural use. The water quality indices such as SAR, SSP, RSC and KR were calculated to find out its suitability for irrigation. The results based on these indices indicated that quality of groundwater samples fall into excellent and good categories for irrigation use. The water quality index (WQI) has been determined to better assess the suitability of groundwater for irrigation and it is observed that all the samples were "good" but few were found "poor" in post-irrigation season. Therefore, in respect of all evaluating criteria, groundwater of the study area was found suitable and can safely be used for irrigation purpose.

11.2.2. Component-2: BRRI

11.2.2.1. Trend of groundwater level fluctuation

The graphical representations with trend line of results of historical water table data were shown in Fig. 11.34. The Fig. 11.34 showed that fluctuation of minimum and maximum ground water table is not steady in all locations. The trend lines revealed that among the locations the maximum declination of groundwater level occurred in Ishwardi.

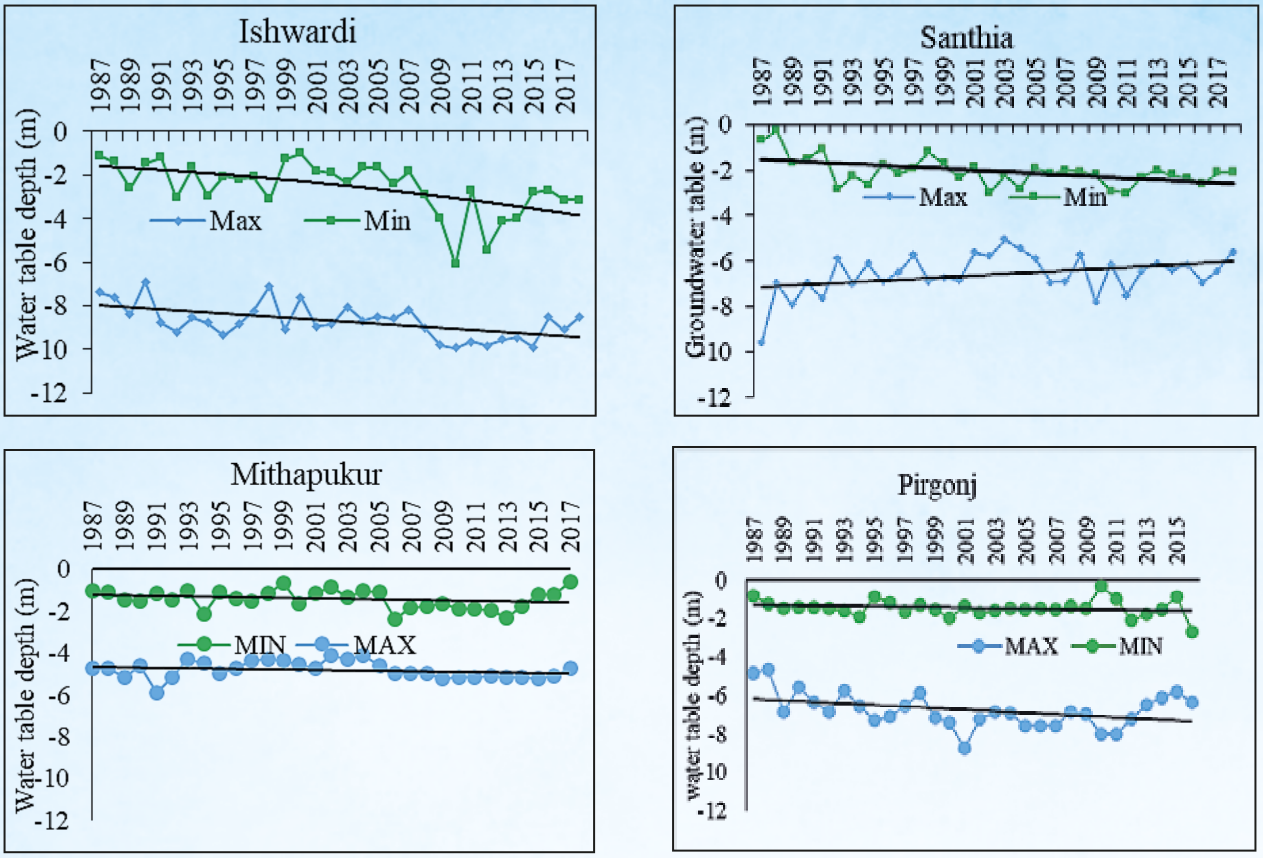


Fig. 11.34. Trend and fluctuation of groundwater table in different locations of the project area

Annual rainfall and its trend

Rainfall was one of the main sources for groundwater recharge. This study at first investigated the annual rainfall trend of the two districts form historical rainfall data. The amount of annual rainfall was not same in every year variation was observed (Fig. 11.35). But deviation was higher in Pabna district. A declining trend in annual rainfall was observed in Pabna district.

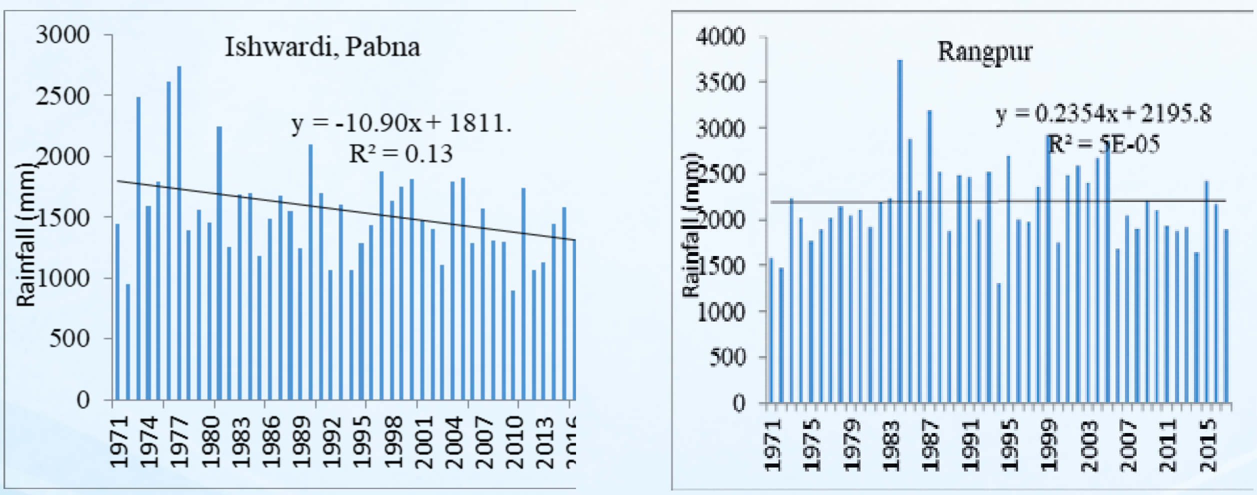


Fig. 11.35. Trend analysis of historical annual rainfall at Pabna and Rangpur district

Annual rainfall and recharge relationship

Although annual rainfall was one of the main sources for recharge but sometimes linear relationship was not observed between annual rainfall and recharge. This study developed relationship between annual rainfall and recharge at four locations but found linear relation at two locations out of four (Fig. 11.36).

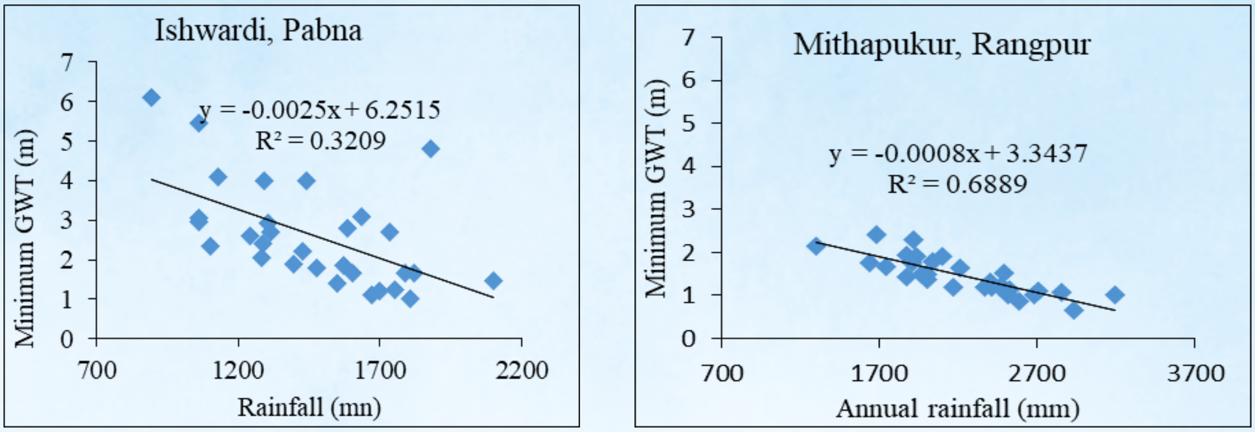


Fig. 11.36. Relationship between annual rainfall and minimum groundwater table at Ishwardi (Pabna) and Mithapukur (Rangpur)

Recharge period rainfall and recharge depth relationship

An attempt was taken to explore the relationship between recharge period rainfalls (RPRF) and corresponding recharge depth. Recharge period means the required time to reach groundwater table from its maximum depth position to minimum depth position in the same year (generally May to October). Again, the depth between maximum groundwater table and minimum groundwater table in the same year is recognized as recharge depth (RD). However, Fig. 11.37 showed that RD increase with the increased of RPRF.

From the above analysis it was clear that GWT declining was a great problem in most of the locations of the project area. This project developed a technique to retard GWT declining which is described below.

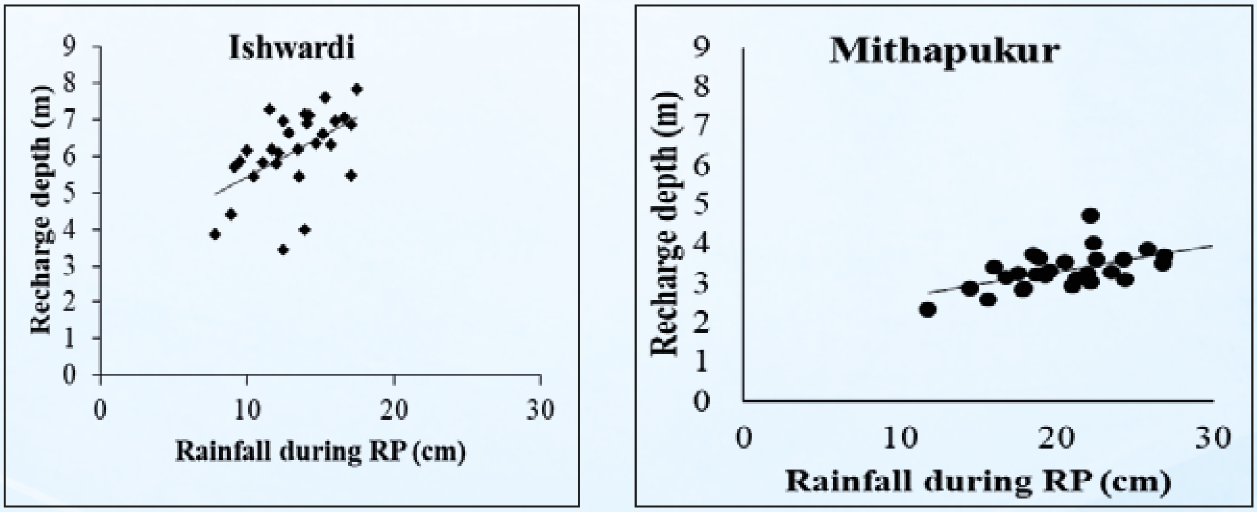


Fig. 11.37. Relationship between recharge depth and rainfall during recharge period at Ishwardi and Mithapukur

A declining trend of groundwater table was observed in the study area except at Pirganj. The maximum total depletion was 205 cm with the maximum average 6.6 cm per year depletion and number of years of negative recharge was more than that of positive recharge during 32 years. The maximum groundwater table remained below suction limit at Iswardi causing non- functioning of shallow tubewell (STW) during that period. A declining trend in annual rainfall was observed in Pabna district. A linear relationship between rainfall and recharge was found at two locations of the study area.

11.2.2.2. Recharge assessment

Although artificial recharge is a sensitive matter but still its importance and demands of age is inevitable in our country. It was mentioned in methodology chapter that a prototype consisting of three filters (FM_1, FM_2 and FM_3) consisting with different materials was used for artificial recharge and rainfall runoff water was tested as recharged water. Amount and rate of discharge was determined and chemical analysis was done prior and after filtration to test quality of filtered water. Here discharge rate and recharge rate were same thing. However, results of the analysis are given below.

Recharge rate

Discharge rate of water from each treatment (filter) was shown in Fig. 11.38. It was found that after filling the recharge tank about 18 minutes for FM_3, 27 minutes for FM_2 and 72 minutes for FM_1 time was required for starting of discharge. Peak discharges were found 0.82, 0.74 and 0.9 L s^{-1} which was found after 2.5, 2.0 and 1.5 hours for FM_1, FM_2 and FM_3 respectively.

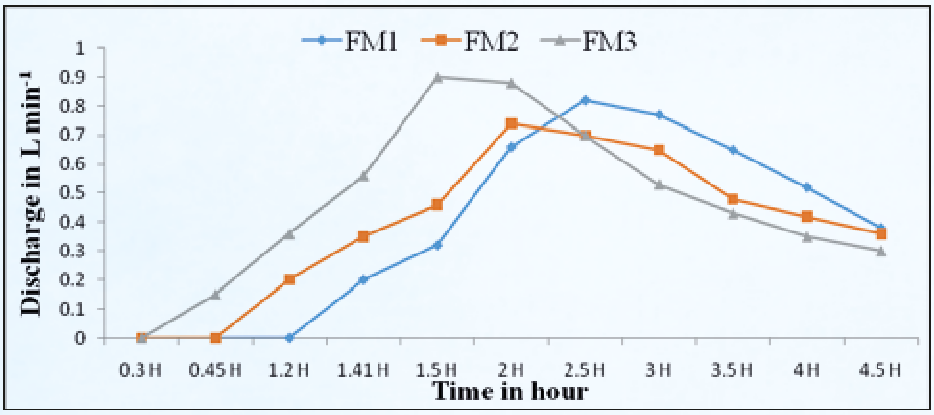


Fig. 11.38. Discharge pattern for different filter media

Chemical and biological properties of water

Chemical properties of runoff water from rainfall and after filtration by different filter media were analyzed and shown in table 11.17. All the chemical properties were compared with World Health Organization (WHO) drinking water standard. Electrical conductivity of water remained in desired limit (<1 dS m^{-1}) in all the treatments although slightly increased in FM_3. This may be caused due to presence of charcoal. Almost same pH value (7.5-7.8) was found in each treatment and source. Each filter media had a great potentiality to remove solid particles. Source water (runoff water) had the highest turbidity 305 NTU but after filtration it came down to 1.7, 3.7 and 2.1 NTU in FM_1, FM_2 and FM_3, respectively. Since desired limit of turbidity was less than 5 FNU, so all filtered water was suitable for drinking in context of turbidity. Residual free chlorine found suitable (<0.2 mg L^{-1}) in all treatment except source water (0.43 mg L^{-1}). Source water had alkalinity of 190 mg L^{-1} and this value reduced in FM_1 and FM_2 but increased in FM_3. Calcium value found suitable (<75 mg L^{-1}) in FM_1 and FM_2 but increased in FM_3 (110 mg L^{-1}). Magnesium, potassium and sodium content in water for all treatments and source showed suitable for drinking and irrigation. The most important matter was presence of Microbial in filtered water. Huge presence of it may contaminate the groundwater. In this study presence of individual microbe was not identified but presence of group microbes was identified. Only from 1.3 to 3.6 logCFU/ml microbes was presence in filtered water (Table 11.17).

Table 11.17. Chemical compositions of water from runoff and after filtration by different filter media during 2019 at BRRI farm, Gazipur

Parameters	Source	FM_1	FM_2	FM_3	Recommended drinking water limit (WHO standard)
EC (dS m^{-1})	0.36	0.32	0.37	0.6	1.0
pH	7.5	7.7	7.7	7.8	6.5-8.5
Turbidity (NTU)	305	1.7	3.7	2.1	5.0
Free chlorine (mg L^{-1})	0.43	0.04	0.11	0.09	0.2
Alkalinity (mg L^{-1})	190	115	110	**280**	200
Calcium (mg L^{-1})	40	60	60	**110**	75
Iron (µg L^{-1})	195	58	74	150	200
Magnesium (mg L^{-1})	15	10	10	5	30
Sodium (mg L^{-1})	30	19	20	26	200
Potassium (mg L^{-1})	13	1	1	**16**	3.1
Microbial Properties					
Microbial counts (log CFU/ml)	6.9	1.3	2.1	3.6	-

Assessment of water quality for irrigation

Quality of water before and after filtration was analyzed and shown in Table 11.18. Results showed that highest SAR was found 1.0 in source water and 0.6 in FM_1 and FM_2 which indicated that water quality was normal for irrigation. Highest value of MAR was 38.5 which was below the recommended limit. Kelly's ratio remained also within the recommended limit. The highest total hardness was 295 found in FM_3 which was below the recommended limit. Similarly, SSP value in all the treatment remained within the recommended limit.

Table 11.18. Quality of water from different sources for irrigation use

Quality indicator	Source	FM_1	FM_2	FM_3	Recommended limit (FAO)	Status
SAR	1.0	0.6	0.6	0.7	<10	Normal
MAR	38.5	21.7	21.7	6.8	<50	Suitable
KR	0.4	0.2	0.2	0.2	<1	Suitable
TH	162.5	191.5	191.5	295.0	<500	Normal
SSP	33.4	18.2	19.0	20.6	20-40	Normal

Most of the chemical properties of water after filtration by treatment FM_1 and FM_2 satisfied the WHO standard limit. Treatment FM_3 showed higher value of alkalinity, calcium and potassium, although these values were within the permissible limit. This may be the residual effect of charcoal. All the filtered and source water were suitable for irrigation. Peak discharges were found 0.82, 0.74 and 0.9 L s^{-1} for FM_1, FM_2 and FM_3, respectively. Presence of microbes in the filtered water was also at satisfactory level. So, it can be said that FM_1 and FM_2 can be used for artificial filtering of water without risk.

11.2.2.3. Groundwater quality assessment

Quality of groundwater should be monitored at a certain intervel for assuring that the used groundwater is suitable for drinking as well as for irrigation. In this regard, groundwater quality in the project area was analyzed to know whether the quality was suitable for drinking and irrigation or not. Results showed that the total sodium, potassium, calcium and magnesium concentration varied from 11.6 to 19.3, 1.41 to 1.7. 12 to 21.7 and 5 to 13 mgL^{-1} in Pabna region and 10.1 to 36.2, 1.4 to 2.9, 5 to 30, and 5 to 10 mgL^{-1} respectively in Rangpur (Table 11.19). The concentrations of most of the captions were within the WHO recommended limits for irrigation use. The pH of the water samples in the both the locations were found to vary from 7 to 7.9 which indicated practically neutral water. The pH values were well within the normal range of irrigation water quality. On the basis of pH value, all water samples were suitable for irrigation. The electrical conductivity of the water samples varied from 0.26 to 0.56 dSm^{-1} in Rangpur and Pabna. All the samples showed that EC was in excellent class according to WHO standard.

Table 11.19 Major chemical composition of shallow tube well water in Pabna and Rangpur

Parameters	STW1	STW2	STW3	STW4	STW5	STW6	WHO standard
	Ishwardi, Pabna			Santhia, Pabna			
EC (dS m^{-1})	0.38	0.54	0.48	0.32	0.52	0.28	1
pH	7	7.5	7.7	7	7	7.5	6.5-8.5
Calcium (mg L^{-1})	13.3	13.3	21.7	13.3	15.0	12.0	75
Magnesium (mg L^{-1})	13	10	8	7	10	5	30
Sodium (mg L^{-1})	16.2	16.2	19.3	17.8	11.6	12.0	200
Potassium (mg L^{-1})	1.41	1.70	1.56	1.70	1.41	1.70	3.1
	Mithapukur, Rangpur			Pirgonj, Rangpur			
EC (dS m^{-1})	0.26	0.32	0.37	0.56	0.42	0.51	1
pH	7.5	7.7	7.7	7.8	7.9	7.4	6.5-8.5
Calcium (mg L^{-1})	30	21.7	21.7	13.3	5	21.7	75
Magnesium (mg L^{-1})	10	5	5	10	10	5	30
Sodium (mg L^{-1})	27	23.9	28.5	10.1	11.6	36.2	200
Potassium (mg L^{-1})	1.6	2	2.9	1.4	1.4	1.7	3.1

Assessment of water quality for irrigation

Sodium adsorption ratio: From Table 11.20 the highest SAR value 2.6 and lowest 0.7 was found in Mithapukur, Rangpur which was normal quality level for irrigation.

Magnesium Adsorption Ratio**:** The magnesium adsorption ratio (MAR) of the water samples varied from 27.7 to 55.6. FAO mentioned that high MAR affects soil unfavorably; harmful effects on soils appear when MAR exceeds 50. The results showed that fifty percent of the samples had MAR value to some extent above 50. Soluble sodium percentage: Values of SSP ranged from 40.6 to 68.3 which was close to FAO recommended value (Table 11.20).

Table 11.20. Water quality indicators of STW water during Boro, 2018-19 to 2019-20

Quality indicator	STW1	STW2	STW3	STW4	STW5	STW6	Recommended limit (FAO)	Status
	Ishwardi, Pabna			**Santhia, Pabna**				
SAR	1.1	1.2	1.3	1.4	0.8	1.0	<10	Normal
MAR	61.9	55.6	38.1	46.7	52.6	41.0	<50	Suitable
SSP	45.9	50.0	50.1	56.6	40.6	45.9	20-40	Suitable
TH	3.1	2.5	2.7	2.0	2.7	1.6	<500	Normal
KR	0.8	0.9	1.0	1.2	0.6	1.0	<1	Normal
	Pirgonj, Rangpur			**Mithapukur, Rangpur**				
SAR	1.5	1.7	2.0	0.7	0.8	2.6	<10	Normal
MAR	35.7	27.7	27.7	55.6	52.6	27.7	<50	Suitable
SSP	51.0	59.2	63.6	38.8	40.6	68.3	20-40	Suitable
TH	3.6	2.2	2.2	2.5	2.7	2.2	<500	Normal
KR	1.0	1.1	1.2	0.6	0.6	1.1	<1	Normal

Kelly's Ratio: The Kelly's ratio (KR) for the water samples varied from 0.6 to 1.2. These values were close to FAO suggested value except in two locations. Therefore, the results revealed groundwater in the project area was suitable for irrigation. Groundwater quality in the sub-project area has been tested to know whether it was suitable for drinking and irrigation or not. Tested results showed that groundwater in the sub-project area was suitable for drinking and irrigation according to FAO recommendation.

11.2.3. Component-3: BINA

11.2.3.1. Determination of aquifer hydraulic properties by pumping test at Nachole

(a) Nachole study area

Subsurface Lithology

It was observed that the vertical profile of subsurface lithology at Nachole was stratified with clay, silty clay, very fine sand and fine sand at the upper part and similar finding was reported by (IWM 2012, IWM 2006 and Khan *et al.*, 2001) in that area. First 80 feet from ground surface was formed as hard clay. The second part was medium coarse sand, coarse sand and their mixture. Saturated thickness of unconfined aquifer was 25 m (82 feet). To know the grain size distribution of the formation or aquifer materials (depth wise), mechanical analyses were performed using standard sieve in laboratory. The grading curve of aquifer materials according to depth was presented in Fig. 11.39 to Fig. 11.48.

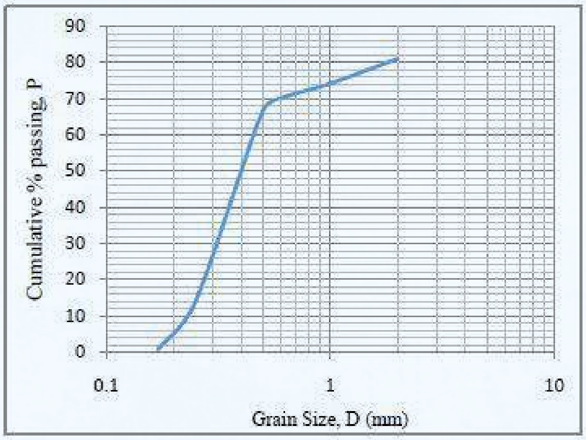


Fig. 11.39. Grading curve (80-90 ft)

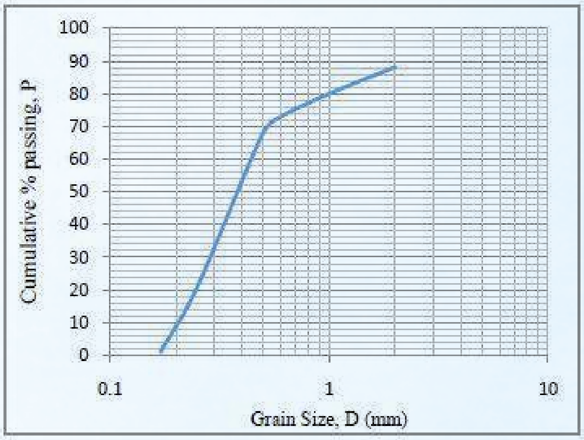


Fig. 11.40. Grading curve (90-100 ft)

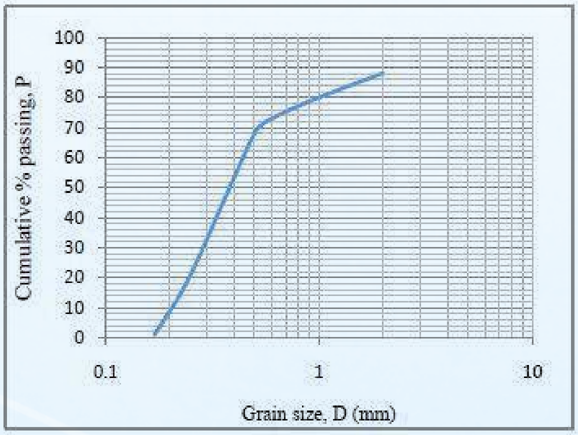


Fig. 11.41. Grading curve (100-110 ft)

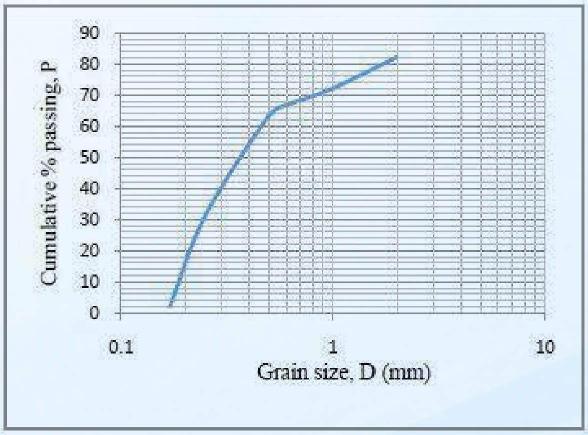


Fig. 11.42. Grading curve (110-120 ft)

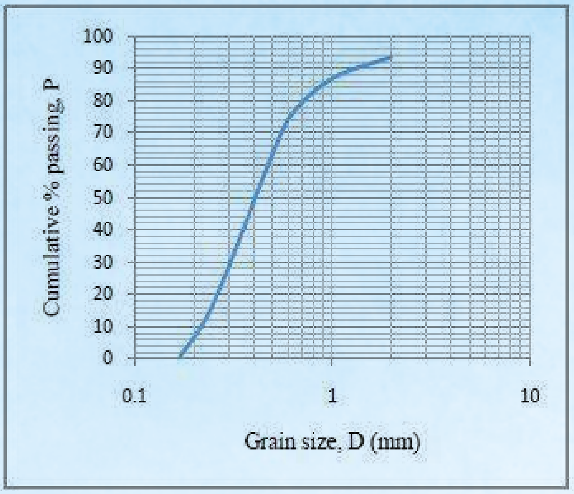


Fig. 11.43. Grading curve (120-130 ft)

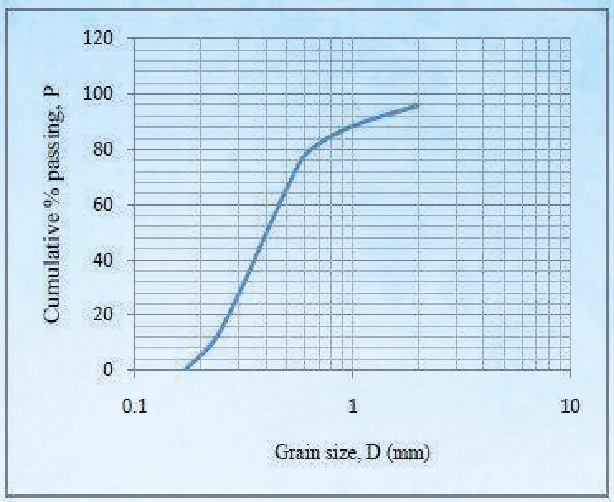


Fig. 11.44. Grading curve (130-140 ft)

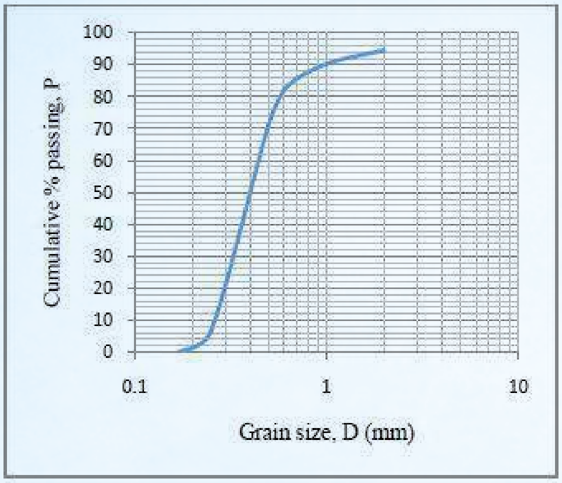


Fig. 11.45. Grading curve (140-150 ft)

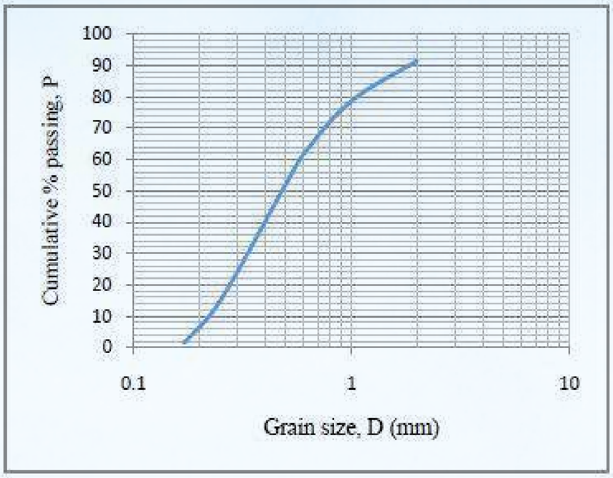


Fig. 11.46. Grading curve (150-160 ft)

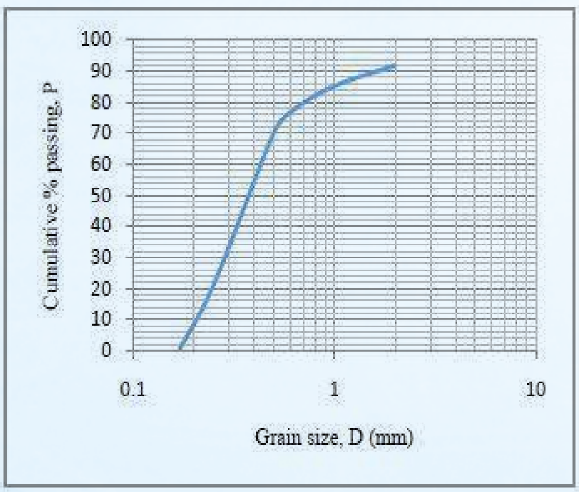


Fig. 11.47. Grading curve (160-170 ft)

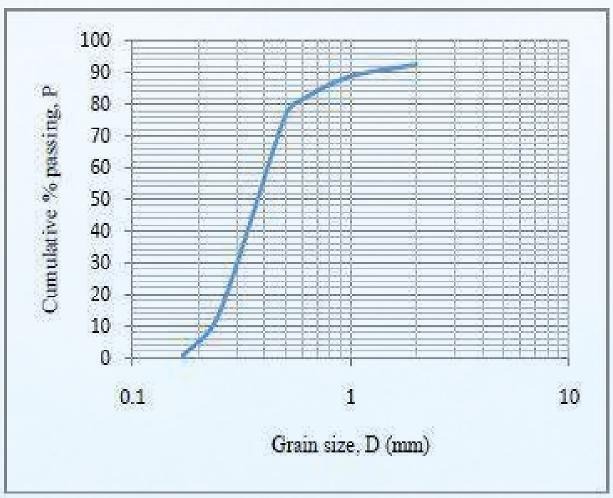


Fig. 11.48. Grading curve (170-180 ft)

Fineness Modulus, Effective size (D_{10} & D_{60}) and Uniformity Coefficient (C_u) of aquifer materials of different depth were presented in Table 11.21. Fineness Modulus of aquifer materials (depth wise) ranged from 2.43 to 2.93. Coefficient of Uniformity (C_u) of aquifer materials was greater than two (110 ft to 160 ft), which indicated well graded materials (Raghunath, 1987). Depth wise specific yield (Sy) determined by laboratory method, were presented in Table 11.22. Average value of specific yield (Sy), specific retention (Sr) and porosity (n) were found as 4.03%, 36.85% and 40.88%, respectively.

Table 11.21. Fineness Modulus, Effective size, Uniformity Coefficient and specific yield of aquifer materials of different depth

Depth (ft)	(FM)	Effective Size (mm)		Uniformity Coefficient (C_u)	Remarks
		D_{10}	D_{60}		
0-80	-	-	-	-	Clay loam soil
80-90	2.93	0.24	0.45	1.88	Uniform materials/poor grading
90-100	2.83	0.24	0.47	1.96	Uniform materials/poor grading
100-110	2.68	0.21	0.43	2.05	Well graded materials
110-120	2.82	0.18	0.46	2.56	Well graded materials
120-130	2.63	0.22	0.47	2.14	Well graded materials
130-140	2.56	0.22	0.46	2.09	Well graded materials
140-150	2.54	0.21	0.42	2.00	Well graded materials
150-160	2.99	0.22	0.58	2.64	Well graded materials
160-170	2.54	0.27	0.44	1.63	Uniform materials/poor grading
170-180	2.46	0.23	0.42	1.83	Uniform materials/poor grading
180-190	-	-	-	-	Clay layer

Table 11.22. Depth wise specific yield, specific retention and porosity measured by laboratory method (simple saturation and drainage)

Depth	Volume of saturated aquifer materials, Vsat. aqi (ml)	Volume of water required to saturate the materials, Vw (ml)	Volume of water drained out by gravity, Vdw (ml)	Volume of water retained within sample, Vrw (ml)	Speciific Yield, Sy (%)	Specific Retention, Sr (%)	Porosity, n (%)
80-90	350	144	11	133.00	3.14	38.00	41.14
90-100	350	143.5	12.5	131.00	3.57	37.43	41.00
100-110	200	79	8.5	70.50	4.25	35.25	39.50
110-120	350	140	14.5	125.50	4.14	35.86	40.00
120-130	470	170	17	153.00	3.62	32.55	36.17
130-140	350	140	15	125.00	4.29	35.71	40.00
140-150	250	121	11	110.00	4.40	44.00	48.40
150-160	355	144.5	15.5	129.00	4.37	36.34	40.70
160-170	460	188	19.5	168.50	4.24	36.63	40.87
170-180	350	143.5	15	128.50	4.29	36.71	41.00
Average					4.03	36.85	40.88

Aquifer hydraulic properties

Pattern of drawdown and residual drawdown during recovery are presented in Fig.11.49 and Fig.11.50, respectively.

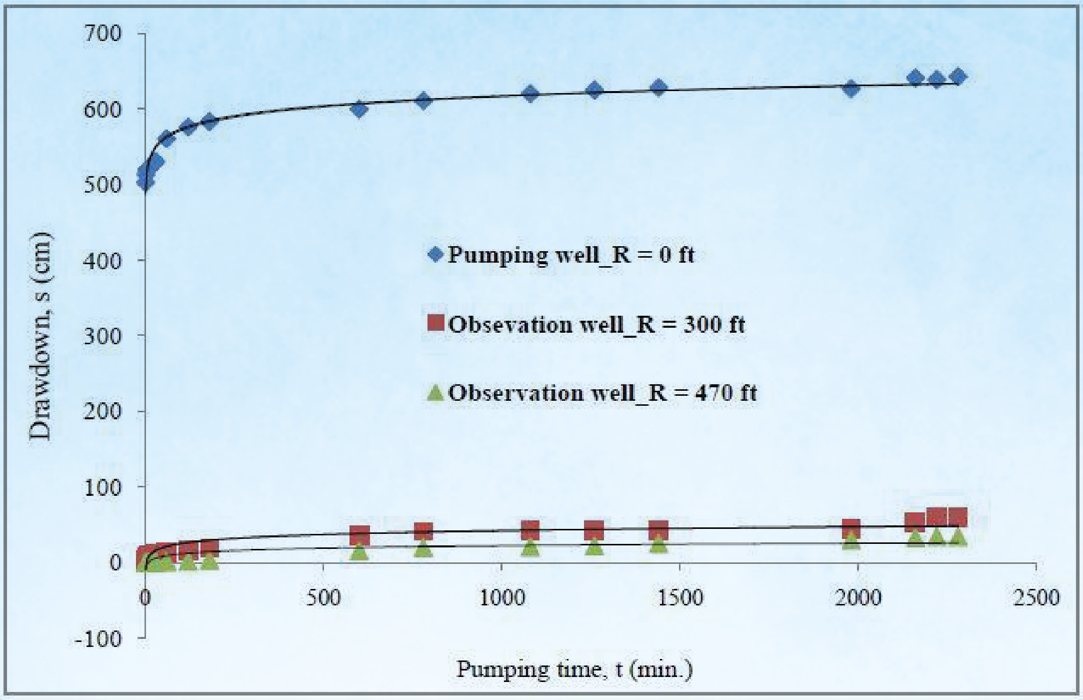


Fig. 11.49. Pattern of drawdown during the course of pumping

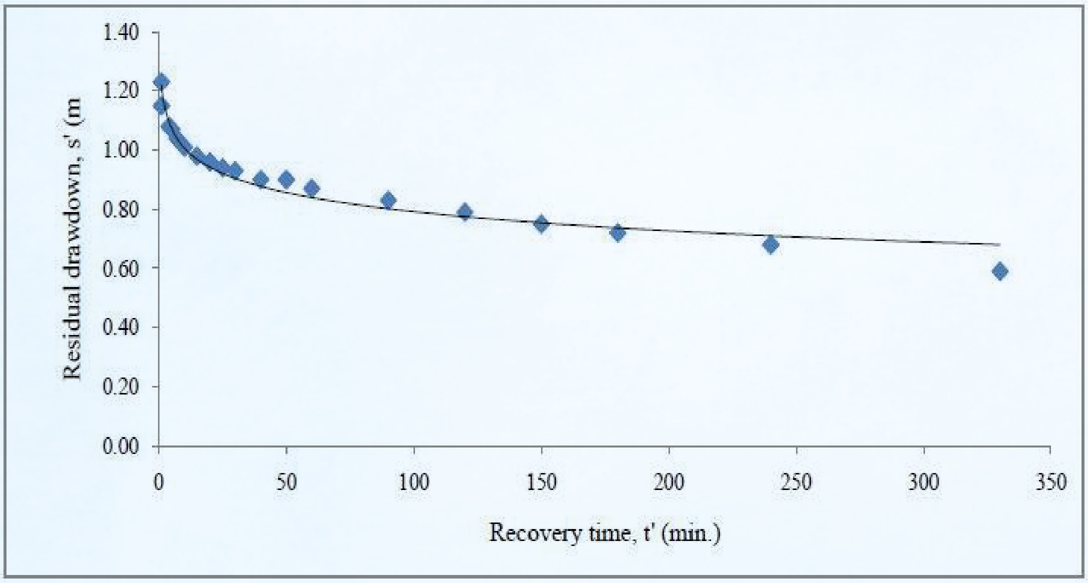


Fig. 11.50. Pattern of residual drawdown during recovery period

Different method-wise hydraulic conductivity (K), Transmissibility (T) and Specific Yield (S_y) of the aquifer are presented in Table 11.23 and Fig. 11.51 to Fig. 11.55. The coefficient of transmissibility (T) at the site ranged from 433.41 to 1383.69 m^3/m/day and hydraulic conductivity (K) ranged from 17.34 to 55.35 m^3/m^2/day. Arithmetic mean of hydraulic conductivity (K) and Transmissibility (T) of aquifer were found as 29.70 m^3/m^2/day and 743.92 m^3/m/day, respectively. Specific yield (Sy) of saturated unconfined aquifer ranged from 4.03 to 5.03%. The IWM (2012) reported that in high Barind area, specific yield varies from 0.01 to 0.06, while in low Barind area, it varies from 0.06 to 0.30. Low specific yield will cause excessive drawdown in tube well, if high abstraction rates are used. The IWM (2006 and 2012) also reported that in Barind area, hydraulic conductivity varied from 10 to 70 m/day and transmissibility was lower than 1000 m^2/day or higher than 1000 m^2/day. The value of transmissibility less than 1000 m^2/day indicated poor opportunity for sustainable groundwater development in a particular area. Amah (2016) reported for unconfined aquifer, transmissibility (T) and hydraulic conductivity (K) ranged from 485 to 1346 m^2/day and 9.7 to 27.9 m/day, respectively.

Table 11.23. Different method-wise hydraulic conductivity (K), Transmissibility (T) and Specific Yield (S_y) of unconfined aquifer in the study area

SI. No.	Method/Procedure	Well/Aquifer	Hydraulic conductivity, K (m^3/m^2/day)	Transitivity, T (m^3/m/day)	Specific Yield, S_y
1	Dupit's Steady State Radial Flow Method	PW & OWs	21.18	529.38	-
2	From Jacob's Distance-drawdown Method	PW & OWs	21.40	535.03	5.03
3	From Jacob's Time-drawdown Method	PW	17.34	433.41	-
		OW-1	30.63	774.87	-
		OW-2	32.29	807.15	-
4	From Time Recovery Method	PW	55.35	1383.69	-
5	From Laboratory Method	Aquifer Materials	-	-	4.03
Average value (arithmetic)			29.70	743.92	4.53
Geometric mean			27.5	688.2	4.13
Range			17.34-55.35	1383.69-433.41	4.03-5.03%

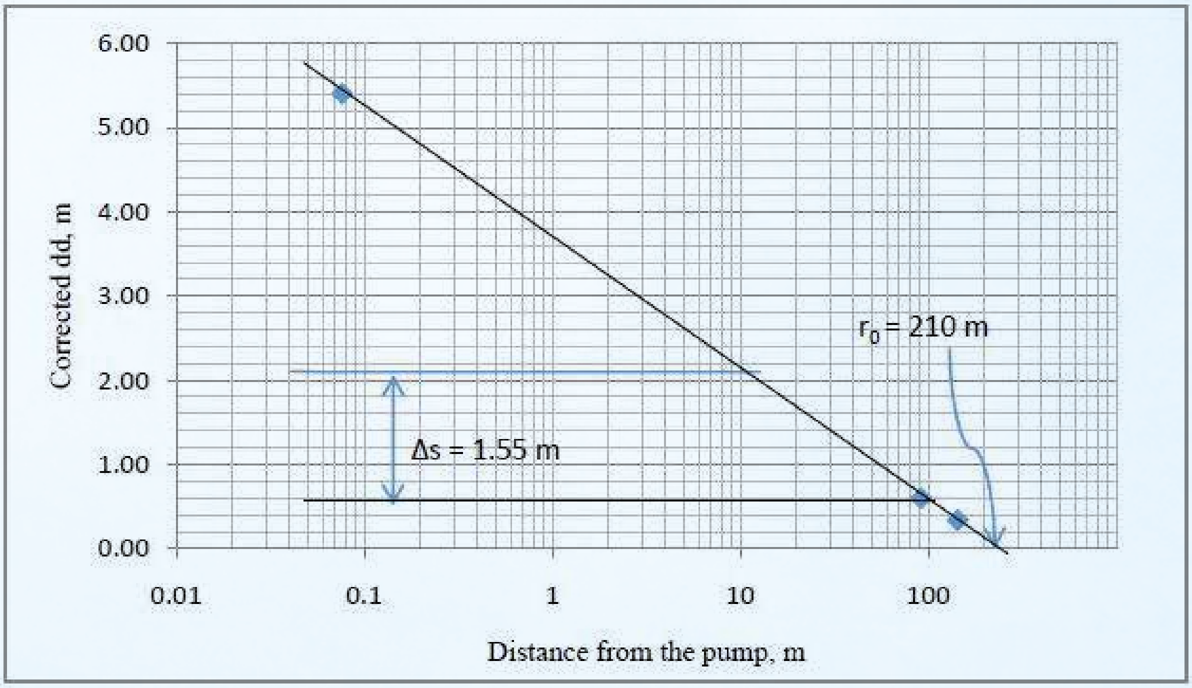


Fig. 11.51. Solution for properties by Jacob's Distance-Drawdown Method

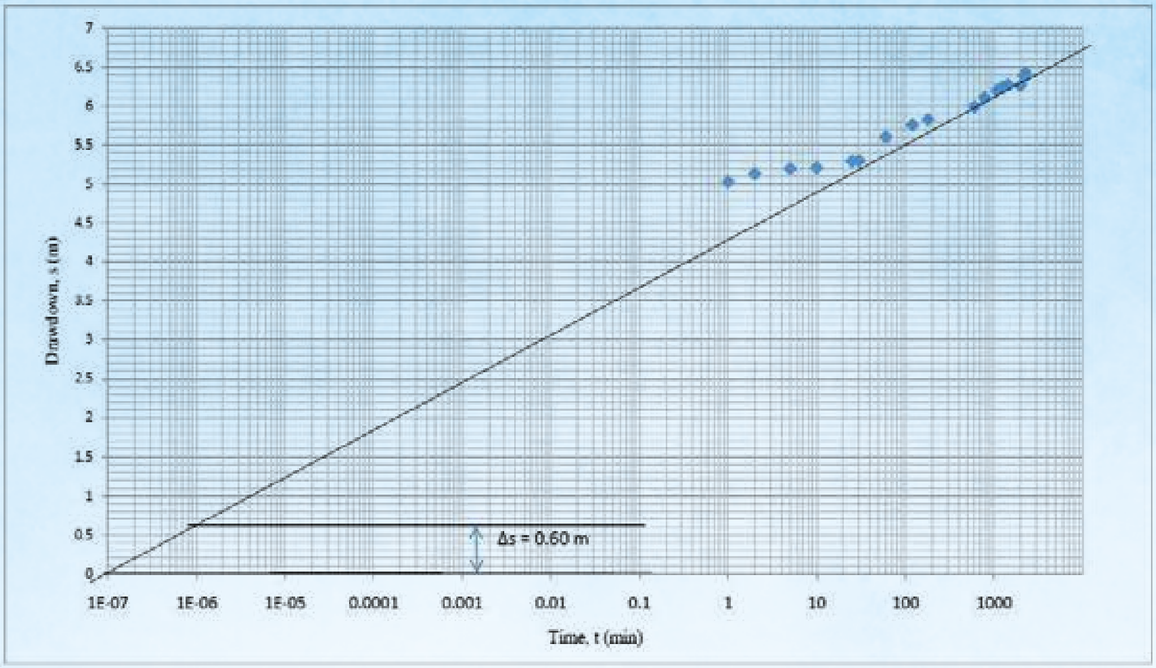


Fig. 11.52. Solution for properties by Jacob's Time-Drawdown Method (#Pumping Well)

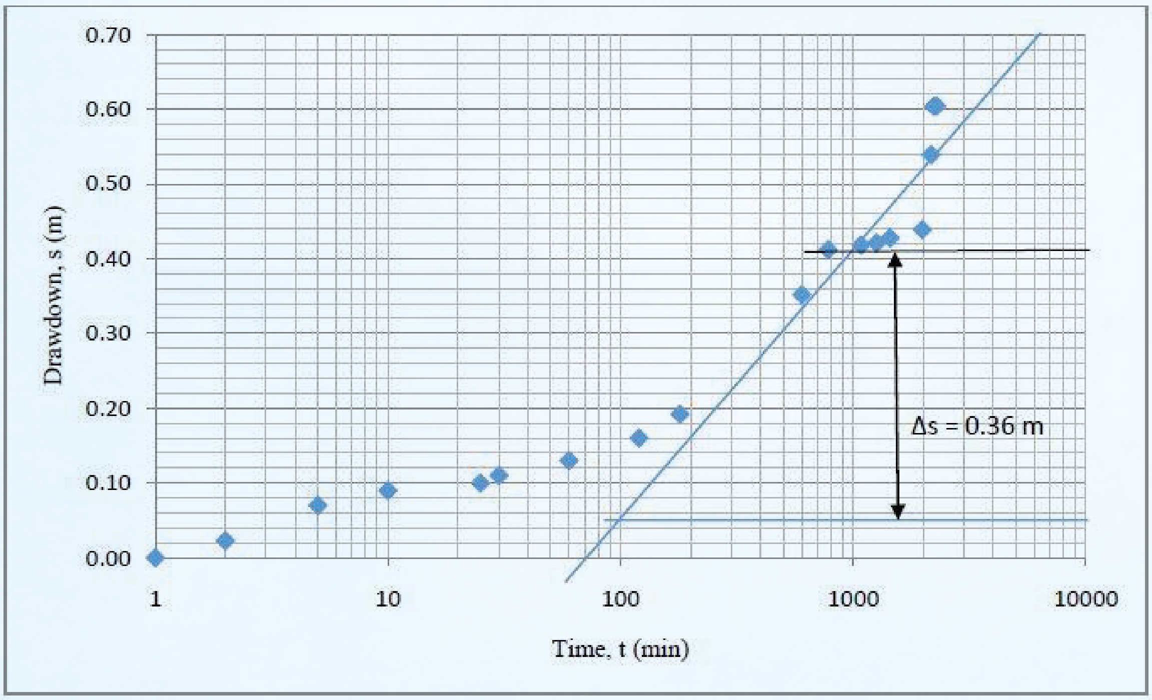


Fig. 11.53. Solution for properties by Jacob's Time-Drawdown Method (#Obs. Well-1)

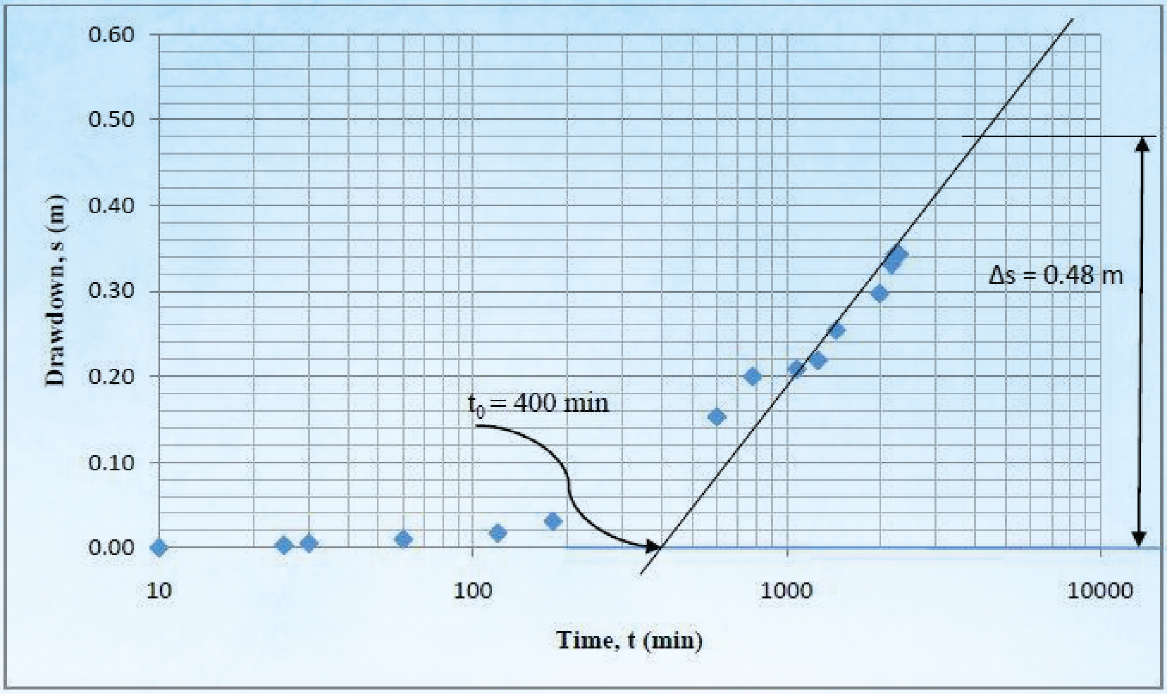


Fig. 11.54. Solution for properties by Jacob's Time-Drawdown Method (#Obs. Well-2)

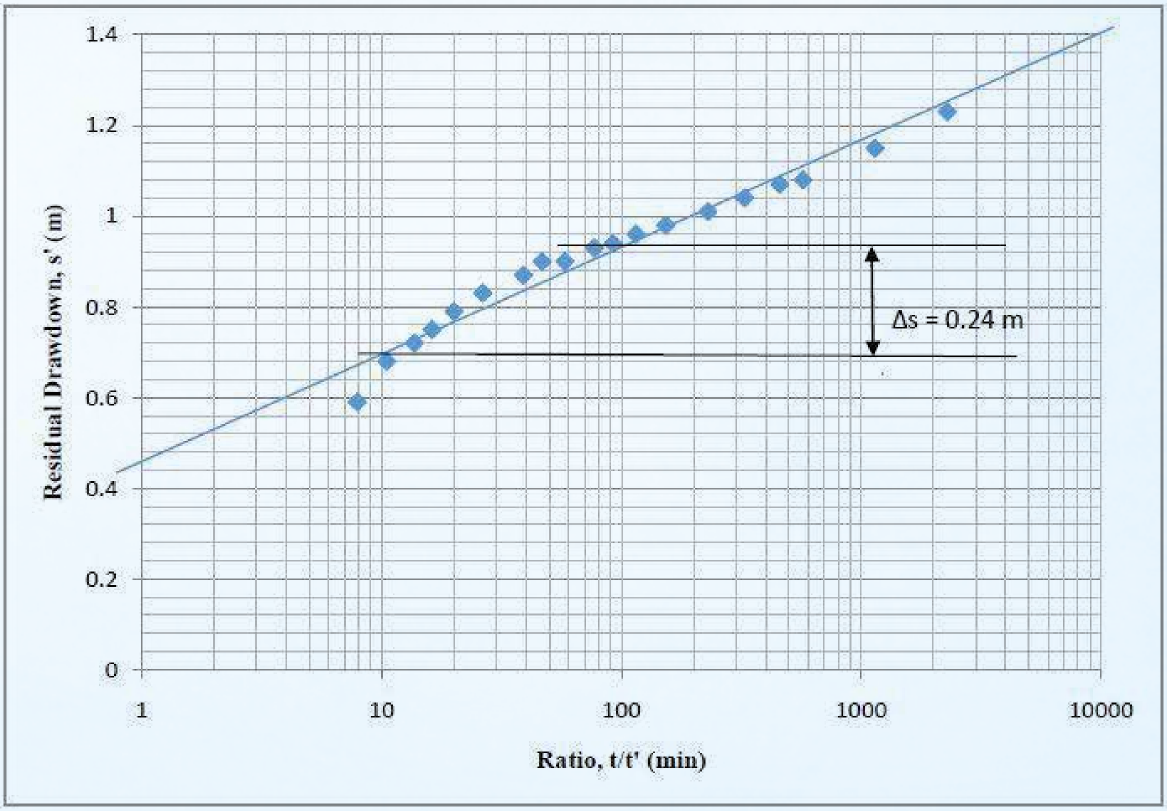


Fig. 11.55. Solution for properties by Time Recovery Method (#Pumping Well)

From pumping test data analysis of Nachole study area, it was shown that a stratified, heterogeneous lithology with clay, silty clay, very fine sand and fine sand at upper part and medium coarse, coarse and their mixture at the lower part just above another impermeable clay layer were found. An unconfined or water table aquifer at depth 27.43 m from the ground surface and 25 m saturated thickness above the bottom of the aquifer were identified. The static water level in the observation well was found at 32.46 m from ground surface and the drawdown in pumping well at steady state condition was 6.43 m. The hydraulic conductivity (K), Transmissibility (T) and Specific yield (Sy) of aquifer were found as 20 to 64.57 m3/m2/day, 499.9 to 1614.3 m2/m/day and 3.83 to 4.03%, respectively, under different methods.

(a) Niamatpur study area

Subsurface Lithology

It was observed that the vertical profile of subsurface lithology of Niamatpur study area was stratified with clay, silty clay, very fine sand and fine sand at the upper part and similar finding was reported by (IWM 2012, IWM 2006 and Khan *et al.*, 2001) at that area. The first 90 feet from ground surface was formed as hard clay and next 10 feet clay with very fine sand. The second part was medium coarse sand, coarse sand and their mixture. Saturated thickness of unconfined aquifer was 20 m (65.60 feet). To know the grain size distribution of the formation or aquifer materials (depth wise), mechanical analyses were performed using standard sieve in laboratory. The grading curve of aquifer materials according to depth was presented in Fig. 11.56 to Fig. 11.62.

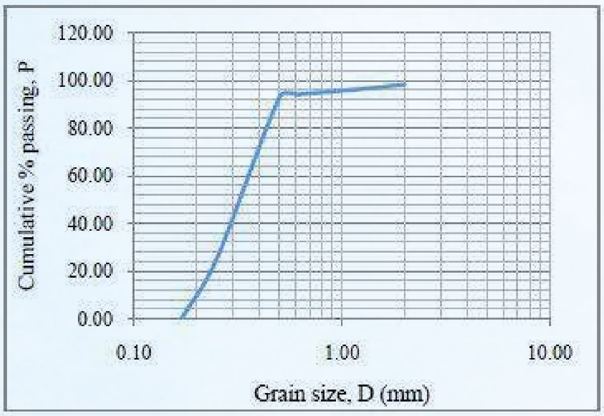


Fig. 11.56. Grading curve (100-110 ft)

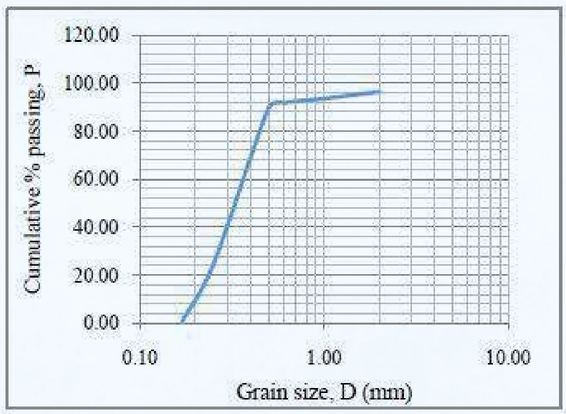


Fig. 11.57. Grading curve (110-120 ft)

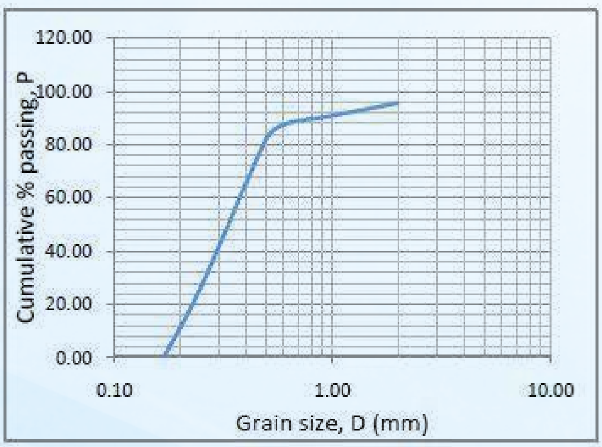


Fig. 11.58. Grading curve (120-130 ft)

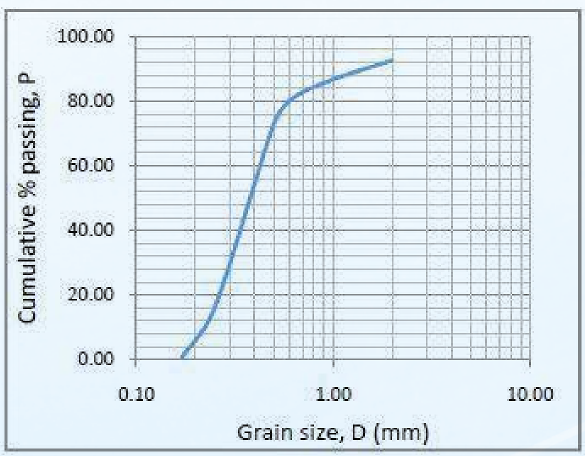


Fig. 11.59. Grading curve (130-140 ft)

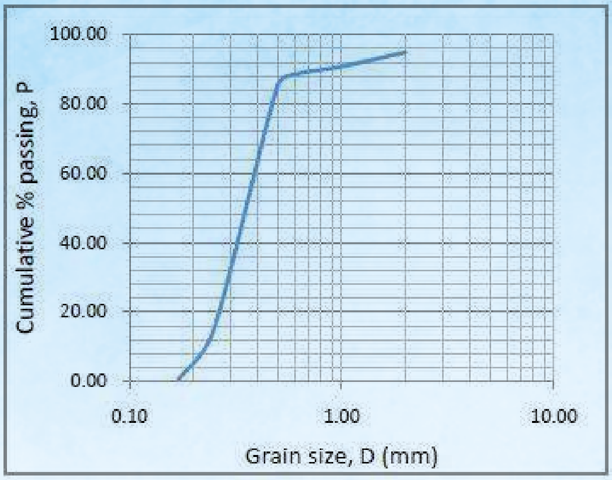


Fig. 11.60. Grading curve (140-150 ft)

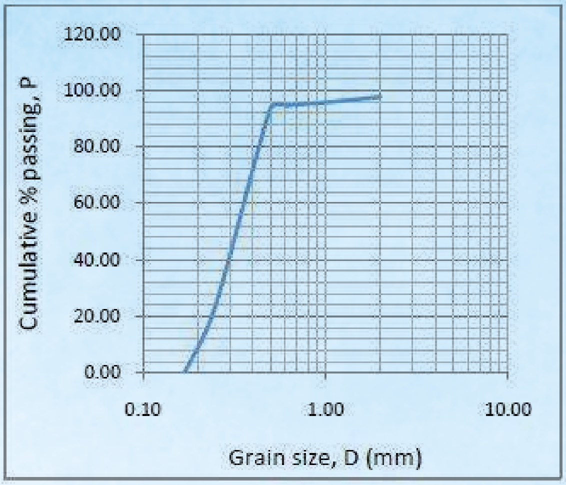


Fig. 11.61. Grading curve (150-160 ft)

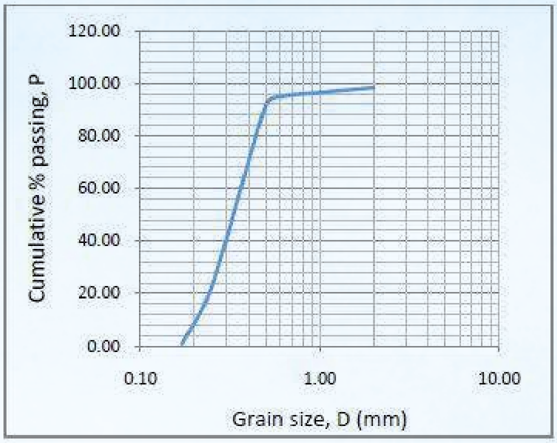


Fig. 11.62. Grading curve (160-170 ft)

Fineness Modulus, Effective size (D10 & D60) and Uniformity Coefficient (Cu) of aquifer materials of different depth were presented in Table 11.24. Fineness Modulus of aquifer materials ranged from 1.94 to 2.50. Coefficient of Uniformity (Cu) of aquifer materials was less than two (except 120 ft to 130 ft), which indicated poor graded materials (Raghunath, 1947). Depth-wise specific yield (Sy) determined by laboratory method, were presented in Table 11.25. Average value of specific yield (Sy), specific retention (Sr) and porosity (n) was found as 4.05%, 35.43% and 39.47%, respectively.

Table 11.24. Fineness Modulus, Effective size, Uniformity Coefficient and specific yield of aquifer materials at different depths

Depth (ft)	(FM)	Effective Size (mm)		Uniformity Coefficient (C_u)	Remarks
		D_{10}	D_{60}		
0-100	-	-	-	-	Clay/Clay loam soil
100-110	1.94	0.2	0.37	1.85	Uniform materials/poor grading
110-120	2.04	0.2	0.38	1.90	Uniform materials/poor grading
120-130	2.16	0.19	0.38	2.01	Well graded materials
130-140	2.50	0.22	0.43	1.95	Uniform materials/poor grading
140-150	2.25	0.23	0.4	1.74	Uniform materials/poor grading
150-160	1.95	0.21	0.37	1.76	Uniform materials/poor grading
160-170	1.95	0.21	0.38	1.81	Uniform materials/poor grading
170-180	-	-	-	-	Clay layer

Table 11.25. Depth wise specific yield, specific retention and porosity measured by laboratory method (simple saturation and drainage)

Depth	Volume of saturated aquifer materials, Vsat. aqi (ml)	Volume of water required to saturate the materials, Vw (ml)	Volume of water drained out by gravity, Vdw (ml)	Volume of water retained within sample, Vrw (ml)	Speciific Yield, Sy (%)	Specific Retaintion, Sr (%)	Porosity, n (%)
100-110	350	144	11	133.00	3.14	38.00	41.14
110-120	350	143.5	12.5	131.00	3.57	37.43	41.00
120-130	350	143.5	15.1	128.40	4.31	36.69	41.00
130-140	350	140	15.6	124.40	4.46	35.54	40.00
140-150	210	72	8.6	63.40	4.10	30.19	34.29
150-160	200	75.8	8.8	67.00	4.40	33.50	37.90
160-170	460	188.5	20	168.50	4.35	36.63	40.98
Average					4.05	35.43	39.47

Aquifer hydraulic properties

Patterns of drawdown and residual drawdown during recovery are presented in Fig.11.63 and Fig. 11.64, respectively.

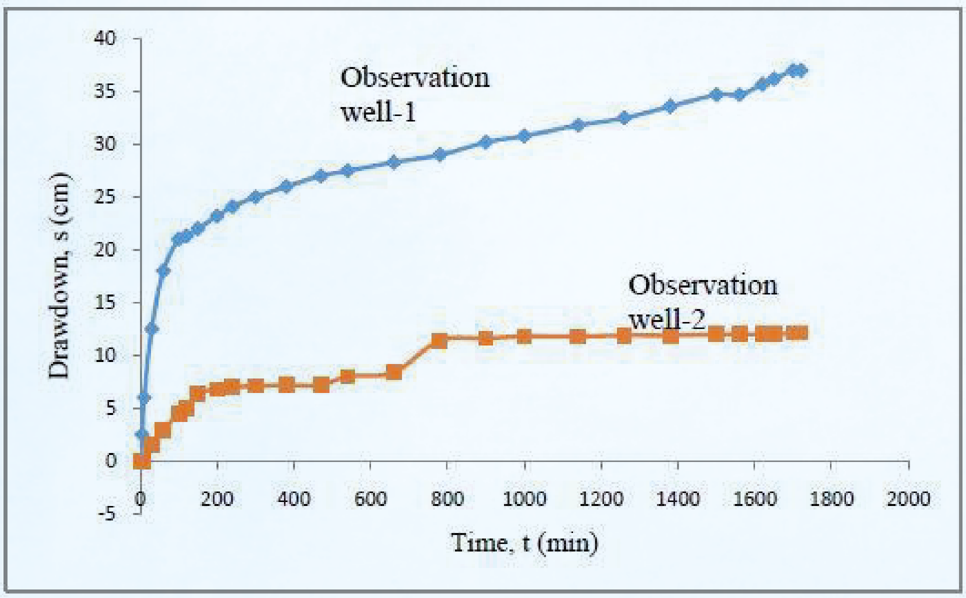


Fig. 11.63. Pattern of drawdown during the course of pumping

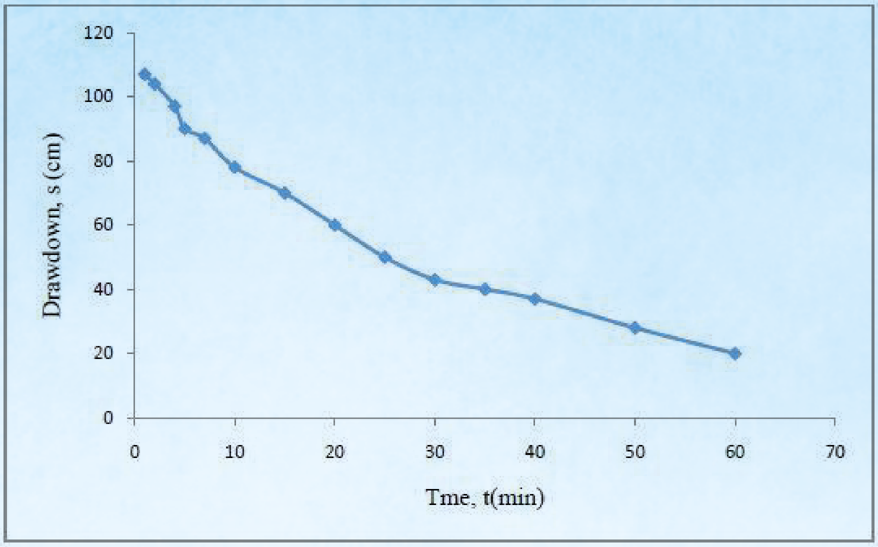


Fig. 11.64. Pattern of residual drawdown during recovery period

The hydraulic conductivity (K), Transmissibility (T) and Specific Yield (S_y) of the aquifer under different methods are presented in Table 11.26, and graphical solutions of various methods are presented from Fig. 11.65 to Fig.11.67. The coefficient of transmissibility (T) at the site ranged from 733.20 to 1299.47 m^3/m/day and hydraulic conductivity (K) ranged from 37.12 to 66.61 m^3/m^2/day. Arithmetic mean of hydraulic conductivity (K) and Transmissibility (T) of aquifer were found as 49.69 m^3/m^2/day and 971.39 m^3/m/day, respectively. Specific yield (Sy) of saturated unconfined aquifer ranged from 4.04 to 9.30. The IWM (2012) reported that in high Barind area, specific yield varied from 0.01 to 0.06, while in low Barind area, it varies from 0.06 to 0.30. Low specific yield will cause excessive drawdown in tube well, if high abstraction rates are used. The IWM (2006 and 2012) also reported that in Barind area, hydraulic conductivity varied from 10 to 70 m/day and transmissibility was lower than 1000 m^2/day or higher than 1000 m^2/day. The value of transmissibility less than 1000 m^2/day indicated poor opportunity for sustainable groundwater development in a particular area. Amah (2016) reported that for unconfined aquifer, transmissibility (T) and hydraulic conductivity (K) ranged from 485 to 1346 m^2/day and 9.7 to 27.9 m/day, respectively. The values K, T and S_y obtained in our study are within the stipulated value.

Table 11.26. Different method-wise hydraulic conductivity (K), Transmissibility (T) and Specific Yield (S_y) of unconfined aquifer in the study area (Niamatpur)

SI. No.	Method/Procedure	Well/Aquifer	Hydraulic conductivity, K (m^3/m^2/day)	Transmissibility, T (m^3/m/day)	Specific Yield, S_y
1	Dupit's Steady State Radial Flow Method	PW & OWs	37.12	733.20	-
2	From Jacob's Distance-drawdown Method	PW & OWs	40.26	785.47	9.30
3	From Jacob's Time-drawdown method	OW-1	66.61	1299.47	4.85
4	From Time Recovery Method	PW	54.71	1067.42	-
5	From Laboratory Method	Aquifer Materials	-	-	4.04
Average value (arithmetic)			49.67	971.39	6.06
Geometric mean			48.31	945.39	5.66
Range			37.12-66.61	733.20-1299.47	4.04-9.30

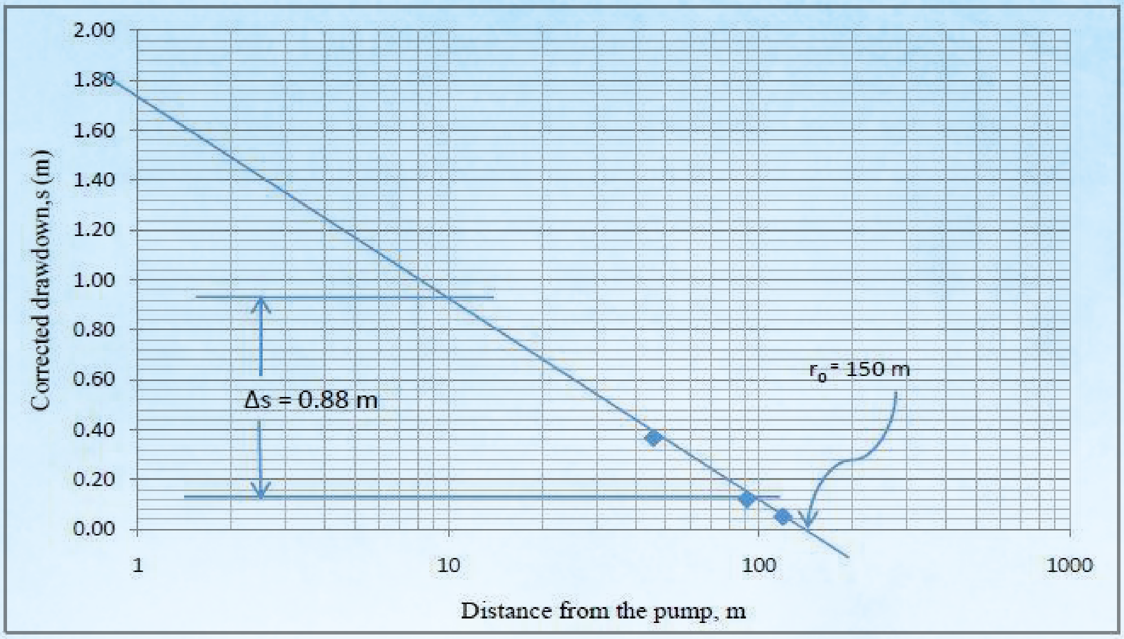


Fig. 11.65. Solution for properties by Jacob's Distance-Drawdown Method

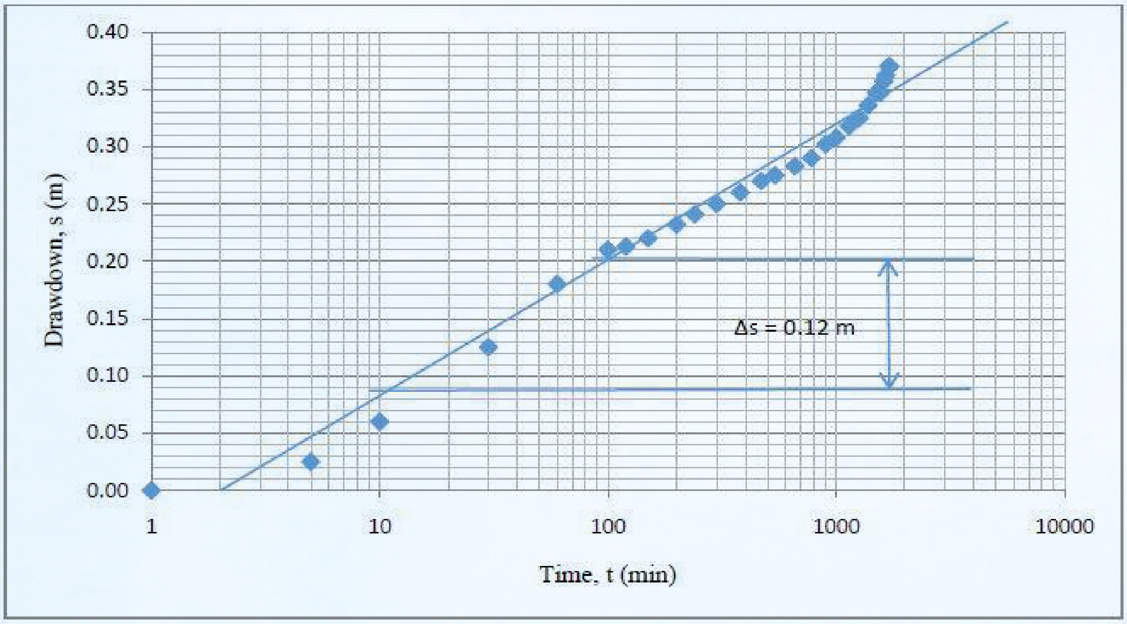


Fig. 11.66. Solution for properties by Jacob's Time-Drawdown Method (#Obs. Well-1)

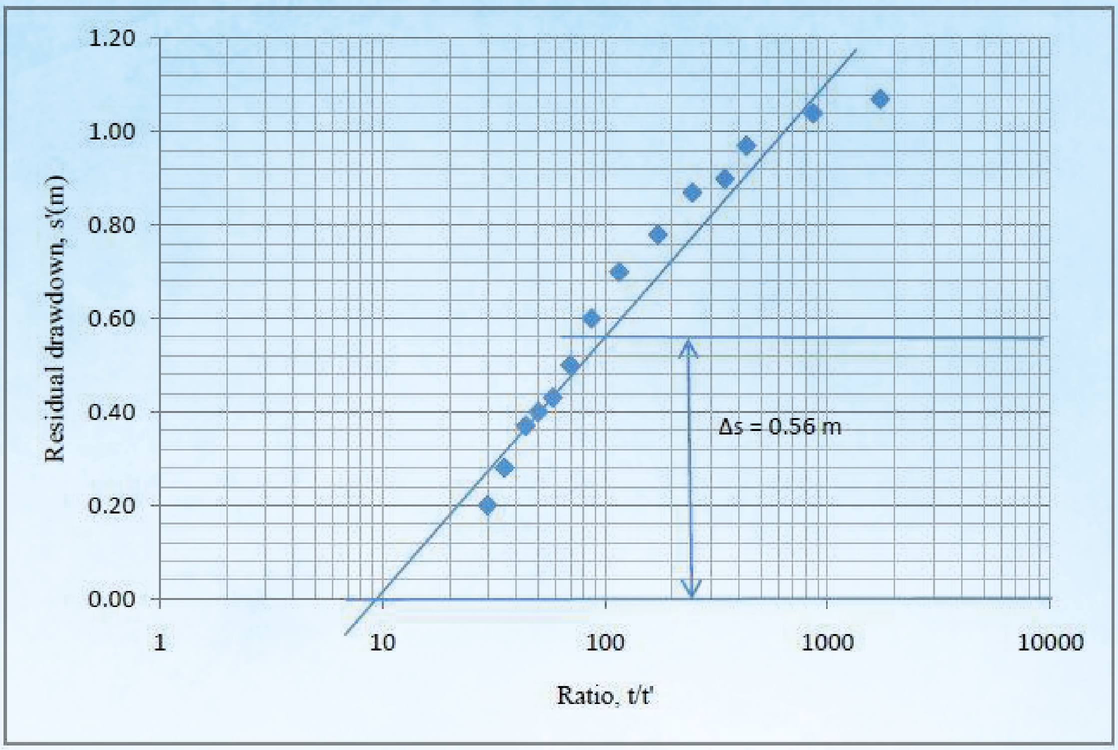


Fig. 11.67. Solution for properties by Time Recovery Method (#Pumping Well)

Well-planned extraction of groundwater resource obviously depends firstly, on aquifer potentiality as evaluated by hydraulic properties. These aquifer parameters were essentially location specific and some of them were dependent on time dynamics. However, from pumping test data analysis it was shown that a stratified, heterogeneous litho logy with clay, silty clay, very fine sand and fine sand at upper part and medium coarse, coarse and their mixture at the lower part just below another impermeable clay layer were found. The aquifer was unconfined or water table in nature and saturated thickness above the bottom of the aquifer was 20 m (65.60 feet). The static water level in the observation well was found as 33.23 m (109 ft) from ground surface and drawdown in pumping well at steady state condition was 1.55 m (5 ft). The hydraulic conductivity (K), Transmissibility (T) and Specific yield (Sy) of aquifer were found as 17.34 to 55.35 m^3/m^2/day, 433.41 to 1383.69 m^3/m/day and 4.03 to 5.03%, respectively under different methods. For Niamatpur area, the K, T and Sy were found as 37.12 to 54.71 m^3/m^2/day, 733.20 to 1299.47 m^3/m/day and 4.04 to 9.30%, respectively.

11.2.3.2. Trend of groundwater level fluctuation

The patterns of yearly maximum and minimum water-table data of 40 years from 1981 to 2020 at Nachole were depicted in Fig.11.68 and Fig.11.69, and Niamatpur in Fig.11.70 and Fig.11.71, respectively. Here, the magnitude between maximum and minimum depth to water-table was decreasing over time, meaning that the recharge rate was decreasing.

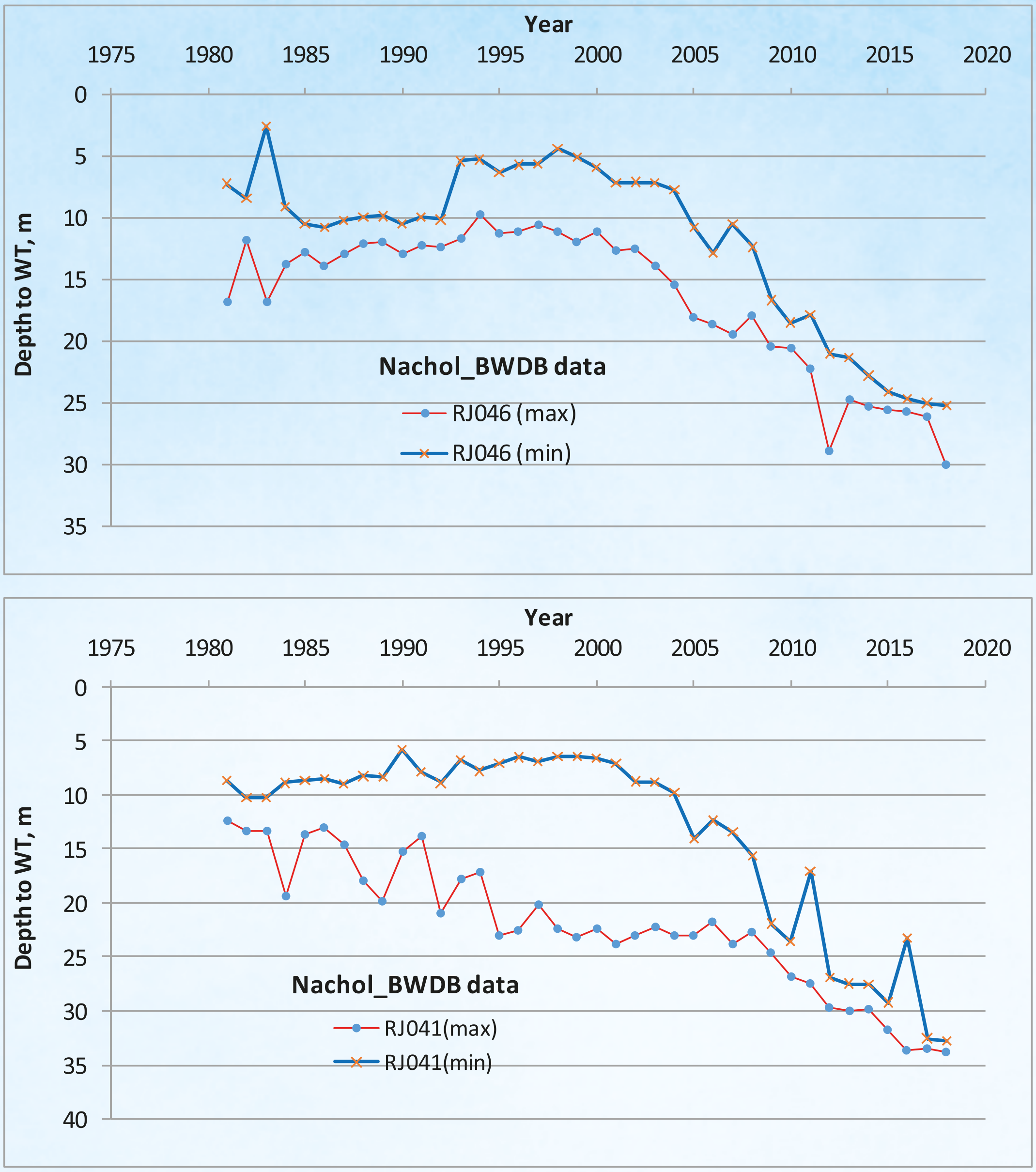


Fig. 11.68. WT fluction pattern of two wells at Nachole

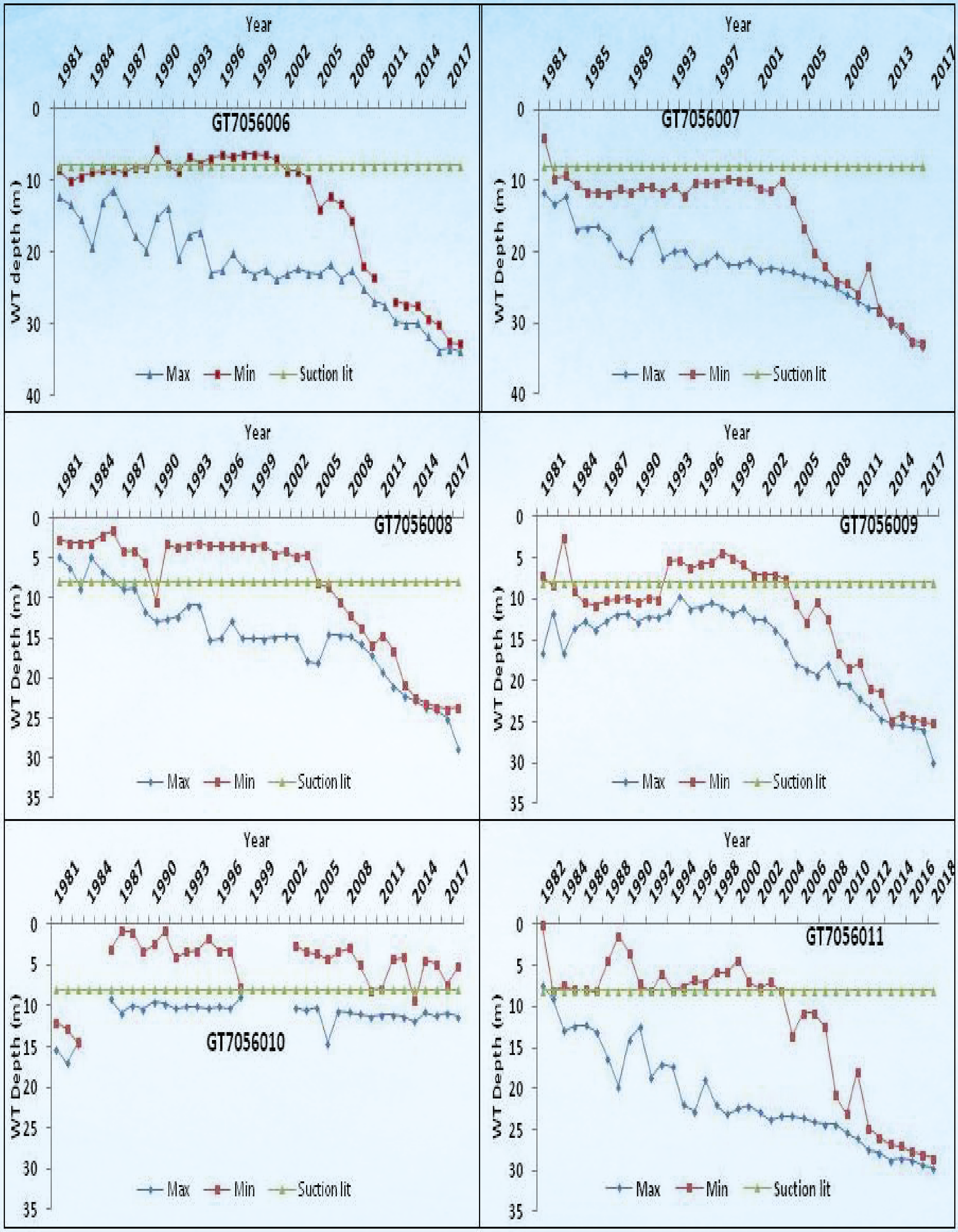


Fig. 11.69. Long-term yearly maximum and minimum WT depth scenario of different wells at Nachole upazila

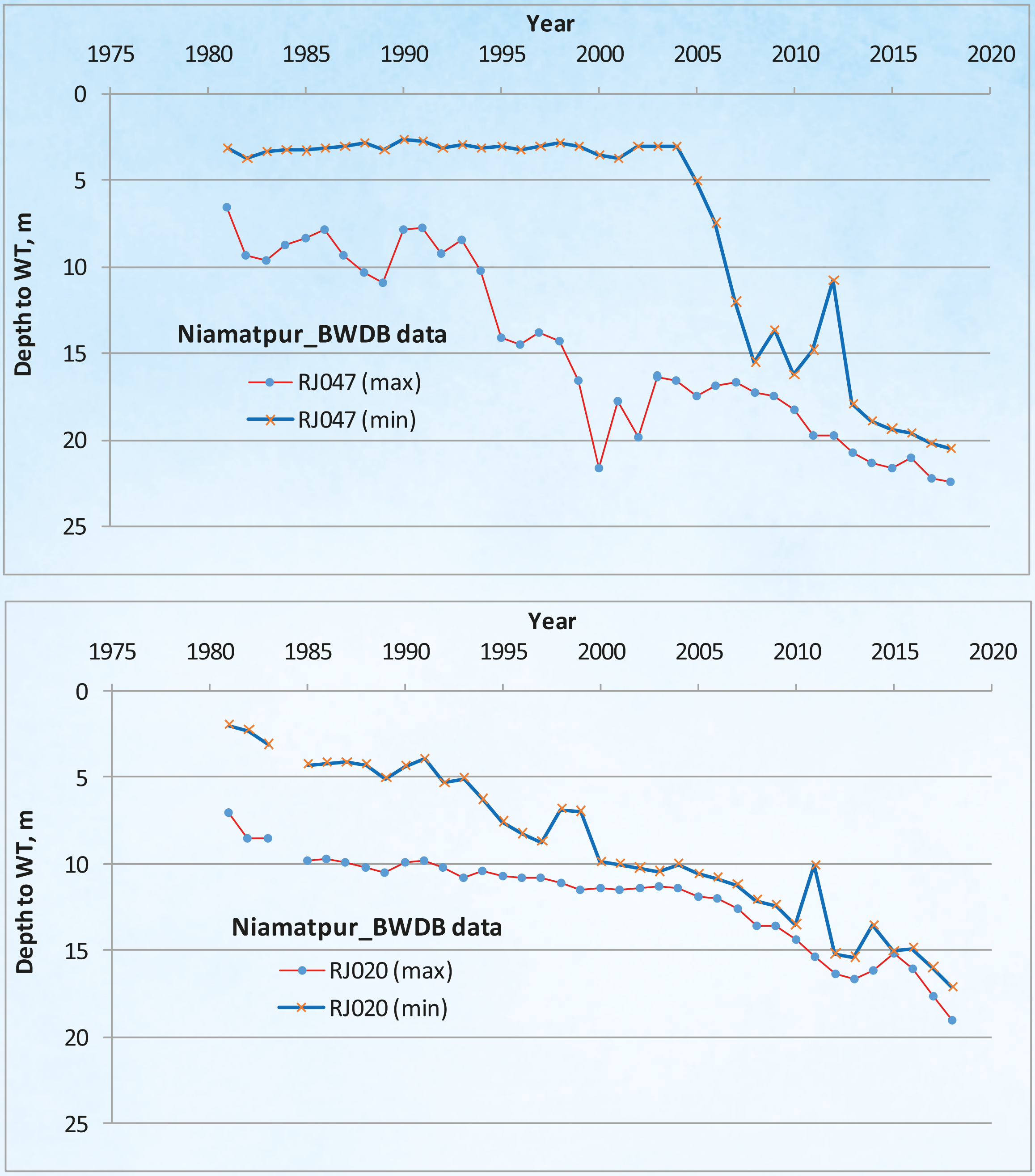


Fig. 11.70. WT fluctuation pattern of two wells at Niamatpur

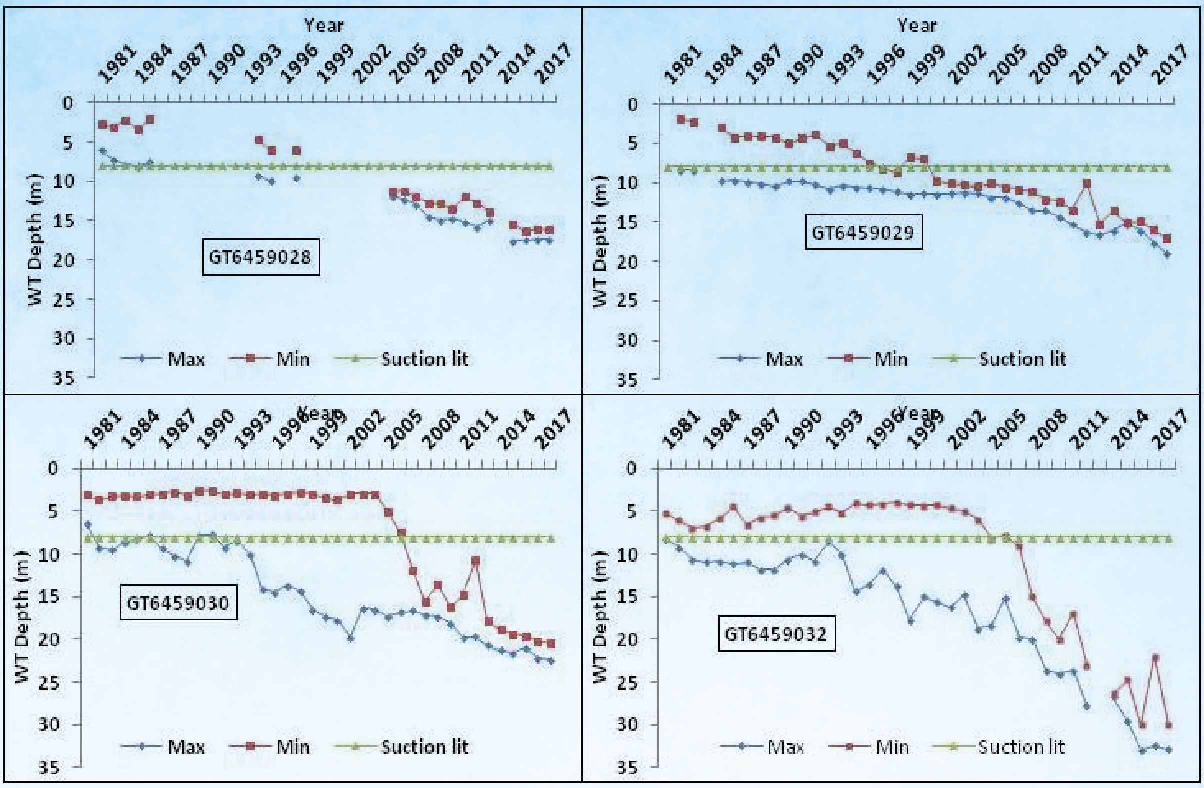


Fig. 11.71. Long-term yearly maximum and minimum WT depth of different wells at Niamatpur upazila

11.2.3.3. Groundwater table scenario by MAKESENS model

The position of water-table (both maximum and minimum) in different wells of Nachole and Niamatpur in 1981 and 2018, and the predicted scenario for 2050, 2075 and 2100 are tabulated in Table 11.27 and Table 11.28 for Nachole and in Table 11.29 and Table 11.30 respectively for Niamatpur. In 2050, the depth to water-table would be about 1.5 times and that in 2075, would be nearly double of those in 2018.

Table 11.27. Position of maximum WT depth in the past, at present and simulated scenario for future, using MAKESENS software at Nachole upazilla

Upazilla	Well no	WT depth (m) in year		B	Q	Predicted WT depth(m) in year			Significance level of trend
		1981	2018			2050	2075	2100	
Nachole	GT7056006	12.3	33.45	12.38	0.523	48.49	61.57	74.66	***
	GT7056007	11.72	33.52	13.53	0.469	45.90	57.63	69.36	***
	GT7056008	4.82	25.1	5.80	0.490	39.61	51.86	64.11	***
	GT7056009	16.72	26.00	8.63	0.410	36.94	47.19	57.45	***
	GT7056010	15.27	10.88	9.81	0.037	12.35	13.27	14.19	*
	GT7056011	7.37	29.69	11.30	0.518	47.06	60.01	72.97	***

Table 11.28. Position of minimum WT depth in the past, at present and simulated scenario for future, using MAKESENS software at Nachole upazilla

Upazilla	Well no	WT depth (m) in year		B	Q	Predicted WT depth(m) in year			Significance level of trend
		1981	2018			2050	2075	2100	
Nachole	GT7056006	8.56	32.72	2.60	0.57	41.67	55.82	69.97	***
	GT7056007	4.03	32.85	5.49	0.59	46.08	60.78	75.49	***
	GT7056008	2.67	23.6	-0.55	0.50	33.69	46.09	58.50	***
	GT7056009	7.22	25.2	4.78	0.45	35.66	46.85	58.04	***
	GT7056010	12.00	5.22	2.19	0.08	7.49	9.41	11.32	*
	GT7056011	8.00	28.02	0.17	0.62	43.26	58.87	74.49	***

Table 11.29. Position of maximum WT depth in the past, at present and simulated scenario for future, using MAKESENS software at Niamatpur upazilla

Location	Well no	WT depth (m) in year		B	Q	Predicted WT depth(m) in year			Significance level of trend
		1981	2018			2050	2075	2100	
Niamatpur	GT6459029	8.46	19.05	7.91	0.213	22.57	27.89	33.20	***
	GT6459030	9.28	21.3	7.06	0.419	35.98	46.45	56.93	***
	GT6459031	7.02	13.44	6.72	0.215	21.55	26.93	32.30	***
	GT6459032	9.25	26.8	6.18	0.587	46.68	61.36	76.03	***

Table 11.30. Position of minimum WT depth in the past, at present and simulated scenario for future, using MAKESENS software at Niamatpur upazilla

Location	Well no	WT depth (m) in year		B	Q	Predicted WT depth(m) in year			Significance level of trend
		1981	2018			2050	2075	2100	
Niamatpur	GT6459029	1.8	17.12	1.35	0.395	28.59	38.46	48.33	***
	GT6459030	3.05	20.5	-0.19	0.425	29.14	39.76	50.39	***
	GT6459031	0.95	16.00	-0.36	0.404	27.54	37.65	47.76	***
	GT6459032	5.24	30.00	2.09	0.426	31.45	42.09	52.73	***

In case of cell is blank, the significance level is greater than 0.1
B = Intercept of linear regression equation
Q = Slope of linear regression equation
*** trend is significant at α=0.001
** trend is significant at α=0.01
* trend is significant at α=0.05
+ trend is significant at α=0.1

The patterns of yearly maximum and minimum water-table at Nachole and Niamatpur indicated that, the magnitude between maximum and minimum depth to water-table is decreasing over time, meaning that the recharge rate is decreasing. The predicted scenario of WT for 2050 and 2075 indicated that in 2050, the depth to water-table would be about 1.5 times and that in 2075, would be nearly double of those in 2018.

11.2.3.4. Climatic parameter analysis: Rainfall pattern and trend

Yearly rainfall pattern and trend

Long-term (1975 – 2019) rainfall pattern of yearly rainfall is shown in Fig.11.72. The rainfall is erratic having mean, standard deviation and co-efficient of variation of 1447 mm, 297 mm and 487 percent respectively. Yearly rainfall showed decreasing trend, which, on average, was 6.899 mm per year.

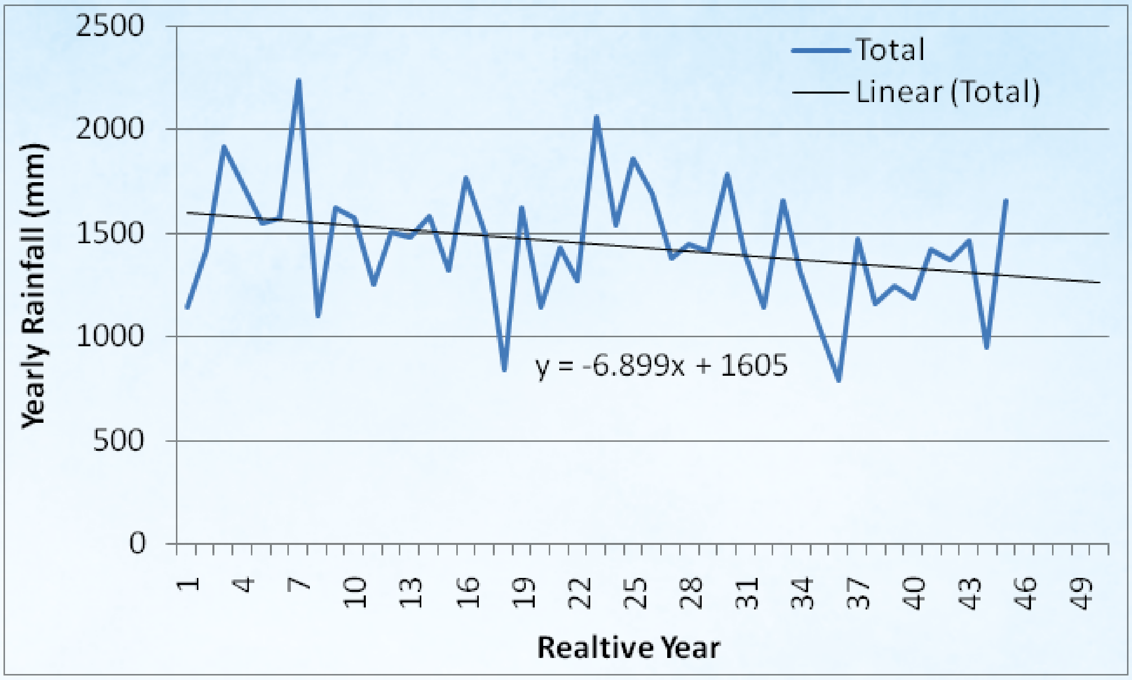


Fig. 11.72. Pattern of yearly rainfall at Rajshahi

The trend of yearly total rainfall was found significant by non-parametric method (*Rho*-test), and insignificant by regression slope test.

Monthly rainfall pattern and trend

The long-term (1975-2019) average monthly rainfall in different months of the year is shown in Fig.11.73. Although the rainy season was started in April and continued up to October, the period from June to September were normally water surplus (rain>ET) period.

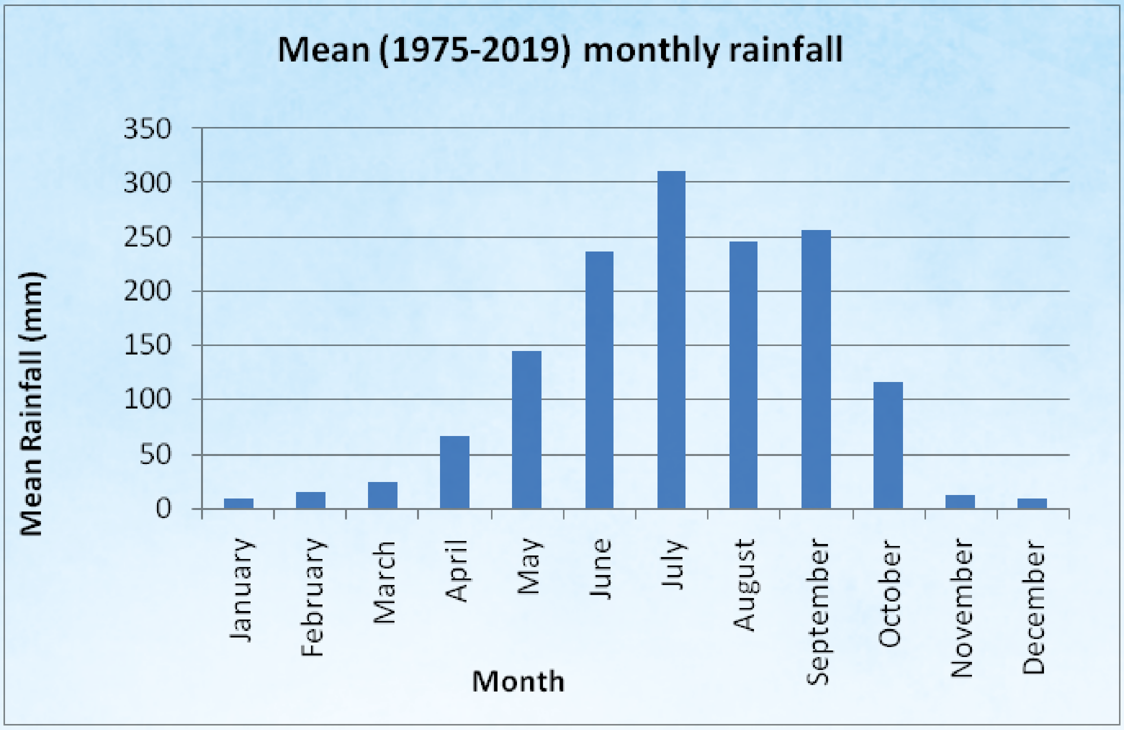


Fig. 11.73. Long-term (1975-2019) average monthly rainfall pattern at Rajshahi

The long-term (1975 – 2019) pattern of monthly rainfall is shown in Fig.11.74 and Fig.11.75. The patterns were also uneven and erratic.

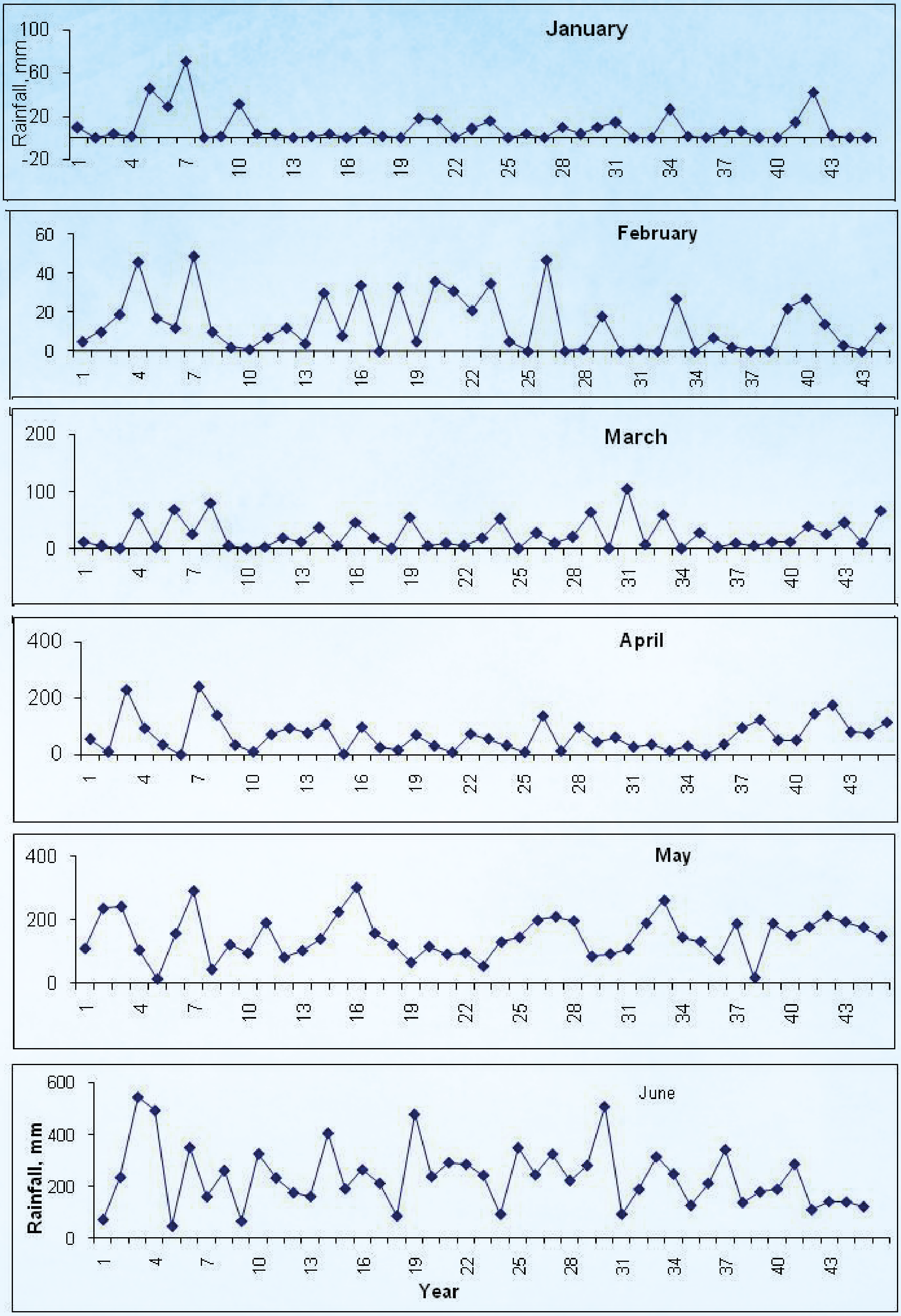


Fig. 11.74. Pattern of monthly rainfall (Jan. - June) throughout the period (1975-2019) at Rajshahi

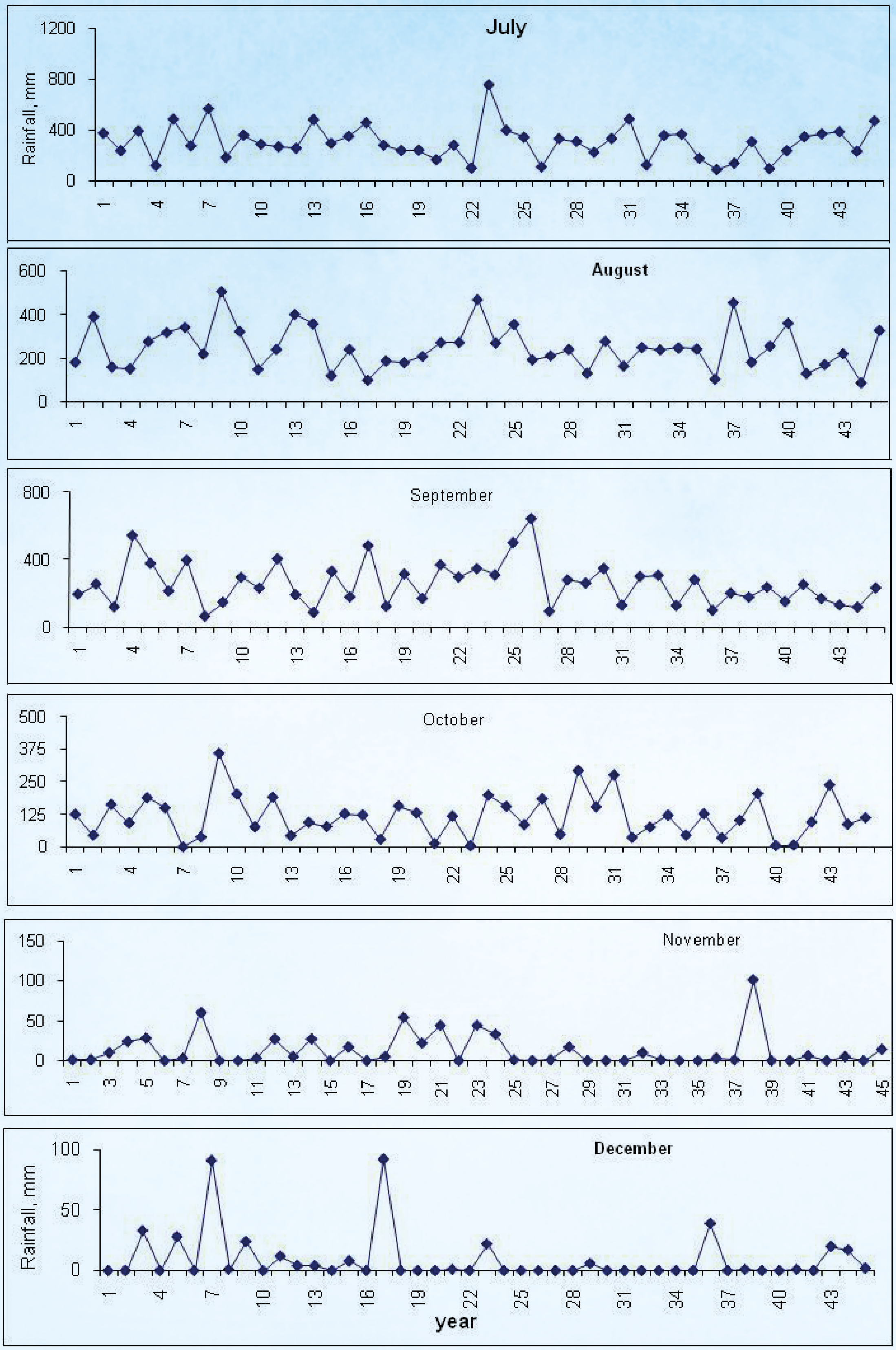


Fig. 11.75. Pattern of monthly rainfall (July – Dec.) throughout the period (1975-2019) at Rajshahi

Trend of monthly rainfall

Monthly rainfall trend, as examined by non-parametric, 'Spearman's Rho' test, is summarized in Table 11.28. All of the months except December showed 'no trend'.

Table 11.31. Trend of monthly rainfall (from non parametric test) of Rajshahi

Month	Trend (from non parametric test)
January	0
February	0
March	0
April	0
May	0
June	0
July	0
August	0
September	0
October	0
November	0
December	+

Note: ' + ' , ' – ' , and ' 0 ' implies' increasing', 'decreasing' and 'no trend', respectively.

Yearly rainfall showed decreasing trend, which on average, was 6.899 mm per year. Both yearly and monthly rainfall fluctuates considerably. The trend of yearly rainfall was found significant by non-parametric method (Rho-test), but insignificant by regression slope test. In case of monthly rainfall, all of the months except December showed 'no trend' by 'Rho-test'.

11.2.3.5. Groundwater recharge assessment

Nachole - Year 2018

The pattern of tracer concentration throughout the soil profile was depicted in Fig. 11.76. From tracer technique, the yearly recharge was found as 180 mm (12.4 % of rainfall) (Table 11.32). From water balance method, the yearly recharge was found as 96.5 mm (6.7% of rainfall); while from water-table fluctuation (WTF) method, it was estimated as 98.7 mm (5.4 % of RF).

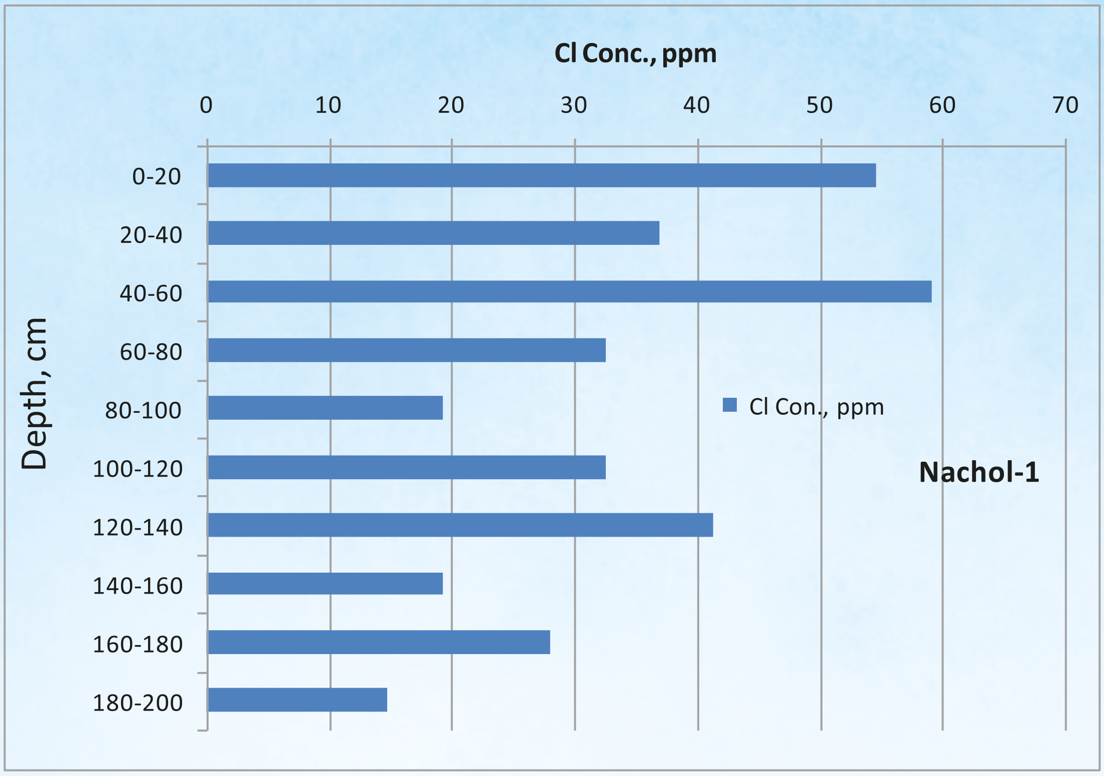


Fig. 11.76. Concentration profile of tracer at Nachole during 2018

Table 11.32. Recharge estimates at Nachole during 2018

Method	Recharge (mm/year)	Yearly rainfall (mm)	Recharge as percentage of rainfall
Tracer	180	1450	12.4
Water balance	96.5	1450	6.7
WTF method	98.7	1450	6.8

Nachole - Year 2019

The pattern of tracer concentration throughout the soil profile is depicted in Fig. 11.77. From tracer technique, yearly recharge was found as 211.6 mm, which was about 15.3 % of yearly rainfall (Table 11.33). The yearly recharge was found as 149.1 mm by water balance method, which was 10.7 % of rainfall. From WTF method, it was found as 106.6 mm (7.68 % of rainfall).

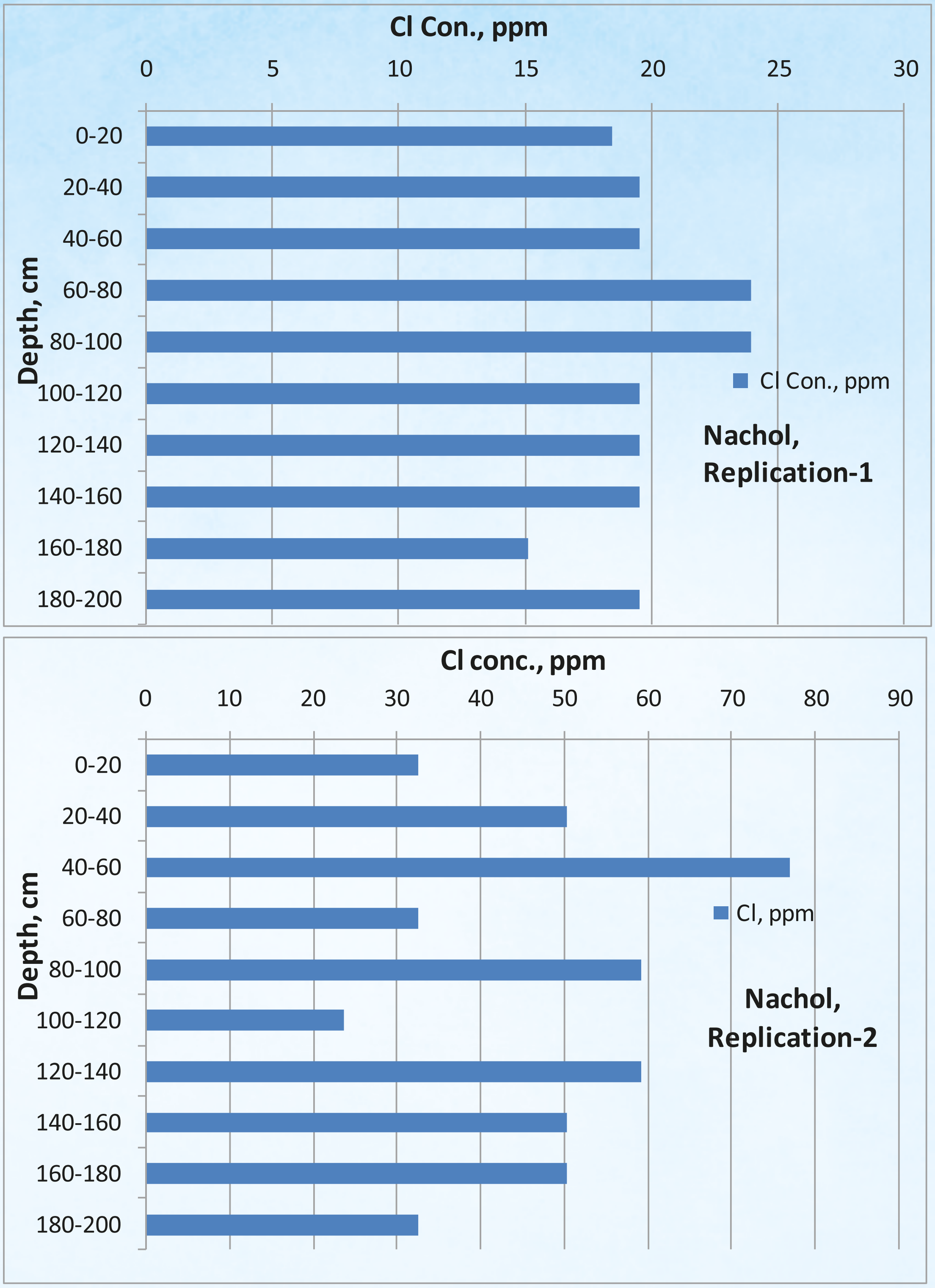


Fig. 11.77. Distribution of tracer concentration at Nachole during 2019

Table 11.33. Recharge estimates at Nachole during 2019 (tracer and water balance method)

Method	Replication	Recharge (mm/year)	Average	Yearly rainfall (mm)	Recharge as percentage of rainfall
Tracer	R1	155	211.67	1387	15.3
	R2	210			
	R3	270			
Water balance	-	149.1		1387	10.7
Water-table fluctuation method	-	106.6	106.6	1387	7.68

Average of two years

When averaged over years (Table 11.34), average yearly recharge from tracer technique, water balance method, and WTF method was found as 195.8 mm, 122.8 mm, and 102.65 mm, respectively.

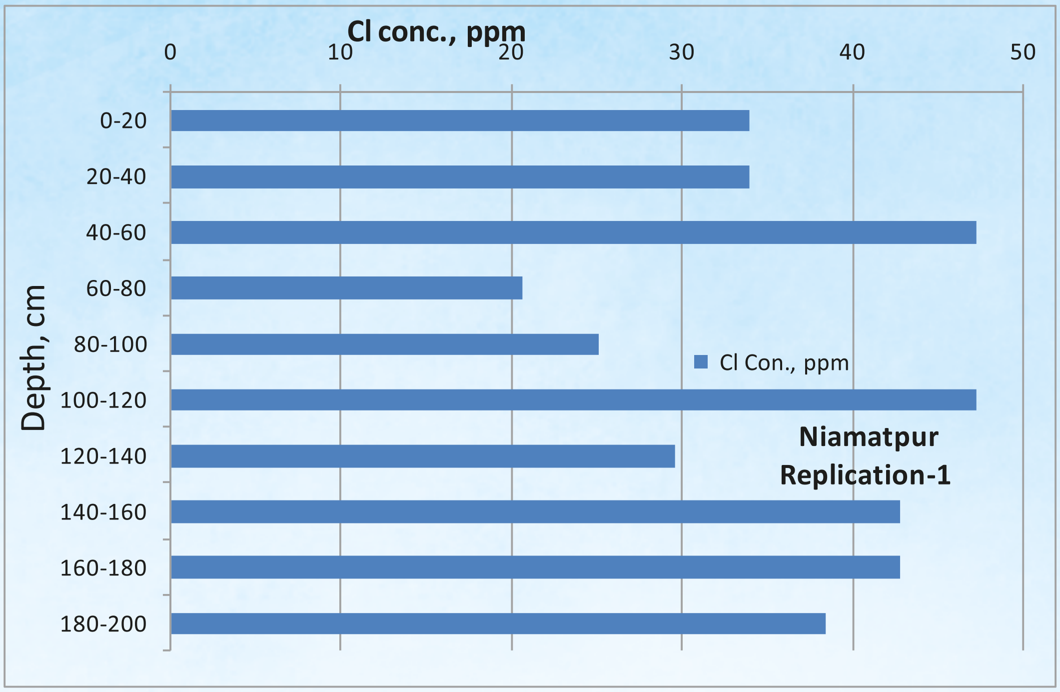
Table 11.34. Average recharge at Nachole under different methods

Method	Yearly recharge (mm)		Average recharge (mm)
	2018	2019	
Tracer technique	180	211.67	195.8
Water balance	96.5	149.1	122.8
WTF method	98.7	106.6	102.65

Yearly recharge at Nachole area varied from 98.7 to 211.7 mm/year under different methods (7.6 – 15.3% of yearly rainfall) for the study period. When averaged over years, it was found as 195.8, 122.8, and 102.65 mm under tracer technique, water balance method, and water-table fluctuating method, respectively.

Niamatpur – Year 2019

The pattern of tracer concentration is depicted in Fig.11.66. From tracer technique, the yearly average recharge was found as 210 mm, which was about 15.14 % of rainfall (Table 11.35). The yearly recharge was found as 149.1 mm by water balance approach, which was about 10.7 % of rainfall; while under WTF method it was found as 137.6 mm (9.92 % of rainfall).



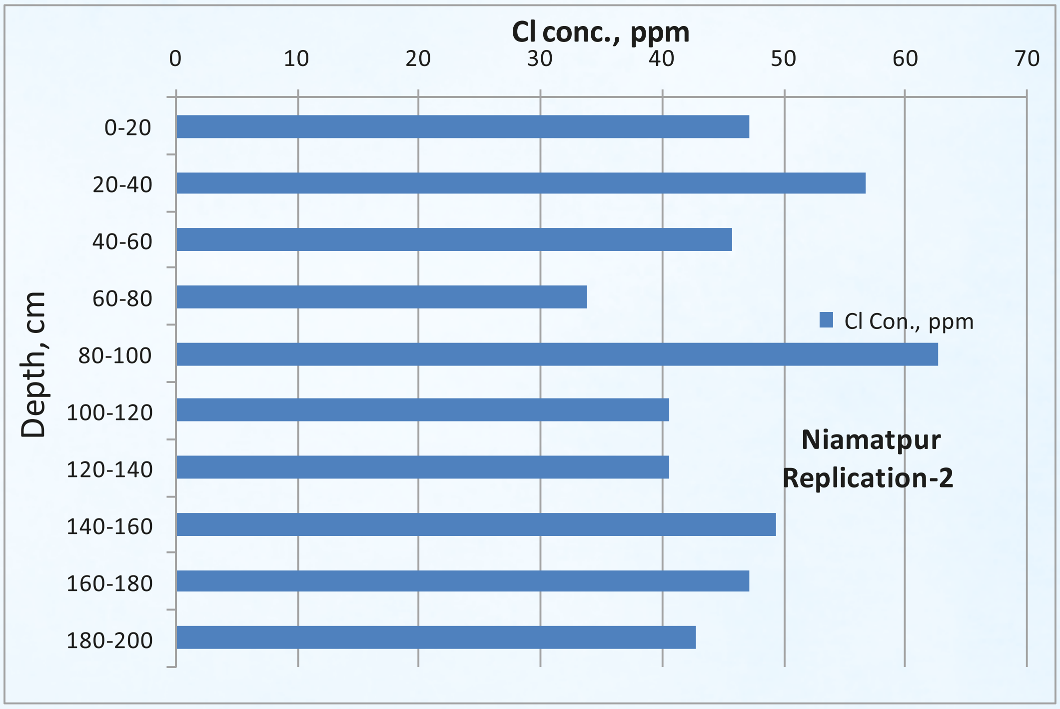


Fig. 11.78. Distribution of tracer concentration at Niamatpur during 2019

Table 11.35. Recharge estimates at Niamatpur during 2019

Method	Replication	Recharge (mm/year)	Average (mm)	Yearly rainfall (mm)	Recharge as percentage of rainfall (%)
Tracer	R_1	150	210	1387	15.14
	R_2	270			
Water balance	R_1	149.1	149.1	1387	10.7
WTF method	-	137.6	137.6	1387	9.92

Yearly recharge at Niamatpur area was found as 210 mm, 149.1 mm, and 137.6 mm under tracer technique, water balance method, and water-table fluctuating method, respectively. In terms of annual rainfall, it was about 15.14%, 10.7%, and 9.92 % of rainfall.

11.2.3.6. Groundwater quality assessment

The quality parameters are summarized in Table 11.33 for Nachole and Niamotpur. A number of 50 samples from 25 of each location were analyzed. The results were compared with the standard of GoB, WHO (2017), ESB (USA, for irrigation) and AHMAD. Most of the parameters were within the permissible limit according to both the guidelines. In terms of irrigation suitability, the water samples were within the permissible limit of FAO and GoB.

Table 11.36. Groundwater quality status of Nachole & Niamatpur

Sample no.	pH	Ec (ds/m)	Fe (mg/L)	Total Cl (mg/L)	Mg (mg/L)	NO3 (mg/L)	TDS (mg/L	PO4 (mg/L)	SO4 (mg/L)	Na (mg/L)	Cr (mg/L)	Ca (mg/L)	K (mg/L)	Cu (mg/L)
Nachole	7.11	0.46	0.08	0.05	16.00	2.42	232.50	0.40	10.89	19.25	3.25	31.64	24.80	0.09
Niamatpur	6.97	0.56	0.14	0.05	22.00	11.06	444.20	0.63	9.29	14.49	22.50	28.86	22.20	0.06
ESB (Irri.)	6.0-8.5	1.2	5	-				15			0.1			0.2
GOB (drink)	-	0.6-1	0.3-1	150-600	30-35	10	1000	6	400	200		75	12	1
WHO (drink)	6.5-8.5	<0.7 ds/m	-	-	-	50 as N	-		-	-		-	10	2
FAO (Irri.)	6.5-8.4	<0.7 ds/m	<5	<92			*<450							<0.2

*Degree of Restriction: None <450 mg/l or ppm; Slight to moderate 450-2000 mg/l or ppm;

Assessment of water quality for irrigation

It is seen from Table 11.37 that all the parameters SAR, MAR, KR, TH and SSP were found within the accessptable limit. Therefore, the result revealed that groundwater in the project area was suitable for irrigation.

Table 11.37. Assessment of water quality

Parameter	Nachole	Niamatpur	Recommended limit (FAO)	Status
SAR	0.77	0.55	<10	Normal
MAR	28.27	35.41	<50	Suitable
KR	0.35	0.24	<1	Suitable
TH	117.90	129.44	<500	Normal
SSP	38.45	31.66	20-40	Normal

In terms of irrigation suitability, the water samples were within the permissible limit of FAO and GoB. In terms of drinking suitability, the water samples were within the permissible limit of WHO.

11.3. Groundwater abstraction pattern

11.3.1. Component-1: BARI

11.3.1.1. Abstraction for irrigation, domestic and municipal water demand

Groundwater abstraction for irrigation, domestic and municipal requirement is presented in Figure 11.79, 11.80, 11.81 and 11.82. While future prediction of groundwater abstraction for irrigation, domestic and municipal use in the study areas are presented in Figure 11.8. From figures, it was apparent that abstraction for domestic uses is increasing almost steadily over the years for all study areas. This is because of gradual increase of population and their demand for domestic uses. Where as abstraction for to irrigation varied over the years with less abstraction in wet (heavy rainfall) year and high in dry year. In dry year, water demand of crops was fully satisfied by groundwater while rainfall partially satisfied the crop water demand in wet year. On average over the years, increasing trend of groundwater abstraction for irrigation was evident and so did the total water abstraction. It was apparent from Figure 83 that groundwater abstraction will continue to increase if the present rate of abstraction continues. As the increasing demand of water is triggering more in Rajshahi than in Joypurhat, so more groundwater need to be abstracted in future from Barind area of Rajshahi. Abstraction will be increasing by 33-35% in Joypurhat study areas while it will be increasing by 40-45% in Rajshahi in the next 20 years. So, appropriate measures should be taken to ensure judicious use of water in all sectors especially in agriculture to protect the groundwater resources from being further depleted.

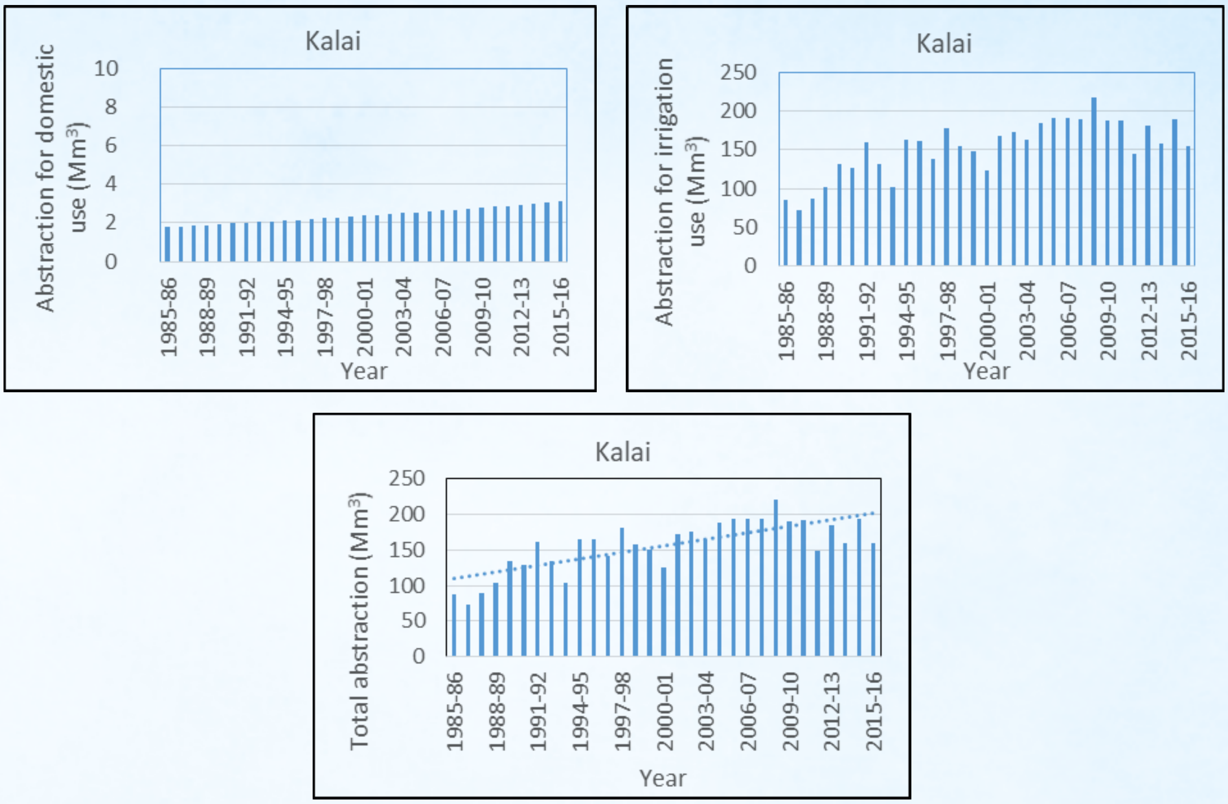


Fig. 11.79. Groundwater abstraction pattern in Kalai upazila

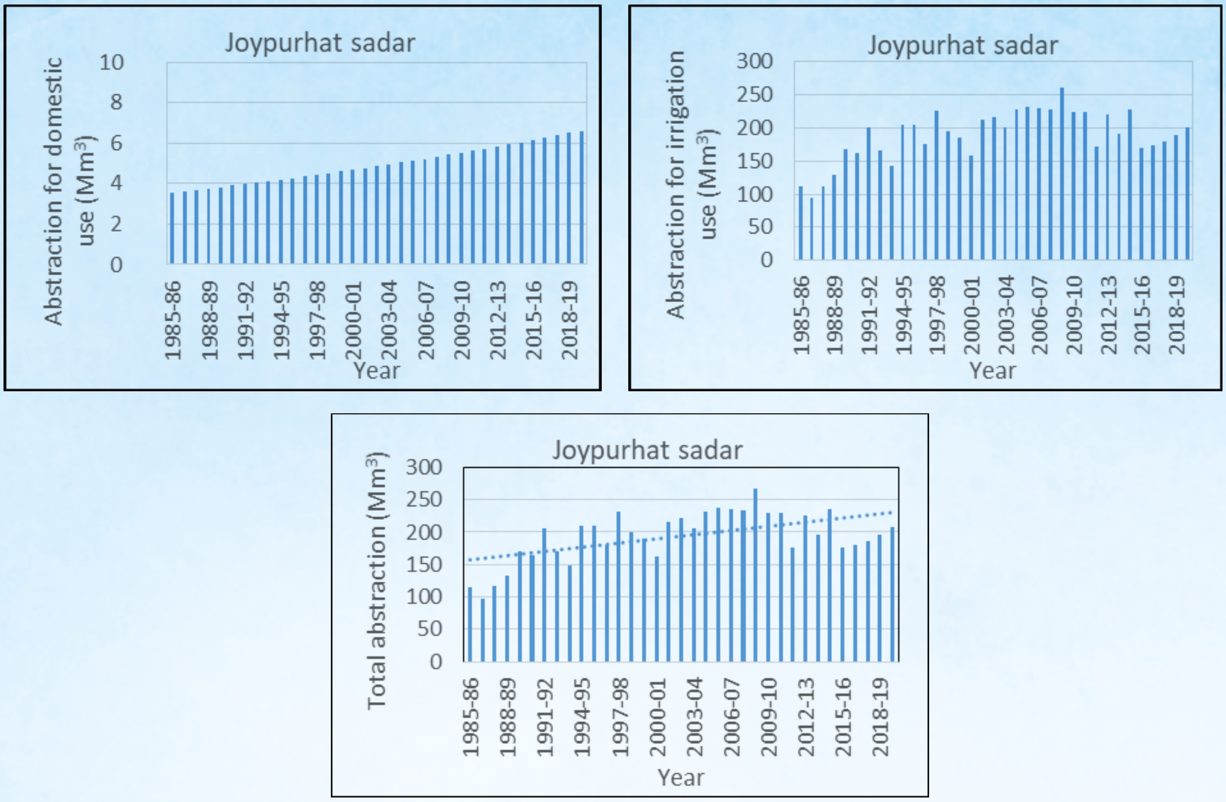


Fig. 11.80. Groundwater abstraction pattern in Joypurhat sadar upazila

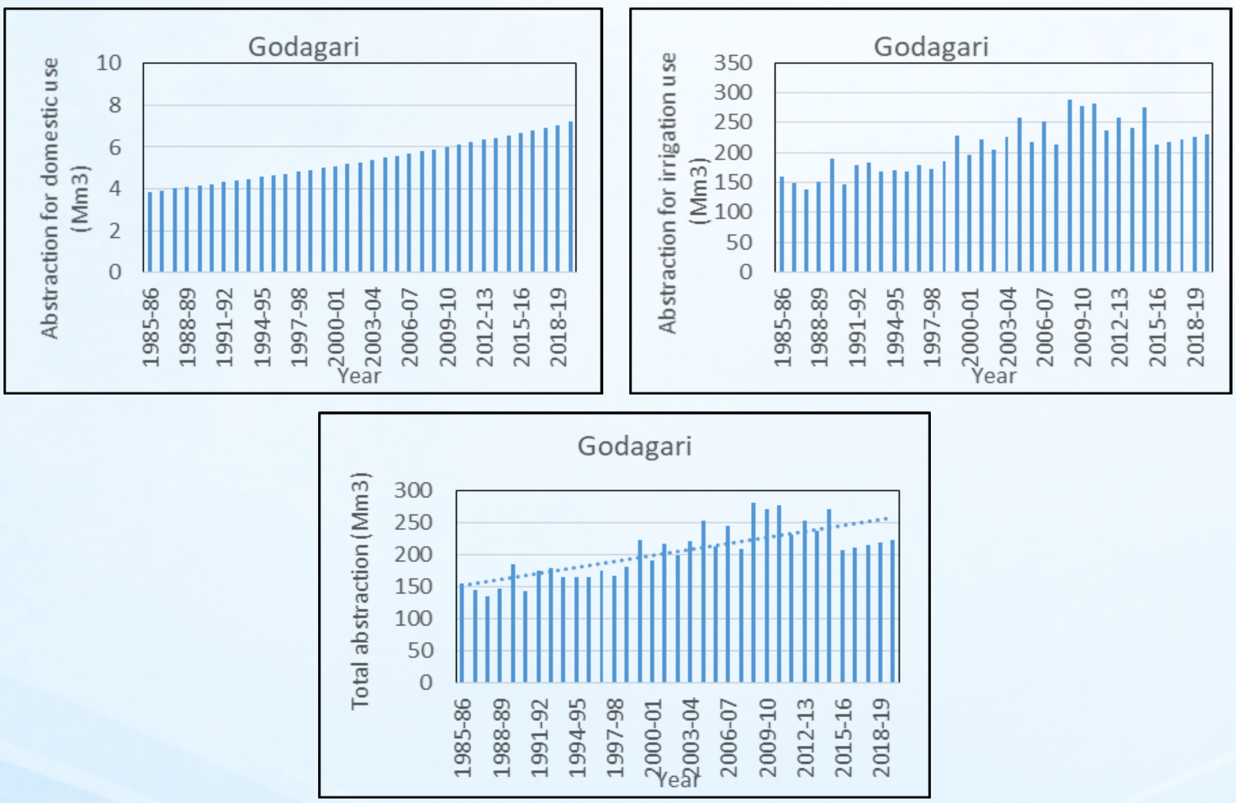


Fig. 11.81. Groundwater abstraction pattern in Godagari upazila

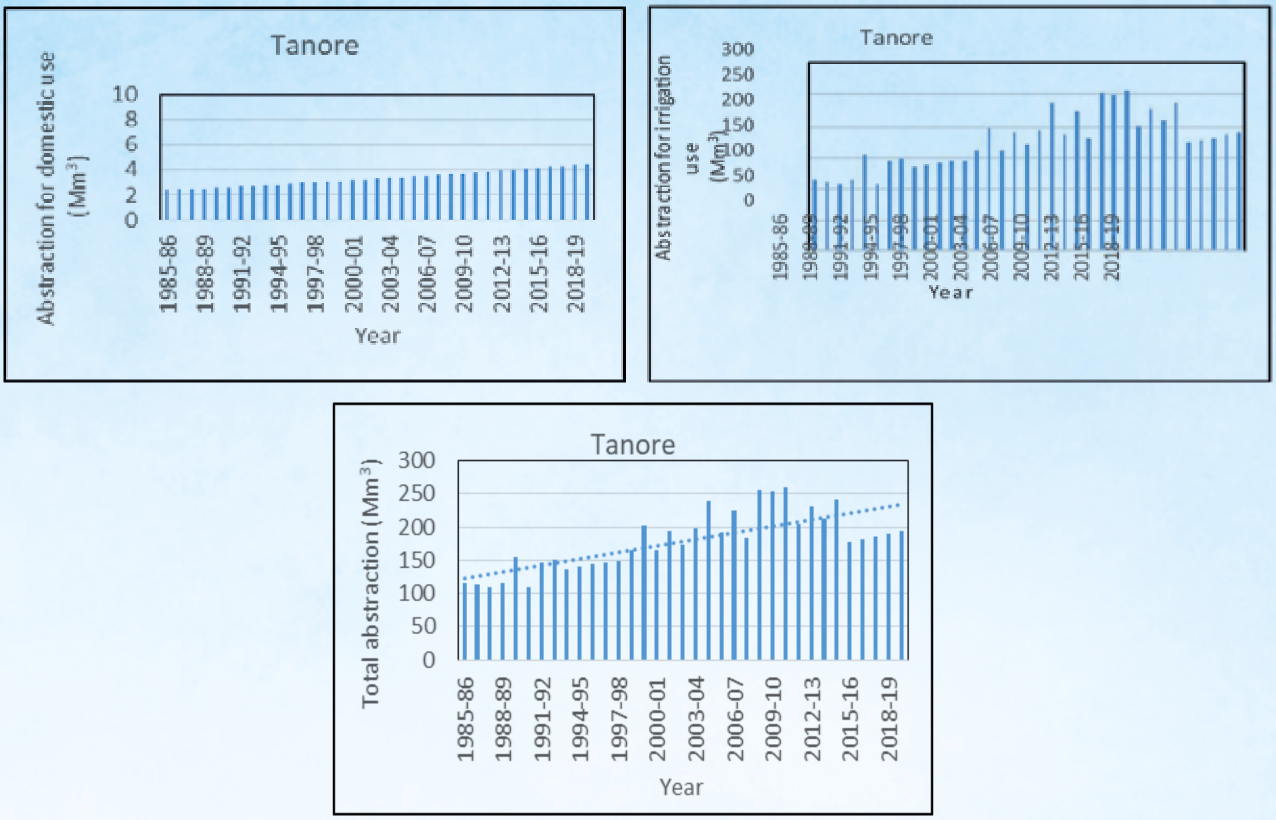


Fig. 11.82. Groundwater abstraction pattern in Tanore upazila

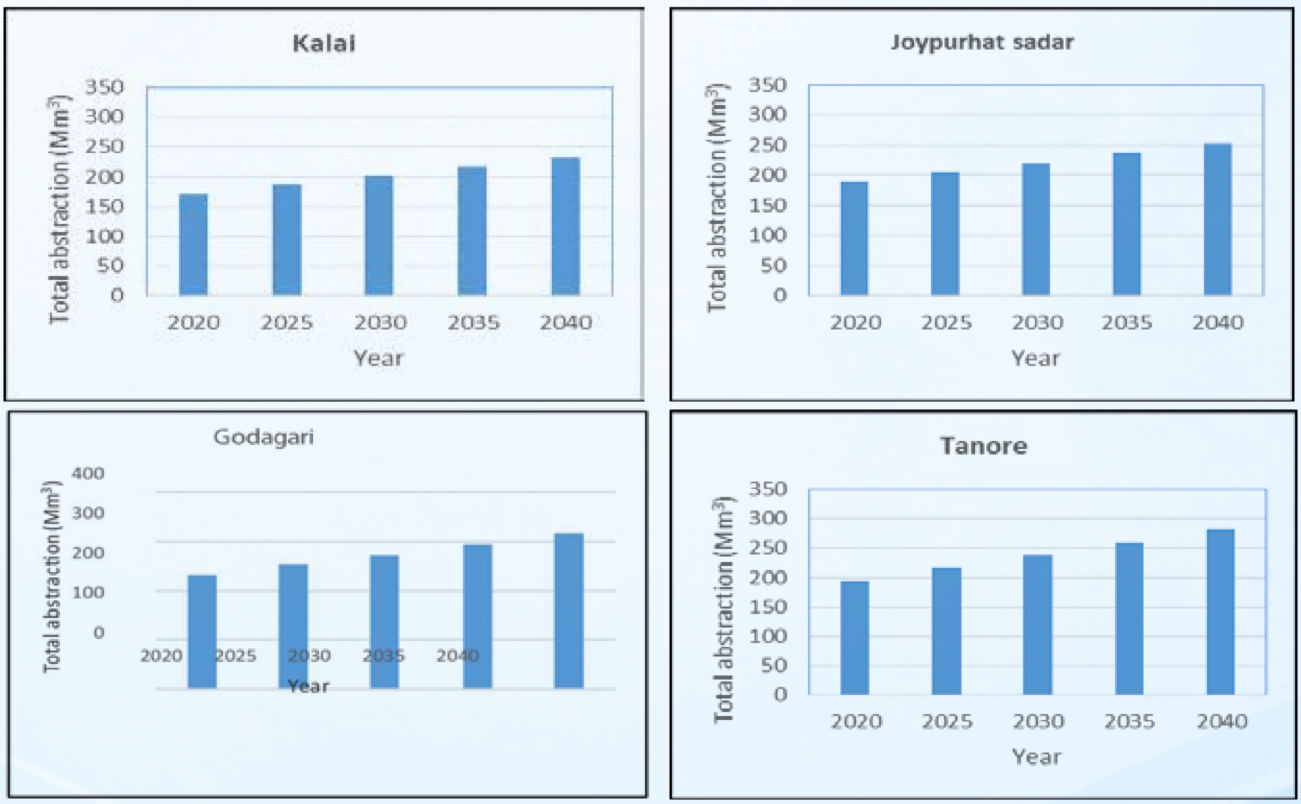


Fig. 11.83. Predicted groundwater abstraction for irrigation, domestic municipal use and in study areas

Optimization - Simulation model, MODFLOW

A numerical simulation model, MODFLOW was applied to determine the groundwater levels as well as to optimize groundwater abstraction at different observation wells in the study areas under three groundwater recharge scenarios. The model was calibrated using the available hydrogeological data of the study areas. The modeling works of the four upazilas in Rajshahi and Joypurhat districts are presented in this section. The study areas of Tanore, Godagari, Joypurhat sadar, and Kalai upazila had the aerial extents of 297.2463 km^2, 446.53 km^2, 244.03 km^2, and 156.99 km^2, respectively. The aerial map of the study areas is presented in Fig. 11.73.

In order to optimize groundwater abstraction, the following three scenarios were considered:

Scenario 1: abstraction <recharge; i.e.< 90% (more sustainable)
Scenario 2: abstraction = recharge; i.e. = 100% (less sustainable)
Scenario 3: abstraction > recharge; i.e.> 110% (business-as-usual)

The aquifer processes of the study areas were simulated using a calibrated 3D finite difference based numerical simulation code MODFLOW. The modelling and the scenario development were performed based on the very limited quantity of available hydrogeological data.

Actual and simulated groundwater levels at the observation wells during the calibration process are presented in Table 11.38.

Table 11.38. Actual and simulated groundwater levels at the observation wells during the calibration process

Observation wells	Actual (m)	Simulated (m)	Residual (m)
Tanore upazila			
GT8194046	17.52	16.388	1.13155
GT8194048	19.191	18.133	1.07832
GT8194049	20.20	22.215	-2.01514
Godagari upazila			
GT8134017	8.70	9.39	-0.68889
GT8134020	11.17	11.05	0.12381
GT8134021	6.35	6.17	0.18004
GT8134022	6.90	6.11	0.78809
Joypurhat sadar upazila			
GT3847001	11.73	11.052	0.67769
GT3847003	4.149	3.9779	0.17103
Kalai upazila			
GT3861004	7.50	7.137	0.36222
GT3861005	6.41	6.445	-0.03516

The calibration targets at different observation wells for the study areas are presented in Fig. 11.85. The components of a calibration target are illustrated in Fig. 11.84. The center of the target corresponds to the observed value. The top of the target corresponds to the observed value plus the interval and the bottom corresponds to the observed value minus the interval. The colored bar represents the error. If the bar lies entirely within the target, the color bar is drawn in green. If the bar is outside the target but the error is less than 200%, the bar is drawn in yellow. If the error is greater than 200%, the bar is drawn in red.

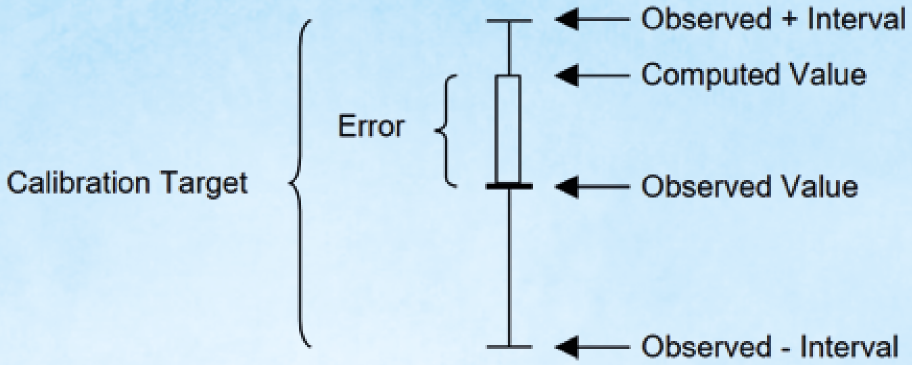


Fig. 11.84. Components of the calibration target

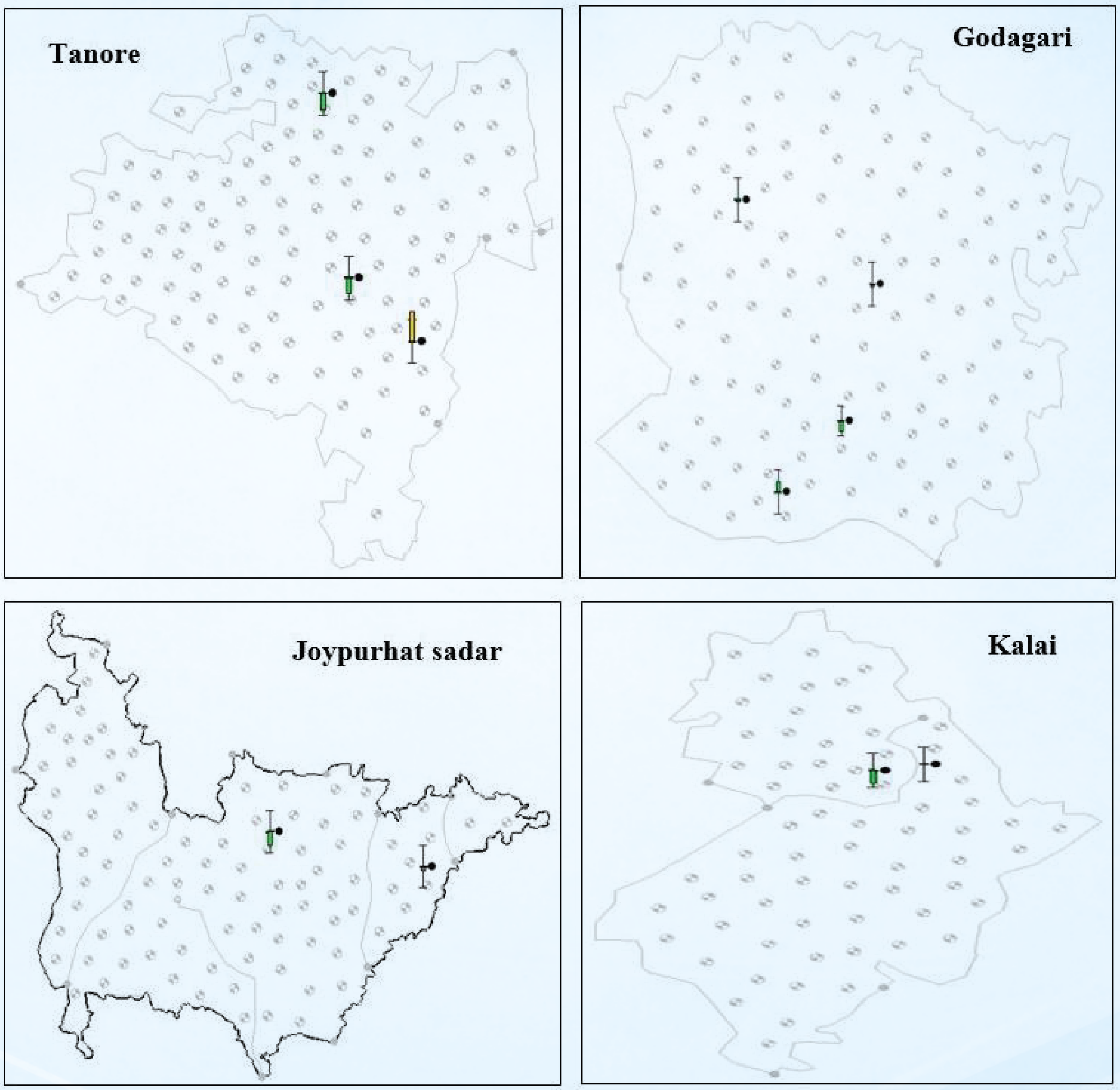


Fig. 11.85. Calibration target error bars at three observation wells

Contour plot of the simulated groundwater heads for the calibrated model is presented in Fig. 11.86. While contour plots of the groundwater heads with respect to the 10% decreased and increased recharge are shown in Fig. 11.87 and 11.88, respectively.

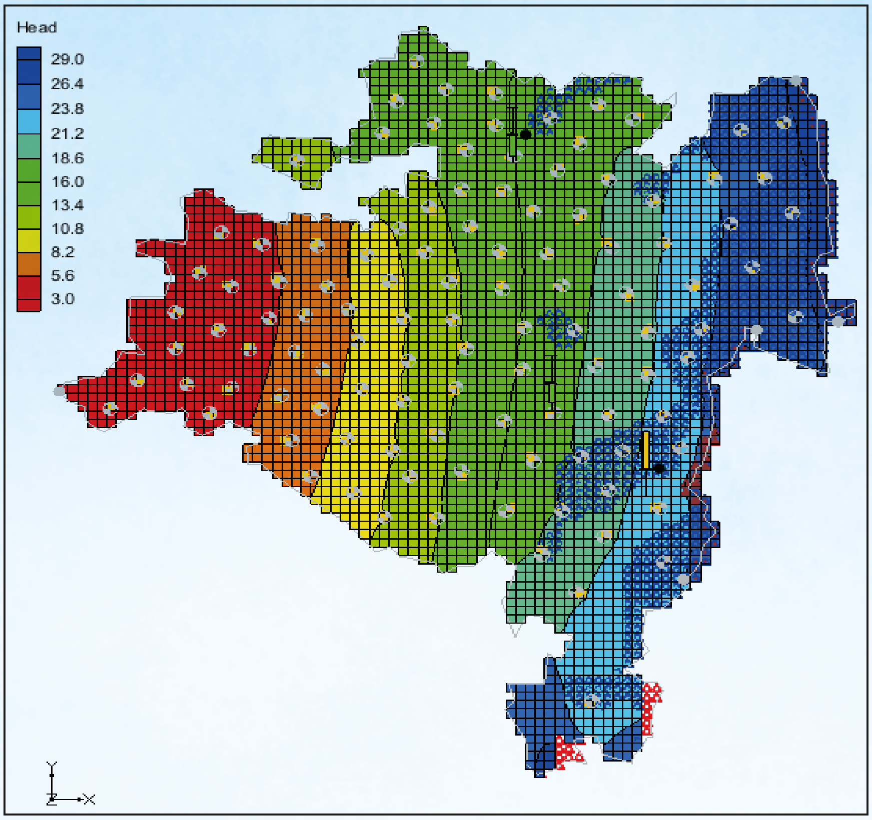


Fig. 11.86. Contour plot of the groundwater heads in the calibrated model

Computed groundwater levels for the two scenarios at the observation wells are presented in Table 11.36.

Table 11.39. Computed groundwater levels for 90% and 110% of the actual recharge

Observation wells	Actual (m)	Computed (m)	
		90% of actual recharge	110% of actual recharge
Tanore upazila			
GT8194046	17.52	7.970	20.707
GT8194048	19.191	11.150	21.745
GT8194049	20.20	18.106	24.413
Godagari upazila			
GT8134017	8.70	6.577	12.155
GT8134020	11.17	5.670	16.325
GT8134021	6.35	-0.475	12.659
GT8134022	6.90	1.447	10.682
Joypurhat sadar upazila			
GT3847001	11.73	9.406	12.688
GT3847003	4.149	3.335	4.6199
Kalai upazila			
GT3861004	7.50	6.306	7.592
GT3861005	6.41	5.533	6.943

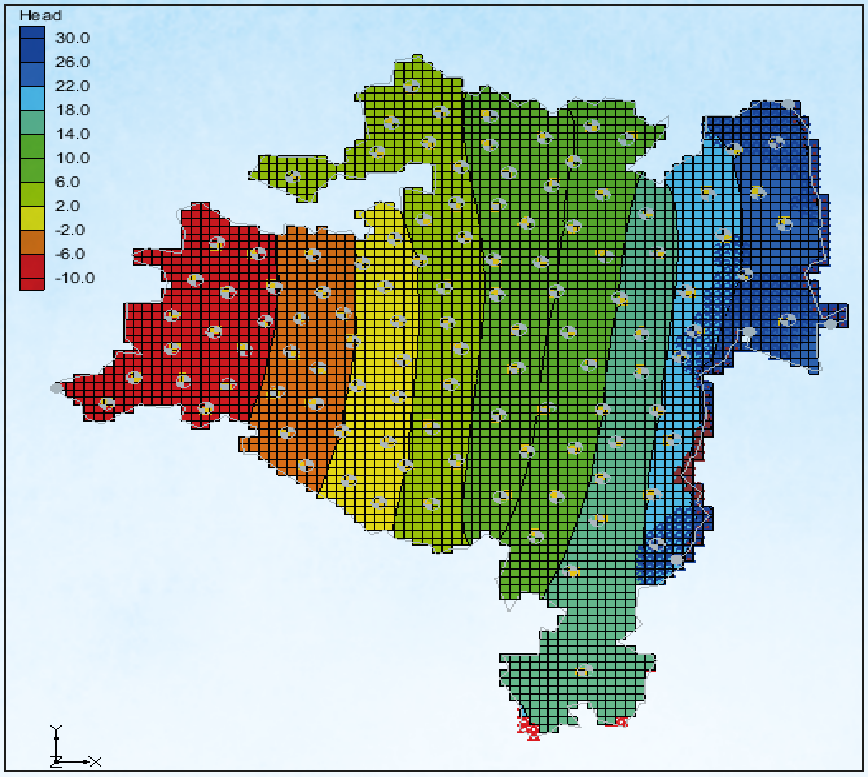


Fig. 11.87. Contour plot of the groundwater heads with respect to the decreased recharge (90% of the actual)

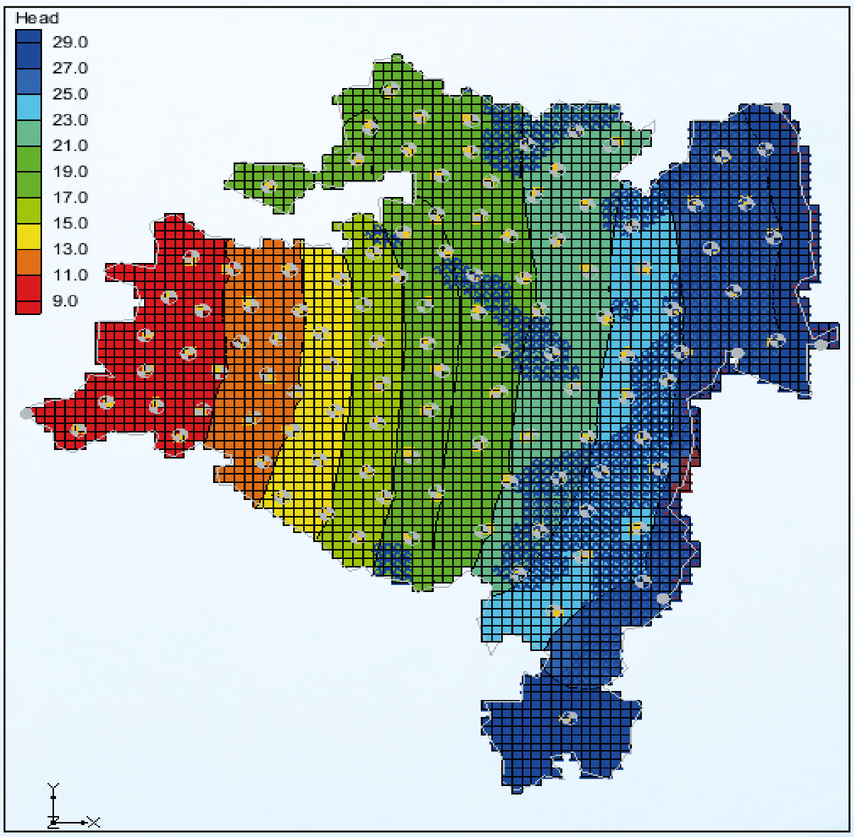


Fig. 11.88. Contour plot of the groundwater heads with respect to the increased recharge (110% of the actual)

The results revealed that the computed groundwater heads at the observation wells varied noticeably as a result of the changes in the recharge scenarios. In the business-as-usual case, the MODFLOW computed heads at the three observation wells GT 8194046, GT8194048, and GT8194049 in Tanore upazila on 24 September 2018 (based on the available groundwater head data obtained from the BWDB) were 16.388m, 18.133m, and 22.215m, respectively. When the recharge was reduced to 90%, the computed heads dropped significantly, and the values were 7.970m, 11.150m, and 18.106m, respectively at the three observation wells. On the other hand, if the recharge would be increased to 110%, the MODFLOW computed heads at the observation wells were found as 20.707m, 21.745m, and 24.413m, respectively which indicated a substantial increase in the quantity of head development. In Godagari upazila, the observed and computed heads were monitored at four observation wells (GT 8134017, GT 8134020, GT 8134021, and GT 8134022). In this upazila, the MODFLOW computed heads for the business-as-usual case were 9.389m, 11.046m, 6.170m, and 6.112m at the observation wells GT 8134017, GT 8134020, GT 8134021, and GT 8134022, respectively. When the recharge was reduced to 90%, the computed heads dropped, and the values were 6.577m, 5.670m, - 0.475m, and 1.447m, respectively at the four observation wells. On the other hand, if the recharge would be increased to 110%, the MODFLOW computed heads at the observations were found as 12.155m, 16.325m, 12.660m, and 10.682m, respectively which indicated a substantial increase in the quantity of head development. In Joypurhat sadar upazila, the observed and computed heads were monitored at two observation wells (GT 3847001 and GT 3847003). In this upazila, the MODFLOW computed heads for the business-as-usual case were 11.05231m and 3.980m at the observation wells GT 3847001 and GT 3847003, respectively. When the recharge was reduced to 90%, the computed heads dropped, and the values were 9.406m, and 3.335m, respectively at the two observation wells. On the other hand, if the recharge would be increased to 110%, the MODFLOW computed heads at the observation wells were found as 12.688m, and 4.620m, respectively. In Kalai upazila, the observed and computed heads were monitored at two observation wells (GT 3847001 and GT 3847003). In this upazila, the MODFLOW computed heads for the business-as-usual case were 11.05231m and 3.980m at the observation wells GT 3861004 and GT 3861005, respectively. When the recharge was reduced to 90%, the computed heads dropped, and the values were 6.306m, and 5.533m, respectively at the two observation wells. On the other hand, if the recharge would be increased to 110%, the MODFLOW computed heads at the observation wells were found as 7.592m, and 6.943m, respectively. The increased and decreased recharge scenarios were computed using the existing groundwater pumping values in the year 2018. Therefore, it was concluded that groundwater recharge has a significant effect on the head development in the groundwater aquifers of the Tanore and Godagari upazila, Rajshahi and Joypurhat sadar and Kalai upazila, Joypurhat.

The optimal groundwater abstraction strategy has been considered an effective measure of maintaining groundwater levels in aquifers for the safe and beneficial abstraction. In this research, a finite difference based 3-D flow based numerical code, MODFLOW, was utilized to simulate the groundwater heads with respect to different recharge scenarios in Tanore and Godagari upazila of Rajshahi district and Joypurhat sadar and Kalai upazila of Joypurhat district in the northern Bangladesh. Input data for the selected study areas were collected from different sources. Scarcity and reliability of available data was a challenging issue in implementing regional scale saltwater intrusion models in this location. Therefore, the best possible subjective judgment was used in choosing the data for simulating the aquifer processes. The limited assessment results demonstrated that, groundwater recharge has an influential effect on the groundwater level fluctuations, and using a carefully planned groundwater abstraction strategy, it was possible to modify the groundwater storage that will help in preserving the precious groundwater storage in the study area.

Groundwater abstraction pattern analyzed by TI model

Long term GWT data of different locations were analyzed and different outputs are given in Table 11.40 and Table 11.41. In Table 11.40, ranges of maximum and minimum GWT depth were from 18.30m to 5.80m and from 7.14m to 0.99m respectively at Tanore and Joypurhat sadar. These values were comparatively high than the values of other locations. It indicated that the groundwater table depth from the ground surface at Tanore always remained lower than those at Kalai, Godagari and Joyprhat sadar. Average withdrawal depth i.e. difference between minimum and maximum GWT depth was highest (6.08m) at Godagari among the locations. It means that per year withdrawal of groundwater is more at Godagari than other locations. However, number of years of negative recharge, was highest in Tanore and positive recharge highest in Godagari. Beside that number of years of excess withdrawal (when maximum GWT depth of any year is greater than that of previous year) at every location was higher than number of years of less withdrawal (reverse of excess withdrawal). Because of more negative recharge and more excess withdrawal depletion in groundwater level was taking place.

Table 11.40. Water table, recharge and withdrawal pattern of groundwater in Rajshahi and Joypurhat

Location	Period	Max GWT	Min GWT	Average withdrawal	Positive Recharge	Negative Recharge	Less withdrawal	Excess withdrawal
	year	Range (m)	Range (m)	(m)	No. of yrs	No. of yrs	No. of yrs	No. of yrs
Godagari	39	10.89-6.54	9.31-0.62	6.08	20	18	17	21
Tanore	39	18.30-5.80	16.24-0.86	3.44	12	25	11	26
Joypurhat sadar	39	9.72-2.90	7.14-0.99	4.39	14	22	18	20
Kalai	39	12.22-3.00	11.03-2.56	2.47	13	25	13	24

Table 11.41. Groundwater table depletion pattern in Rajshahi and Joypurhat

Location	Period	GWT beyond Suction limit	Excess Suction limit	Total depletion	Average per year depletion
	No of yrs	No of yrs	No of yrs	(cm)	(cm)
Godagari	39	13	26	306	7.84
Tanore	39	9	29	1509	38.69
Joypurhat sadar	39	25	13	462	11.84
Kalai	39	13	26	837	24.46

In Table 11.41, total depletion (difference between minimum GWT depths before 39 years and present year) in Tanore was highest (15009cm) among the locations and average per year depletion was 38.69cm. In Joypurhat sadar, maximum GWT was depleted beyond suction limit in 25 years out of 39 years (suction limit means a reference depth generally 8 meter below the ground surface).

Table 11.42. Deficit recharge during 1988-2018 in different locations of the project in Rajshahi and Joypurhat

Location	Period (no.of yrs)	Present GWT depth	Tt year before GWT depth	Deficit recharge volume
	t (yr)	y_2 (cm)	y_1 (cm)	DRV (%)
Godagari	39	400	94	76.50
Tanore	39	1618	109	93.26
Joypurhat sadar	39	635	173	72.75
Kalai	39	1103	266	75.88

As a part of groundwater assessment, historical groundwater data of each site of the project were used in TI model to know the present status of groundwater whether there is deficit or not, compared to previous years. Thirty nine years' minimum groundwater table data of each location were analyzed and the results are shown in Table 11.42. The table revealed that maximum 93.26 percent deficit recharge occurred in Tanore other than Godagari, Kalai and Joyurhat sadar.

Future groundwater utilization strategy

Since deficit recharge was observed in most of the locations. Therefore, withdrawal or utilization of groundwater should be reduced so that groundwater level could be remained as it was in any of the expected previous year or in other ward to recover the deficit. However, the most suitable way of reducing groundwater utilization is use of water saving technology in respective field. It was mentioned earlier that highest groundwater is used in Boro cultivation and water saving technology can easily be used in this season. But question is how much area should be brought under water saving technology. The TI model has given the answer in Table 43. The table revealed that minimum coverage by the technology (MCT) depends on mainly i) total deficit recharge, ii) number of targeted years (t_1) to recover deficit, iii) reduced utilization percent (RUP) per year, it also depends on targeted year and iv) percentage of ater saving using the technology (θ). Such as in Tanore, when the value of t_1, α and θ are 5 years, 18.65 and 30 percent respectively then MCT is 97.15 percent. Again when t_1 becomes 10, MCT becomes 48.57 percent. MCT is also changed due to change of technology. Table 11.43 showed MCT (97.15%) for alternate wetting and drying irrigation system (AWD) is less than MCT (116.58%) for PVC pipe water distribution system (PWDS). Thus combined technology such as AWD and PWDS together needs comparatively less MCT than any single technology.

Table 11.43. Minimum coverage by the technology to recover deficit recharge in different location in Rajshahi and Joypurhat

Location	Targeted year for recovery	Per year reduced utilization (RUP)	Groundwater used by Agril	Groundwa ter used by Boro	Technology & saving percent (average)		Area coverage by Technology (MCT)	
					AWD	PVC	AWD	PVC
	t_1 (year)	α(%)	β(%)	ᵧ(%)	θ(%)	θ(%)	α/βᵧθ (%)	α/βᵧθ (%)
Godagari	5	15.30	80	80	30	25	79.68	95.62
	10	7.56	80	80	30	25	39.84	47.81
Tanore	5	18.65	80	80	30	25	97.15	116.58
	10	9.32	80	80	30	25	48.57	58.29
Joypurhat sadar	5	14.55	80	80	30	25	75.78	90.94
	10	7.28	80	80	30	25	37.89	45.47
Kalai	5	15.18	80	80	30	25	79.04	94.85
	10	7.59	80	80	30	25	39.52	47.42

The TI model quantified that maximum 93.26 percent deficit recharge occurred in aquifer in the study area and maximum reduced utilization of groundwater per year should be 18.65 percent if it is targeted to recover deficit recharge within five years. The maximum coverage (97.15 % of Boro area) by the AWD technology will be able to recover deficit recharge within five years in the study area through retarding declination of groundwater per year. It was obvious that groundwater declination can be retarded and groundwater deficit can be recovered by proper management after assessment of groundwater behavior. TI model suggested that determination of DRV and MCT was needed for all over the country for using ground water judicially, safely and effectively.

11.3.2. Component-2: BRRI

11.3.2.1. Groundwater abstraction pattern analyzed by TI model

There was relationship between withdrawal and recharge of groundwater. If the amount of withdrawal of groundwater was greater than the amount of recharge, deficit in groundwater storage (aquifer) occurs. As a result, both maximum ground water table (MXGWT) and minimum ground water table (MNGWT) was from its previous position. If this scenario happens in maximum years through long period, a declining trend both in MXGWT and MNGWT will be seen after couples of years. It is mentionable that MXGWT and MNGWT depth occurs in April-May and Sep-Oct period respectively in Bangladesh.

Long term GWT data of different locations were analyzed to know why the declination of groundwater occurred. Withdrawal and recharge pattern of groundwater at different locations were investigated and outputs were given in Table 11.44 and Table 11.45. In Table 11.44, maximum and minimum GWT depths were ranged from 9.95 m to 6.92 m and from 6.1 m to 1.0 m respectively at Iswardi. These values are comparatively higher than those of other locations. It indicated that the groundwater table depth from the ground surface at Iswardi always remained lower than those at Santhia, Mithapukur and Pirganj. Average fluctuation i.e. difference between minimum and maximum GWT depth was also the highest (6.20 m) at Iswardi among the locations. It means that per year withdrawal of groundwater was higher at Iswardi than other locations. However, number of years of negative recharge (when minimum GWT depth of any year is greater than previous year means negative recharge) at every location except Mithapukur was higher than number of years of positive recharge (when minimum GWT depth of any year is smaller than previous year means positive recharge). Besides that number of years of excess withdrawal (when maximum GWT depth of any year was greater than that of previous year) at every location was higher than number of years of less withdrawal (reverse of excess withdrawal). Because of more negative recharge and more excess withdrawal depletion in groundwater level took place. As for example, out of 30 years in 14 years there were positive recharges whereas in 15 years were negative recharge and in one year there was no positive & negative recharge. Excess withdrawal years were higher than less withdrawal at Ishwardi so trend of groundwater level was declining.

Table 11.44. Water table, recharge and withdrawal pattern of groundwater in Pabna and Rangpur

Location	Period (year)	MaxGWT range (m)	MinGWT range (m)	Average fluctuation (m)	Positive Recharge (no. of years)	Negative Recharge (no. of years)	Less Withdrawal (no. of years)	Excess Withdrawal (no. of years)
Iswardi	30	9.95-6.92	6.1-1.0	6.20	14	15	15	17
Santhia	32	9.56-5.05	3.02-0.25	4.40	14	17	17	14
Mithapukur	30	5.92-4.1	2.4-0.51	3.37	15	15	14	16
Pirganj	27	8.75-4.64	2.7-0.35	5.40	14	13	11	16

In Table 11.45, total depletion (difference between minimum GWT depths before 30 years and present year) occurred in Iswardi which was highest (205cm) among the locations and average per year depletion was 6.8 cm. Nevertheless, there was no depletion in groundwater level in Mithapukur. In Iswardi, maximum GWT in 28 years out of 30 years depleted beyond suction limit (suction limit means a reference depth generally 8 meter below the ground surface). As a result, no shallow tubewell worked during dry period in Iswardi. But in Mithapukur, maximum GWT depth always remained above suction limit.

Table 11.45. Groundwater table depletion pattern in Panba and Rangpur district

Location	Period (no. of yrs)	GWT beyond Suction limit (No. of yrs)	Total depletion (cm)	Average depletion (cm)
Iswardi	30	28	205	6.6
Santhia	32	1	140	4.38
Mithapukur	30	0	0	0
Pirganj	27	3	155	5.7

As a part of ground water assessment, historical groundwater data of each location was used in TI model to know the present status of groundwater whether there was deficit or not, compared to previous years. Thirty years' minimum groundwater table data of each location were analyzed by TI model to determine DRV and the results are shown in Table 11.46. The table revealed that maximum 66.67 percent DRV occurred in Santhia where as there was no deficit recharge in Mithapukur.

Table 11.46. Deficit recharge during 1988-2018 in different locations of the project

Location	Period (no. of yrs)	Present minimum GWT depth	t year before minimum GWT depth	Deficit recharge volume
	t (yr)	y2 (cm)	y1(cm)	DRV (%)
Iswardi	30	315	145	53.97
Santhia	32	210	70	66.67
Pirganj	30	270	150	44.44
Mithapukur	30	100	100	0.00

11.3.2.2. Groundwater utilization strategy

Since deficit recharge was observed in most of the locations. Therefore, withdrawal or utilization of groundwater should be reduced so that groundwater level could be remained as it was in any of expected previous year or in another word to recover the deficit. However, the most suitable way of reducing groundwater utilization is use of water saving technology in respective field. It was mentioned earlier that groundwater was used highest in Boro cultivation and water saving technology can easily be used in this season. But question is how much area should be brought under water saving technology. The TI model has given the answer in Table 11.47. The table reveals that minimum coverage by the technology (MCT) depends on mainly i) total deficit recharge ii) number of targeted years (t_1) to recover deficit iii) reduced utilization percent (RUP) per year, it also depends on targeted year and iv) saving percentage of the technology (θ). Such as in Iswardi, when the value of t_1, α and θ are 5 years, 10.79 and 30 percent respectively then MCT is 56.22 percent. Again, when t_1 becomes 10, MCT becomes 28.11 percent. MCT is also changed due to change of technology. Table 11.47 is showing MCT (56.22%) for alternate wetting and drying irrigation system (AWD) which is less than MCT (67.46%) for PVC pipe water distribution system (PWDS). Thus, combined technology such as AWD and PWDS together needs comparatively less MCT than any single technology. Here it is mentionable that since RUP for Mithapukur is zero so MCT is zero.

Table 11.47. Minimum coverage by the technology to recover deficit recharge in different locations

Location	Targeted year for recovery	Per year reduced utilization (RUP)	Ground water used by Agril,	Ground water used by Boro	Technology & saving percent (average)		Area coverage by Technology (MCT)	
					AWD	PVC	AWD	PVC
	t_1 (year)	α(%)	β(%)	ɣ(%)	θ(%)	θ(%)	α/βɣθ (%)	α/βɣθ (%)
Iswardi	5	10.79	80	80	30	25	56.22	67.46
	10	5.40	80	80	30	25	28.11	33.73
Santhia	5	13.33	80	80	30	25	69.44	83.33
	10	6.67	80	80	30	25	34.72	41.67
Pirganj	5	8.89	80	80	30	25	46.30	55.56
	10	4.44	80	80	30	25	23.15	27.78
Mithapukur	5	0.00	80	80	-	-	0.00	0.00
	10	0.00	80	80	-	-	0.00	0.00

The TI model quantified that maximum 66.67 percent deficit recharge occurred in aquifer in the study area and maximum reduced utilization of groundwater per year should be 13.33 percent if it is targeted to recover deficit recharge within five years. The maximum coverage (69.44 % of Boro area) by the AWD technology able to recover deficit recharge within five years in the study area through retarding declination of groundwater per year. It was obvious that groundwater declination can be retarded and groundwater deficit can be recovered by proper management after assessment of groundwater behavior. TI model suggested that determination of DRV and MCT was needed for all over the country for using ground water judicially, safely and effectively.

11.3.3. Component-3: BINA

11.3.3.1. Groundwater abstraction pattern as safe yield assessment

Safe yield for pumping of ground water of the study area was estimated by using a simplified hydrological balance method for year 2020. The basic input parameters in equations were taken from different sources as well as calculated values conducting experiments and others analyzed data during sub-project period. From BMD and BMDA data, parameter P, E and H were found to be 1634mm, 861 mm and 1803 mm, respectively for Nachole and 1634 mm, 861 mm and 584 mm, respectively for Niamatpur. From three years cropping pattern experiment and pumping test, parameter I and S_y were calculated and found to be 1120 mm and 0.0404, respectively for Nachole and 1000 mm and 0.06, respectively for Niamatpur. The coefficient r, ɑ̡ and a were calculated based on collected data which were found to be 0.27, 0.185 and 0.0039, respectively for both study area (Khan et al., 2001). The other parameters i.e D and the co-efficient (c) were taken as 300 mm and 0.15, respectively (UNDP, 1982 and BWBD, 2014). The above mentioned data were then used in the simplified hydrological balance equation for calculating safe yield of aquifer at Nachole and was found to be 291 mm and at Niamatpur 326 mm.

11.3.3.2. Groundwater utilization strategy for Deficit recharge by TI model

Determination of groundwater declining and deficit

It was obvious that there was relationship between withdrawal and recharge of groundwater. If the amount of withdrawal of groundwater is greater than the amount of recharge, deficit in groundwater storage (aquifer) occurs. As a result, both maximum ground water table (MXGWT) and minimum ground water table (MNGWT) go down from its previous position. If this scenario happens maximum years through long period, a declining trend both in MXGWT and MNGWT is shown after couples of years. It is mentionable that MXGWT depth and MNGWT depth occur respectively, in general, during April-May and Sep-Oct period in Bangladesh, and also in the study area.

Characteristics of ground water table (GWT)

Long term GWT data (fom 1980 to 2020) of study area was analyzed to know why declination of groundwater occurred. Withdrawal and recharge pattern of groundwater was investigated and outputs are given in Table 11.48.

Table 11.48. Water table, recharge and withdrawal pattern of groundwater

Location	Period (Year)	Max GWT (Rang, m)	Min GWT (Rang, m)	Average withdrawal (m)	Positive recharge (No. of yrs)	Negative recharge (No. of yrs)	Less withdrawal (No. of yrs)	Excess withdrawal (No. of yrs)
Nachole	40	12.3 - 34.19	5.74- 32.18	8.31	14	24	14	25
Niamatpur	33	6.99- 17.91	1.96- 16.56	3.09	11	28	11	27

The range of maximum and minimum GWT depth was found to be respectively, 12.3 to 34.19 m and 5.74 to 32.18 m at Nachole and 6.99 m to 17.91m and 1.96m to 16.56m at Niamatpur (Table 11.48). Average withdrawal depth i.e. difference between minimum and maximum GWT depth was 8.31 m for Nachole and 3.09 m for Niamatpur and number of years of positive and negative recharge was respectively, 14 and 24 among 40 years for Nachole and 11 and 28 among 40 years for Niamatpur. Besides, in 25 years there were excess withdrawal whereas in 14 years were less withdrawal and in one year there was neutral in Nachole and in 27 years, there was excess withdrawal whereas 11 years were less withdrawal and in one year there was neutral for Niamatpur. Because of more years of negative recharge and excess withdrawal resulted in groundwater level declining at the study area.

Table 11.49. Groundwater table depletion pattern

Location	Period	GWT within Suction limit	GWT beyond Suction limit	Total depletion	Average depletion per year
	No of yrs	No of yrs	No of yrs	(cm)	(cm)
Nachole (GT 06)	40	0	40	2301	57.53
Niamatpur (GT 29)	40	1	39	1381	34.52

From 1981 to 2020 (40 years) total depletion was found to be 2301 cm and average depletion was 57.53 cm/year in Nachole and in Niamatpur, total depletion was 1381 cm and average depletion was 34.52 cm/year. In every year, the GWL was below the suction limit in Nachole and most of the years, the GWL was below the suction limit except one year out of 40 years at the study area (Table 11.49).

Deficit recharge volume by (DRV) TI model

As a part of ground water assessment, historical groundwater data of each location was used in TI model to know the present status of groundwater whether there is deficit or not, compared to previous years. Forty years' minimum groundwater table data of each location were analyzed by TI model to determine DRV and the results were shown in Table 11.50. The table revealed that maximum 72.89 percent DRV occurred at Nachole and maximum 87.57 percent at Niamatpur.

Table 11.50. Deficit recharge during 1981-2020

Location	Period (no. of yrs)	Present minimum GWT depth	40 years before minimum GWT depth	Deficit recharge volume
	t (yr)	y_2 (cm)	y_1 (cm)	DRV (%)
Nachole	40	3157.32	856.00	72.89
Niamatpur	40	1577	196	87.57

Groundwater utilization strategy

Since deficit recharge was observed in the study area, therefore, withdrawal or utilization of groundwater should be reduced so that groundwater level could be remained as it was in any of expected previous year or in other word, to recover the deficit. However, the most suitable way of the reducing groundwater utilization is use of water saving technology in respective field. It was mentioned earlier that groundwater was used mostly in Boro cultivation and water saving technology can easily be used in this season. But the question is how much area should be brought under water saving technology. The TI model has given the answer in Table 11.48. The table reveals that minimum coverage by the technology (MCT) depends on mainly i) total deficit recharge, ii) number of targeted years (t1) to recover deficit, iii) reduced utilization percent (RUP) per year, and iv) saving percentage of the technology (θ).

For different targeted year, maximum coverage by water saving technologies to recover deficit recharge at Nachole and Niamatpur are presented in Table 11.51. Per year reduced utilization (RUP) were found 14.58, 7.29 and 4.86% for Nachol and 17.51, 8.76 and 5.84% for Niamatpur for different targeted year 5, 10 and 15 year, respectively. To meet deficit recharge volume by using 55 percent water saving Aus-based cropping pattern (ABCP), 34.87, 17.44 and 11.62% area coverage is required for next targeted years of 5, 10 and 15, respectively for Nachol region. To meet deficit recharge volume by using 50 percent, water saving Aus-based cropping pattern (ABCP) requires 48.65, 24.32 and 16.22 % area coverage for next targeted years of 5, 10 and 15, respectively. In case of 24 percent new Boro-based cropping pattern (NBBCP), 79.92, 39.96 and 26.64 % area coverage is needed to fill the desire amount for next targeted 5, 10 and 15 years, respectively at Nachol. In case of 25 percent new Boro-based cropping pattern (NBBCP), 97.30, 48.65 and 32.43 % area coverage is needed to fill the desired amount for next targeted 5, 10 and 15 years, respectively at Niamatpur.

Table 11.51. Minimum coverage by the technology to recover deficit recharge

Location	Targeted year for recovery	Per year reduced utilization (RUP)	Ground water used by Agril,	Groundwater used by Existing BBCP	Technology & saving percent (average)		Minimum area coverage by Technology (MCT)	
					ABCP	**NBBCP**	**ABCP**	**NBBCP**
	t (year)	α(%)	β(%)	γ(%)	θ(%)	θ(%)	α/βγθ(%)	α/βγθ (%)
Nachole (GT 06)	5	14.58	95	80	55	24	34.87	79.92
	10	7.29	95	80	55	24	17.44	39.96
	15	4.86	95	80	55	24	11.62	26.64
Niamatpur (GT 29)	5	17.51	90	80	50	25	48.65	97.30
	10	8.76	90	80	50	25	24.32	48.65
	15	5.84	90	80	50	25	16.22	32.43

Note: ABCP = Aus Based Cropping Pattern
BBCP = Boro Based Cropping Pattern
NBBCP = New Boro Based Cropping Pattern

11.3.3.3. Simulation of WT position under different cropping pattern/withdrawal rate

Model Calibration

Model calibration was conducted by adjusting the vertical hydraulic conductivity. The vertical hydraulic conductivity has been selected 1/10 times the horizontal hydraulic conductivity. The calibration model and the calibration curve for Nachole are given in Fig.11.89 and Fig.11.90 and for Niamatpur those are given in Fig.11.91 and Fig.11.92, respectively.

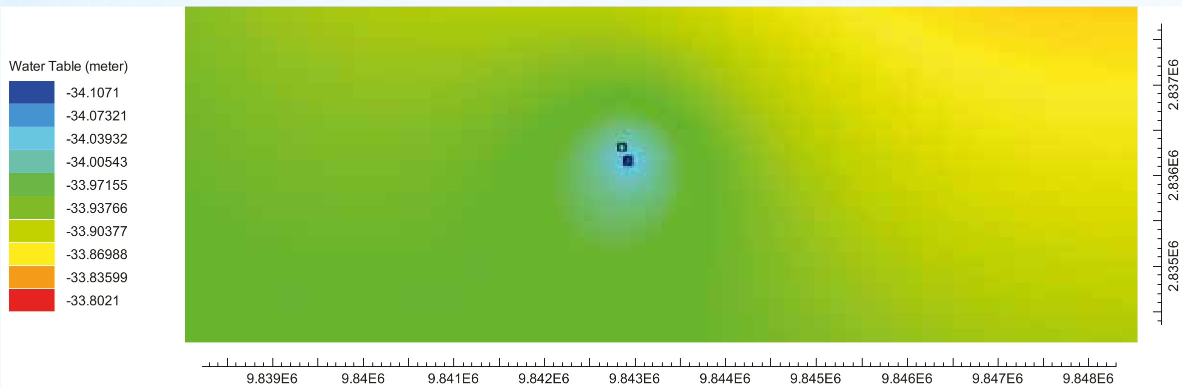


Fig. 11.89. Calibrated model (Nachole)

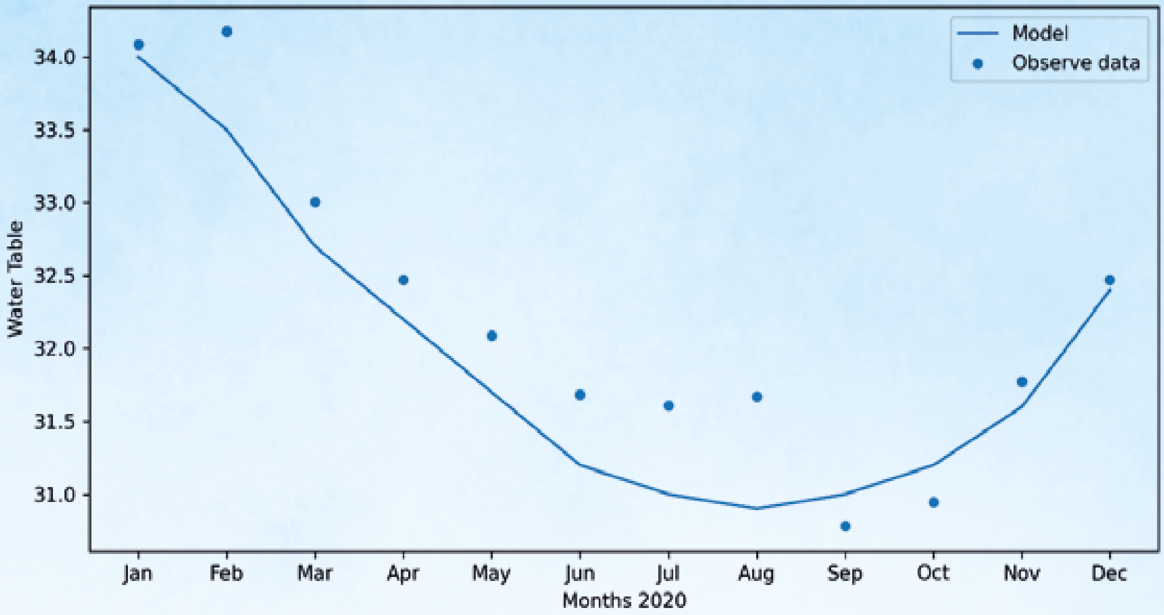


Fig. 11.90. Calibration curve (Nachole)

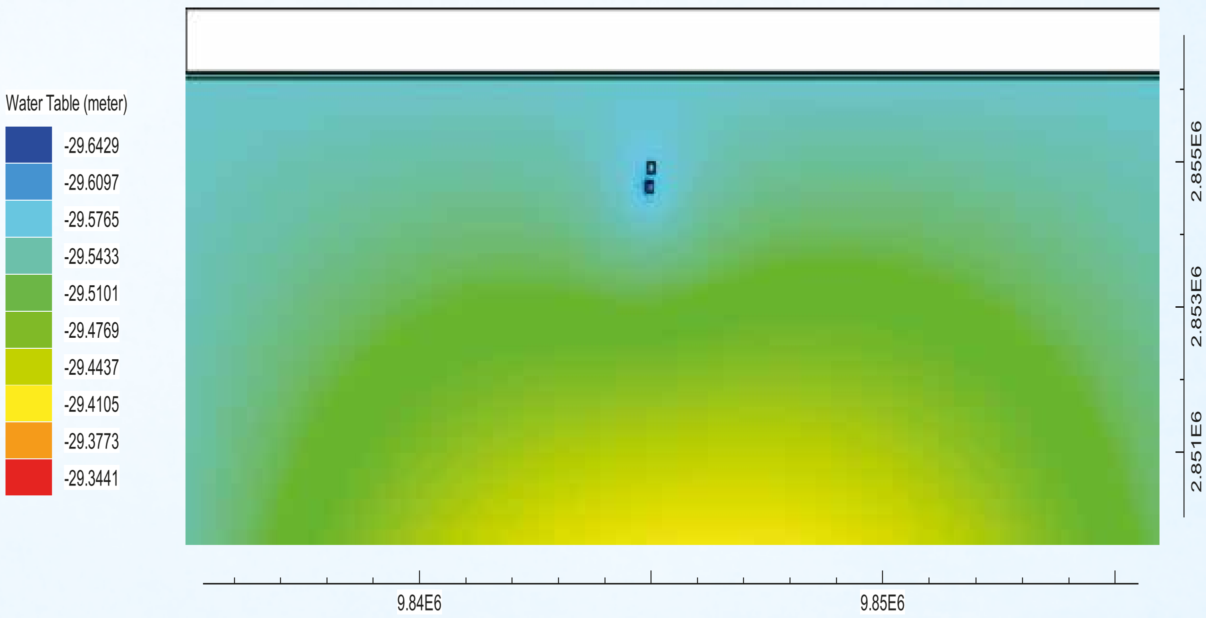


Fig. 11.91. Calibrated model (Niamatpur)

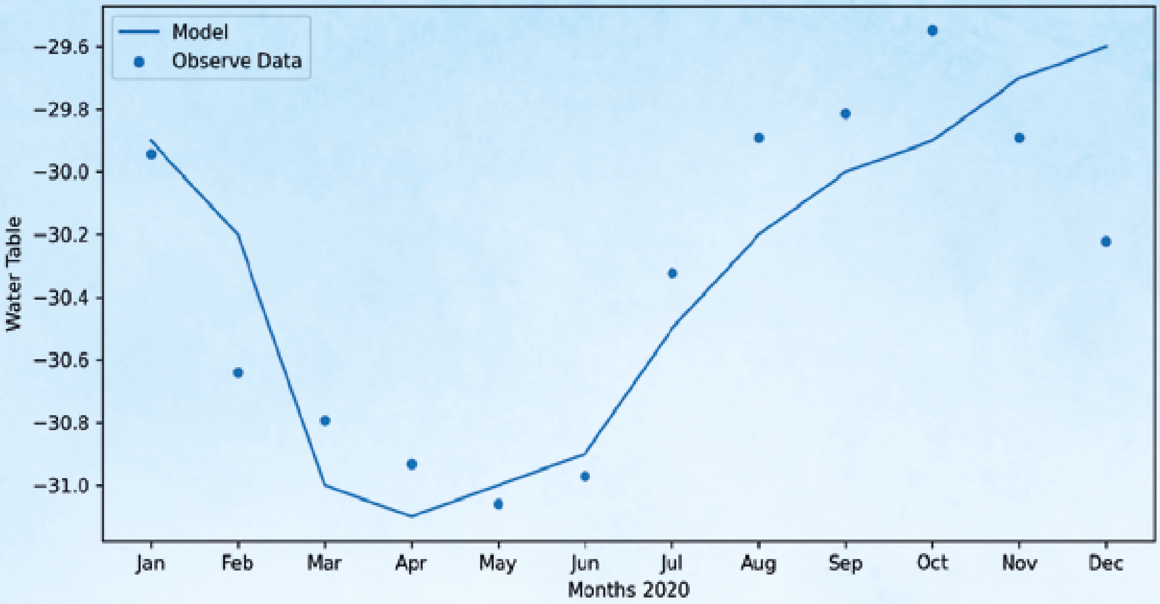


Fig.11.92. Calibration curve (Niamatpur)

Simulation Scenario (Nachole)

The water-table scenarios under different 'cropping pattern'/ 'groundwater withdrawal scenario' are depicted in Fig. 11.81. Here, S0 represents the water-table depth (WT) in 2019.

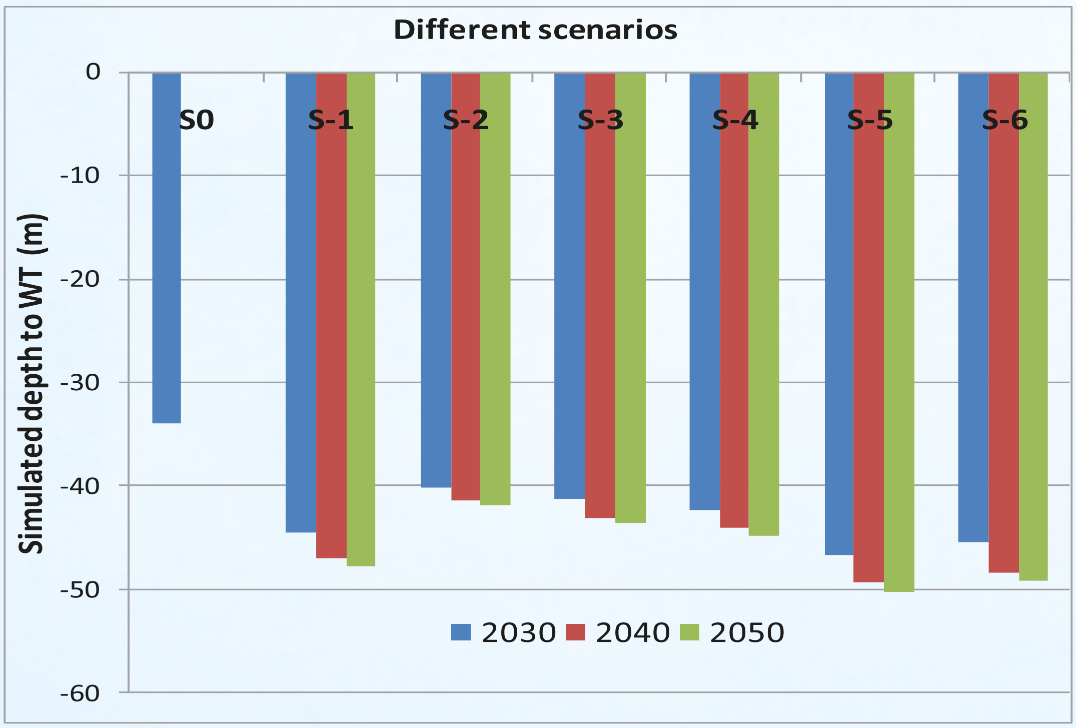


Fig. 11.93. Simulated scenario of WT by MODFLOW model under different withdrawal pattern (Nachole)

Under present withdrawal condition (S1), the simulated depth to WT at Nachole for the year 2030, 2040, and 2050 will be 44.5 m, 46.9 and 47.7 m, respectively (Fig.11.93).

If the present Boro rice (100%) is replaced by Aus (S2), the WT for the year 2030, 2040, and 2050 will be 40.2 m, 41.4 m and 41.8 m, respectively; which indicated that the WT condition will be nearly stable, that is, no significant declination of WT.

For 30% and 50% replacement of Boro by Aus (S3 and S4), the projected WT position will be from 42.3m to 44.8m and 41.3m to 43.6m, respectively, for the year 2030 to 2050. These indicated that, with the incremental replacement of Boro by Aus, WT situation will be improved.

If the recharge rate is reduced from its present condition (S1) to 80% (S5) and 90% value (S6), the WT will also respond consequently (Fig.11.81). The WT position will be declined compared to control, S1 scenario.

Thus, the simulated WT scenario will be helpful for the policy makers to adopt appropriate policy regarding cropping patterns or groundwater withdrawal amount targeting the long-term sustainability of groundwater.

Simulation Scenario (Niamatpur)

The water-table scenarios under different 'cropping pattern' (and hence, under different 'groundwater withdrawal scenario') are depicted in Fig.11.94. Here, S0 represents the WT position in 2019.

Under present withdrawal condition (S1), the simulated depth to water-table (WT) at Niamatpur for the year 2030, 2040, and 2050 will be 40.3m, 42.7m and 43.5m, respectively (Fig.11.94).

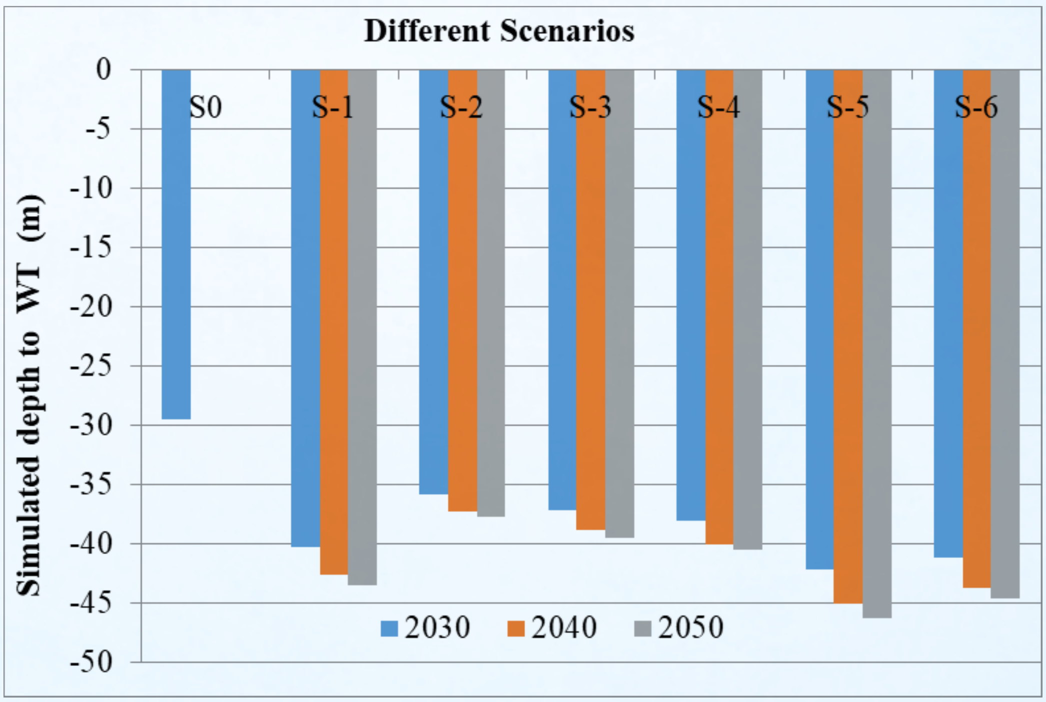


Fig. 11.94. Simulated scenario of WT by MODFLOW model under different withdrawal pattern (Niamatpur)

If the present Boro rice (100%) is replaced by Aus (S2), the WT for the year 2030, 2040, and 2050 will be 35.9 m, 37.3 m and 37.8 m, respectively; which indicated slower declination of WT.

For 30% and 50% replacement of Boro by Aus rice (S3 and S4), the projected WT position for the year 2030 to 2050 will be from 38.1m to 40.6m and 37.2m to 39.8m, respectively. This indicated that, with the incremental replacement of Boro by Aus, WT situation will be improved compared to present scenario (S1). If the recharge rate is reduced from its present condition (S1) to 80% (S5) and 90% value (S6), the WT will also respond consequently (Fig.11.94). The WT position will be declined compared to control, S1 scenario.

Thus, the simulated WT scenario will be helpful for the policy makers to adopt appropriate policy regarding cropping pattern or groundwater withdrawal amount targeting the long-term sustainability of groundwater in the area.

Under present withdrawal condition (S1), the simulated depth to WT at Nachole for the year 2030, 2040, and 2050 will be 44.5 m, 46.9 and 47.7 m, respectively and at Niamatpur for the year 2030, 2040, and 2050 will be 40.3m, 42.7m and 43.5m, respectively. The simulation results indicated that with the incremental replacement of Boro by Aus (30%, 50%, 100%), the declination of WT will be reduced, and hence the WT situation will be improved. If the recharge rate is reduced from its present condition (e.g. to 80% or 90%), the depth to WT will also be increased.

11.4. Crop production and Cropping Pattern

11.4.1. Component-1: BARI

11.4.1.1. Yield, water requirement and water productivity of crops

T. Aman

Yield, water requirement and water productivity of T.Aman rice obtained from the separate experimental fields at four locations during 2018-2019 are presented in Table 11.52 and 11.53. Over the locations, yields varied from 2.65 to 4.17 t/ha in 2018 with minimum in farmers' practice treatment T_1 and maximum in T_2 where AWD with 20 cm depth was used for determining irrigation timing. In Rajshahi, grain yield was significantly lowest in T_1 compared to both AWD treatments T_2 and T_3. In Joypurhat too, highest yield was obtained from T_2 and it was insignificant compared to both T_1 and T_3. This happened because treatment T_2 and T_3 received almost same number and amount of irrigation water. Even treatment T_1 received ample amount of water from rainfall that almost satisfied the water requirement of T. Aman rice. But in Rajshahi, as number and amount of irrigation were different among treatments, so difference in grain yields were found a significant. In 2019 too, highest yields were obtained from T_2. But yields obtained from T_1 and T_2 were almost same as these treatments received same amount of water from irrigation as well as from rainfall. In 2018, however, Water Productivities (WPs) were found highest in T_3, except Godagari where highest WP was obtained from T_1. Over the other three locations, WP varied from 1.58 m^3/kg for T_1 to 1.83 m^3/kg for T_3. That is, 1580 to 1830 liters of water was applied to produce one kilogram of rice whereas in 2019, 1180 to 1500 litres of water were applied. As yield was found higher in 2019, so does the water productivity. Water supply was varied from 528 mm to as much as 729 mm in 2018 whereas in 2019 it varied from 537 to 686 mm with minimum in T_1 and maximum in T_2.

Table. 11.52. Yield, water requirement and water productivity of T. Aman during 2018

Treat-ment	Applied water (mm)	Eff. rainfall (mm)	Total water supply (mm)	Yield (t/ha)	Water productivity (m^3/kg)	Yield increased (%)
Godagari (cv. BRRI dhan 51)						
T_1	200	328	528	2.65	1.99	
T_2	412	328	740	4.17	1.77	57.36
T_3	384	328	712	3.96	1.80	49.43
Tanore (cv. BRRI dhan 62)						
T_1	210	306	516	2.90	1.78	
T_2	423	306	729	3.98	1.83	37.24
T_3	346	306	652	3.56	1.83	22.76
Kalai (cv: Swarna)						
T_1	207	362	569	3.61	1.58	
T_2	287	362	649	3.77	1.72	4.43
T_3	296	362	658	3.79	1.74	4.99
Joypurhatsadar (cv: Guti Swarna)						
T_1	204	354	558	3.41	1.64	
T_2	294	354	648	3.66	1.77	7.33
T_3	294	354	648	3.63	1.79	6.45

Table. 11.53. Yield, water requirement and water productivity of T. Aman rice during 2019

Treat-ment	Applied water (mm)	Eff. rainfall (mm)	Total water supply (mm)	Yield (t/ha)	Water productivity (m^3/kg)	Yield increased (%)
Godagari (cv. BRRI dhan 51)						
T_1	155	421	576	4.17	1.29	
T_2	237	421	658	4.77	1.30	13.42
T_3	155	421	576	4.13	1.30	-0.89
Tanore (cv. Sumon Swarna)						
T_1	162	375	537	4.26	1.18	
T_2	241	375	616	4.86	1.19	13.16
T_3	162	375	537	4.32	1.16	1.32
Kalai (cv: Swarna)						
T_1	130	494	624	3.91	1.48	
T_2	192	494	686	4.35	1.48	10.45
T_3	130	494	624	3.87	1.50	-0.95
Joypurhatsadar (cv: Guti Swarna)						
T_1	120	431	551	4.05	1.27	
T_2	178	431	609	4.24	1.34	4.37
T_3	120	431	551	4.03	1.27	-0.46

Boro

The effects of different irrigation treatments on yield, water requirement and water productivity of boro rice grown in four different upazilas are presented in Table 11.54. Two different rice varieties: BRRI dhan 28 and BRRI dhan 29 were used as test crops. BRRI dhan 29 performed better in terms of yield, but in terms of water requirement and water productivity BRRI dhan 28 performed better under all irrigation regimes. Irrespective of variety, treatment T_1 and/or T_2 produced the highest and identical yield of rice. AWD method with 15 cm depth (T_2) yielded more or less similar yield that obtained by farmers' practice. In some plots, AWD with 15 cm depth performed better while in some other plots farmers' practice produced the highest yield. While AWD with 25 cm depth (T_3) produced about 3% less yield than farmers practice treatment T_1. However, water requirement was obviously higher in treatment T_1 as this treatment received irrigation more frequently than AWD treatments. Water productivity was found highest (less water required to produce 1.0 kg of rice) in AWD method with 25 cm depth as this treatment produced the highest yield with more efficient water use. Water required to produce highest yield ranged from 1017 to 1096 mm for AWD with 15 cm depth and from 1139 to 1176 mm for farmers' practice with minimum values for BRRI dhan 28 and Maximum values for BRRI dhan 29. The difference in water requirement between these two varieties was due to difference in their growing period.

Table 11.54. Yield, water requirement and water productivity of boro rice during 2019

Treatment	WR (mm)	Yield (t/ha)	Water productivity (m^3/kg)	Yield reduction (%)	Water saved (%)	TWU (mm)	WUE (%)
Godagari (cv. BRRI dhan 28)							
T_1	1128	5.31	2.12	-		727	64.45
T_2	1017	5.27	1.93	0.75	9.84	662	65.09
T_3	912	5.06	1.80	2.82	19.15	635	69.63
Tanore (cv. BRRI dhan 29)							
T_1	1176	5.80	2.03	-		746	63.44
T_2	1096	5.78	1.90	0.34	6.80	684	62.41
T_3	952	5.56	1.71	3.62	19.05	658	69.12
Kalai (cv: BRRI dhan 29)							
T_1	1149	5.63	2.04	-		739	64.32
T_2	1044	5.78	1.81	-2.66	9.14	676	64.75
T_3	958	5.49	1.74	0.71	16.62	662	69.10
Joypurhatsadar (cv: BRRI dhan 28)							
T_1	1139	5.19	2.19			718	63.04
T_2	1027	5.16	1.99	0.58	9.83	658	64.07
T_3	908	5.03	1.81	3.08	20.28	636	70.04

Wheat

Yield, water requirement and water productivity of wheat obtained from the two separate experimental fields at two locations are presented in Table 11.55. Highest yields (4.73 t/ha at Godagari and 4.36 t/ha at Tanore) were obtained from T_3 treatment that received three irrigations at CRI, booting and grain filling stage up to field capacity at both locations. Only 3-4% decrease in yields were recorded in treatment T_2 (two irrigation at CRI and booting stages) which were at per with T_3. The results revealed that less frequent irrigation can reduce the yield of wheat, but the amount of reduction can significantly be minimized by changing the timing of irrigation application. Therefore, where water is scare, two irrigations at CRI and grain filling stage (T_2) can be suggested rather than irrigation at CRI and booting stage (T_1). A reasonably good yield, though the lowest, was obtained from treatment T_1 receiving irrigation only at CRI stage. Total water use was highest in irrigation treatment T_3 as it received three numbers of irrigations. Although the number of irrigations was same for T_1 and T_2, T_2 received slightly more water, because irrigation interval in this treatment was higher and the soil was more dried to receive more amount of irrigation water. WPs were also found highest (2.34-2.63 kg/m^3) in this treatment T_2 with water saving of about 24% over treatment T_3. So, considering water saving, water productivity and grain yield, two irrigations at CRI and booting stages can be suggested for growing wheat crop in this drought prone and water scarce area, brcause this treatment can save about 24% water with only 3-4% yield reduction.

Table 11.55. Yield, water requirement and water productivity of wheat

Treatment	WR (mm)	Yield (t/ha)	Water productivity (kg/m^3)	Yield increased (%)	Yield decreased (%)	Water saved over T_3 (%)
Godagari (cv. BARI Gom-30)						
T_1	161	4.08	2.53	-	13.74	29.69
T_2	174	4.57	2.63	12.0	3.38	24.01
T_3	229	4.73	2.08	15.93	-	-
Tanore (cv. BARI Gom-30)						
T_1	166	3.90	2.35	-	10.55	30.25
T_2	179	4.18	2.34	7.18	4.12	24.07
T_3	238	4.36	1.83	11.79		-

Potato

Variation in tuber yield, water requirement and water productivity of potato under three different irrigation treatments are presented in Table 11.56 and 11.57. The yield of potato was significantly higher in furrow irrigation compared to the farmers practice in all study areas except in Joypurhat where treatment with farmers' practice and furrow irrigation produced almost same yield while alternate furrow irrigation produced the lowest. In other locations, however, alternate furrow irrigation produced the second highest yields those were at per with furrow irrigation. Compared to farmers' practice, the average yield increased in furrow irrigation and alternate furrow irrigation system was 7.42% and 4.30%, respectively. From the result it was clear that both furrow and alternate furrow irrigation can significantly improve the growth and yield of potato, where the difference in yield between furrow and alternate furrow was marginal. It was seen that significantly higher irrigation water was applied in farmers' practice compared to furrow irrigation and alternate furrow irrigation. Therefore, the total water use was also highest in the farmers' practice, whereas the lowest water use was in alternate furrow irrigation treatments. About 40% water was saved in alternate furrow irrigation treatment compared to the farmers' practice, whereas it was about 15% in furrow irrigation treatments. Water productivity was considerably higher in alternate furrow irrigation and furrow irrigation treatments than that of farmers' practice due to higher yield obtained in these treatments with comparatively lower irrigation water use. Highest water productivity (12.61 – 18.27 kg/m^3) was observed in alternate furrow irrigation followed by furrow irrigation treatment (10.02–13.23 kg/m^3), whereas the lowest (8.53–10.40 kg/m^3) was always in farmer's practice. Water productivity was around 65% higher in alternate furrow and around 22% higher in every furrow irrigation compared to the traditional irrigation practice.

Table 11.56. Yield, water requirement and water productivity of potato during 2018-19

Treatment	WR (mm)	Yield (t/ha)	Water productivity (kg/m^3)	Water saved (%)	Yield increased over T_1 (%)
Godagari (cv. BARI Alu-7)					
T_1	336	28.65	8.53	-	-
T_2	285	31.28	10.98	15.17	9.18
T_3	196	30.07	15.34	41.66	4.96
Tanore (cv. BARI Alu-7)					
T_1	342	35.56	10.40	-	-
T_2	281	37.18	13.23	17.83	4.56
T_3	203	35.90	17.68	40.64	0.96
Kalai (cv. BARI Alu-8)					
T_1	307	31.76	10.35	-	-
T_2	276	34.47	12.49	15.18	8.53
T_3	186	33.98	18.27	41.67	6.99
Joypurhat sadar (cv. BARI Alu-26)					
T_1	298	26.64	8.94	-	-
T_2	268	26.86	10.02	17.84	0.83
T_3	193	24.33	12.61	40.64	-8.67

Table. 11.57. Yield, water requirement and water productivity of potato during 2019-20

Treatment	WR (mm)	Yield (t/ha)	Water productivity (kg/m^3)	Water saved (%)	Yield increased over T_1 (%)
Godagari (cv. BARI Alu-7)					
T_1	333	30.76	9.24		
T_2	288	32.58	11.31	13.51	5.92
T_3	201	29.80	14.83	39.64	-3.22
Tanore (cv. BARI Alu-7)					
T_1	326	37.2	11.41		
T_2	284	46.6	15.56	12.88	20.17
T_3	206	44.2	22.62	36.81	18.28
Kalai (cv. BARI Alu-8)					
T_1	315	33.45	10.62		
T_2	279	35.32	12.66	11.43	5.59
T_3	197	33.38	16.94	37.46	-0.21
Joypurhat sadar (cv. BARI Alu-26)					
T_1	292	27.66	9.47		
T_2	257	28.09	10.93	11.99	1.55
T_3	189	26.55	14.05	35.27	-4.18

Mustard

Yield of mustard differed significantly by the number and timing of irrigation (Table 11.58 & 11.59). Grain yield of mustard increased considerably when number of irrigations increased from one to two. But it showed an insignificant yield variation when yield under one irrigation either at vegetative or pre-flowering stage were compared. Though treatments T_1 and T_2 both received one irrigation, yield variation was observed between them due to variation in timing of water application with marginally higher yield in T_2 where water was applied at pre-flowering stage. This result indicated that pre-flowering stage is more responsive than vegetative stage. However, the highest yield (1.56-1.61 t/ha) was obtained from treatment T_3 that received two irrigations at vegetative and pod formation stages. The lowest yield (1.39-1.43 t/ha) was obtained from T_1 when irrigation was applied at vegetative stage. Around 10-15% higher yield was obtained in T_3 compared to T_1, while yield difference between T_1 and T_2 was registered as 2 - 4%. Though treatment T_1 and T_2 both received one irrigation, amount of water requirement was slightly higher in T_2 due to timing of application. Treatment T_2 received irrigation about 10 days later than T_1 when plants were taller with drier field soil, hence more water was needed to fulfill the crop demand. Obviously, treatment T_3 that received two irrigations at vegetative and pod formation stages gave the highest yield with lower water productivity. As increase in yield was not proportionate to water use, so water productivity was slightly lower in treatment T_3 than other two treatments. A reasonably good yield and water productivity was obtained from treatment T_2 with one irrigation only at pre-flowering stage is preferred to irrigation at vegetative stage, even it is preferred to two irrigations at vegetative and pod formation stages in water scarce situation.

Table 11.58. Yield, water requirement and water productivity of mustard during 2018-19

Treatment	WR (mm)	Yield (t/ha)	Water productivity (kg/m^3)	Yield increased (%)	Water saved over T_3 (%)
Godagari (cv. BARI Sarisha-14)					
T_1	139	1.43	1.03		19.19
T_2	142	1.47	1.04	2.16	17.44
T_3	172	1.56	0.91	9.09	-
Tanore (cv. BARI Sarisha-14)					
T_1	143	1.39	0.97		19.66
T_2	149	1.48	0.99	4.20	16.29
T_3	178	1.61	0.90	15.83	-

Table 11.59. Yield, water requirement and water productivity of mustard during 2019-20

Treatment	WR (mm)	Yield (t/ha)	Water productivity (kg/m^3)	Yield increased (%)	Water saved over T_3 (%)
Godagari (cv. BARI Sarisha-14)					
T_1	133	1.15	0.91	-	21.30
T_2	145	1.19	0.85	1.65	14.20
T_3	169	1.49	0.80	12.40	-
Tanore (cv. BARI Sarisha-17)					
T_1	136	1.21	0.94	-	21.39
T_2	147	1.25	0.88	1.56	15.03
T_3	173	1.57	0.82	10.16	-

Effect of irrigation on the yield of rabi crops and rice equivalent yields

Individual crop yield under different cropping sequences is presented in Table 11.60. It was seen that irrigation had significant effects on the yield of rabi crops wheat, mustard, tomato and potato. Yield of mustard differed significantly when number of irrigations increased from one to two. But it showed an insignificant yield variation when irrigation was applied either at vegetative stage or at flowering stage. Similarly, yield of wheat increased slightly when number of irrigations increased from two to three. The highest yield of wheat was obtained from treatment T_3 that received three irrigations at CRI, booting and flowering stages, non-significantly followed by treatment T_2 that received two irrigations at CRI and grain filling stages. The yield under T_1 was significantly lowest compared to T_3. Though both the treatments, T_1 (farmers' practice) and T_2 received two irrigations, a variation in yield was observed due to difference in timing of irrigation with slightly higher yield in treatment T_2. The result revealed that less frequent irrigation can reduce the yield of wheat, but the amount of reduction can significantly be minimized by changing the timing of irrigation application. Therefore, where water is scarce, two irrigations at CRI and grain filling stage (T_2) could be suggested rather than irrigation at CRI and booting stage (T_1). In case of mustard, yield variation was insignificant between treatments T_1 (vegetative) and T_2 (irrigation at pre-flowering stage). A significantly higher yield was obtained from treatment T_3 that received two irrigations at pre-flowering and pod formation stages. This yield under treatment $T_1$and T_2 was at per with slightly higher yield was found when irrigation was applied at pre-flowering stage. So, if only one irrigation is applied, pre-flowering stage is preferred to irrigation at vegetative stage, even it is preferred to two irrigations at vegetative and pod formation stages in water scarce situation.

The yield of potato was significantly higher in every furrow irrigation compared to the farmers' practice (every furrow with different irrigation schedule) in all study areas except in Joypurhat where treatment with farmers' practice in every furrow irrigation produced almost same yield while alternate furrow irrigation produced the marginally lowest. In other locations, however, alternate furrow irrigation produced the second highest yields those were at per with every furrow irrigation. On average, over the locations, the yield of potato was significantly higher in both every furrow irrigation and alternate furrow irrigation compared to the farmers practice. The average yield increase in furrow irrigation and alternate furrow irrigation than that of the farmers practice was 7.42% and 4.30%, respectively. From the result it was clear that both furrow and alternate furrow irrigation can significantly improve the growth and yield of potato, where the difference in yield between furrow and alternate furrow is marginal.

The yield of tomato was significantly influenced by the different irrigation methods. The highest fruit yields of 52.29 t/ha was obtained from the treatment T_2 which received drip irrigation at 3 days interval. This was at par with the yield that obtained under traditional furrow irrigation (T_1) at 10 days interval. Alternate furrow irrigation at 10 days interval produced slightly lower yield than traditional furrow irrigation with a greater saving (about 35%) of irrigation water. Drip fertigation not only produced the highest yield, but also offered a greater saving of water (45%) and fertilizer.

Table 11.60. Rice equivalent yield (REY) of different cropping patterns of the study areas

Pattern	Irrigation treatment	Crop yield (t/ha)				Rice equivalent yield (t/ha)	
		Rabi	Boro	T.aus	T.aman	Rabi	Total
Location: Godagari							
Mustard-Boro-T.Aman	T_1	1.29	5.31	-	2.65	2.30	10.26
	T_2	1.32	5.27	-	4.17	2.35	11.79
	T_3	1.56	5.06	-	3.96	2.78	11.80
Tomato-Boro- T.aus	T_1	48.03	4.8	3.84	-	20.56	29.20
	T_2	52.29	4.06	4.21	-	22.38	30.65
	T_3	45.04	4.51	4.13	-	19.28	27.92
Potato-Boro-T.Aman	T_1	29.7	5.53	-	3.56	10.60	19.69
	T_2	31.93	5.48	-	4.62	11.40	21.50
	T_3	29.93	5.13	-	4.2	10.69	20.02
Maize-T.aus-T.aman	T_1	7.82	-	4.93	2.77	5.02	12.72
	T_2	9.96	-	5.01	3.77	6.39	15.17
	T_3	9.28	-	4.41	3.51	5.96	13.88
Location: Tanore							
Wheat-T.Aus-T.Aman	T_1	4.08	-	3.93	2.71	3.79	10.43
	T_2	4.57	-	4.17	3.48	4.24	11.89
	T_3	4.73	-	4.26	3.57	4.39	12.22
Potato-Boro-T.Aman	T_1	35.56	5.8	-	2.9	12.69	21.39
	T_2	37.18	5.78	-	3.98	13.27	23.03
	T_3	35.9	5.56	-	3.56	12.82	21.94
Potato-T.Aus-T.Aman	T_1	34.64	-	3.62	2.79	12.37	18.78
	T_2	36.49	-	3.87	3.54	13.03	20.44
	T_3	35.2	-	3.36	3.32	12.57	19.25
Location: Kalai							
Potato-Boro-T.Aman	T_1	32.60	5.63	-	3.49	11.64	20.76
	T_2	34.89	5.78	-	3.63	12.46	21.87
	T_3	33.68	5.49	-	3.6	12.02	21.11
Mustard-Boro-T.Aman	T_1	1.1	5.41	-	3.61	1.96	10.98
	T_2	1.11	5.56	-	3.77	1.98	11.31
	T_3	1.39	5.29	-	3.79	2.47	11.55
Location: Joypurhatsadar							
Potato-Boro-T.Aman	T_1	27.15	5.19	-	3.41	9.69	18.29
	T_2	27.47	5.16	-	3.66	9.81	18.63
	T_3	25.44	5.03	-	3.63	9.08	17.74
Mustard-Boro-T.Aman	T_1	1.02	5.41	-	3.56	1.82	10.79
	T_2	1.08	5.56	-	3.71	1.92	11.19
	T_3	1.31	5.29	-	3.65	2.33	11.27

The grain yield of maize was found a bit higher in every furrow irrigation than that of the alternate furrow irrigation while farmers' practice treatment had the significantly lowest yield. The difference in yield between the treatment T_2 (furrow) and T_3 (alternate furrow) was insignificant, but the total water use was significantly lower in alternate furrow irrigation treatment (T_3) compared to every furrow irrigation treatment (T_2), as it received less amount of irrigation water. Thus, alternate furrow irrigation can be a judicious option for maize cultivation in water scarce areas.

As yield of different crops in a particular cropping sequence varied, rice equivalent yield (REY) also varied with different irrigation treatments (Table 11.60). Among the tested crops, tomato had the highest rice equivalent yield (REY) under T_2 water management practice followed by REY of potato. The highest yield of potato under this water regime contributed much to be the highest REY. These two crops have high yield potential to give the higher REY compared to other crops like mustard and wheat. However, the lowest yield of mustard resulted in the lowest REY which was even lower than that of boro rice. Though wheat also gave the lower REY, it was higher compared to the yield of boro rice. Thus, most of the rabi crops had the higher REY than boro rice.

Total rice equivalent yield, total water uses and water productivity of different cropping patterns

Total rice equivalent yield (TREY) in a given pattern was varied with different crops in a crop sequence and irrigation practices (Table. 11.60) while total water use and water productivity of different crops under different cropping sequences in a particular irrigation treatment are presented in Table. 11.61. Here, in most cases, rice equivalent yield was found higher under T_2 irrigation regime where BARI recommended standard practices were followed for non-rice crops and BRRI recommended practices were followed for rice crop. In Tomato-Boro-T.Aman pattern, REY was found the highest in treatment T_2 where the tomato crop yielded the highest under drip irrigation. A drastic improvement of REY happened due to inclusion of very high yielding crop- tomato in the pattern. Next to tomato, potato was another high yielding crop. So inclusion of this crop in Potato-Boro-T.Aman cropping pattern gave the second highest REY with higher value under T_2 water regime followed by Maize-T.Aus-T.Aman cropping pattern. In this regime, all rice and non-rice crops of the patterns such as potato, maize, Boro, T.Aus and T.Aman performed better and helped increasing the TREY. However, the lowest REYs were obtained in farmers' practice irrigation management T_1, except in Potato-Boro-T.Aman at Joypurhat sadar where the lowest REY was obtained from T_3 due to lower yield of potato and boro under this water regime. As mustard was a crop with low yield potential, the Mustard-Boro-T.Aman pattern had the lowest REY compared to other tested patterns.

Total water use and water productivity of different cropping patterns under different management options are shown in Table 11.61. Water used and water productivity was widely varied with cropping pattern and irrigation regimes. Total water use was found highest in Tomato-Boro-T.Aus cropping pattern followed by Potato-Boro-T.Aman and Mustard-Boro-T.Aman patterns and the lowest was recorded by Potato-T.Aus-T.Aman closely followed by Wheat-T.Aus-T.Aman and Maize-T.Aus-T.Aman cropping patterns. Though all were three- crop based patterns, TWU by the previous patterns were higher than latter patterns due to inclusion of more water intensive boro rice. Even tomato consumed more water than other rabi crops. So, the highest water consumed pattern was Tomato-Boro-T.Aus and the TWU by this pattern varied from 1933 mm to 2032 mm with minimum in treatment T_3 and maximum in treatment T_2. In Potato-Boro-T.Aman pattern, TWU varied from 1730 mm for T_3 to 1993 mm for T_1 in Godagari. In other locations, it varied from 1729 mm in T_3 to as high as 2025 mm either in farmers practice T1 or standard practice T¬2. In Tanore, water used by T.Aman under farmers' practice treatment T1 was much lower than T2 as farmer applied less number of irrigation.

Table 11.61. Cropping pattern based water productivity

Pattern	Irrigation treatment	Water use (mm)						
		Rabi	Boro	T.aus	T.aman	TWU (mm)	REY (t/ha/yr)	WP (kg/m^3)
Location: Godagari								
Mustard-Boro-T.Aman	T_1	139	1128	-	528	1795	10.26	0.57
	T_2	142	1017	-	724	1883	11.79	0.63
	T_3	172	912	-	678	1762	11.80	0.67
Tomato-Boro-T.aus	T_1	358	1136	538	-	2032	29.20	1.43
	T_2	266	1019	740	-	2025	30.65	1.51
	T_3	293	917	723	-	1933	27.92	1.44
Potato-Boro-T.Aman	T_1	333	1108	-	552	1993	19.69	0.99
	T_2	288	991	-	699	1978	21.50	1.09
	T_3	201	885	-	644	1730	20.02	1.16
Maize-T.Aus-T.Aman	T_1	296	-	538	533	1367	16.38	1.20
	T_2	348	-	740	728	1816	19.84	1.09
	T_3	266	-	723	714	1703	18.22	1.07
Location: Tanore								
Wheat-T.Aus-T.Aman	T_1	161	-	538	528	1227	10.43	0.85
	T_2	174	-	728	713	1615	11.89	0.74
	T_3	229	-	711	682	1622	12.22	0.75
Potato-Boro-T.Aman	T_1	336	1176		516	2028	21.39	1.05
	T_2	285	1096		729	2110	23.03	1.09
	T_3	196	952		652	1800	21.94	1.22
Potato-T.Aus-T.Aman	T_1	342		542	512	1396	18.78	1.35
	T_2	281		737	721	1739	20.44	1.18
	T_3	203		713	661	1577	19.25	1.22
Location: Kalai								
Potato-Boro-T.Aman	T_1	307	1149		569	2025	20.76	1.03
	T_2	276	1044		649	1969	21.87	1.11
	T_3	186	958		628	1772	21.11	1.19
Mustard-Boro-T.Aman	T_1	110	1146		564	1820	10.98	0.60
	T_2	119	1041		652	1812	11.31	0.62
	T_3	156	953		626	1735	11.55	0.67
Location: Joypurhat sadar								
Potato-Boro-T.Aman	T_1	298	1139		558	1995	18.29	0.92
	T_2	268	1027		648	1943	18.63	0.96
	T_3	193	908		628	1729	17.74	1.03
Mustard-Boro-T.Aman	T_1	107	1129		558	1794	10.79	0.60
	T_2	113	1015		648	1776	11.19	0.63
	T_3	152	902		628	1682	11.27	0.67

The difference in TWU between these two management options arose from difference in water use by T.Aman. In Kalai and Joypurhat sadar, TWU by Potato-Boro-T.Aman patterns were higher than that of Mustard-Boro-T.aman patterns. The difference in TWU between these two patterns was due to difference in water use by mustard and potato. On average, TWU was lower in non-rice rabi crops, except maize, than rice and vegetables crops. Crop water productivity (WP) or water use efficiency (WUE) expressed in kg/m^3 was an efficiency term, expressing the amount of marketable product (e.g.

kilograms of grain) in relation to the amount of input needed to produce that output (cubic meters of water). Among the cropping patterns, Tomato-Boro-T.Aus had the highest WP which ranged from 1.43 to 1.51 kg/m^3 followed by Potato-T.Aus-T.Aman and Potato-Boro-T.Aman patterns in which WP ranged from 1.18 to 1.35 kg/m^3 and 0.99 to 1.16 kg/m^3, respectively, with maximum in water management practice where water saving technologies (drip, AWD, AFI) were adopted. Both the crops potato and tomato had the high yield potential and their inclusion in any pattern perceptibly will increase the TREY and WP as well. Over the locations, WP varied from 0.99 to 1.15 kg/m^3 for Potato-Boro-T.Aman with minimum in T_1 and maximum in T_3 water management option. The pattern Mustard-Boro-T.Aman had the lowest WP ranging from 0.57to 0.67 kg/m^3 for Rajshahi and from 0.60 to 0.67 kg/m^3 for Joypurhat. In this pattern too, WP was found highest under T_3 management option. In general, WP was found higher in water management options where water saving technology was included as a treatment. Cropping pattern base total water use (TWU) and water productivity (WP) were shown in Fig. 11.95 to 11.97.

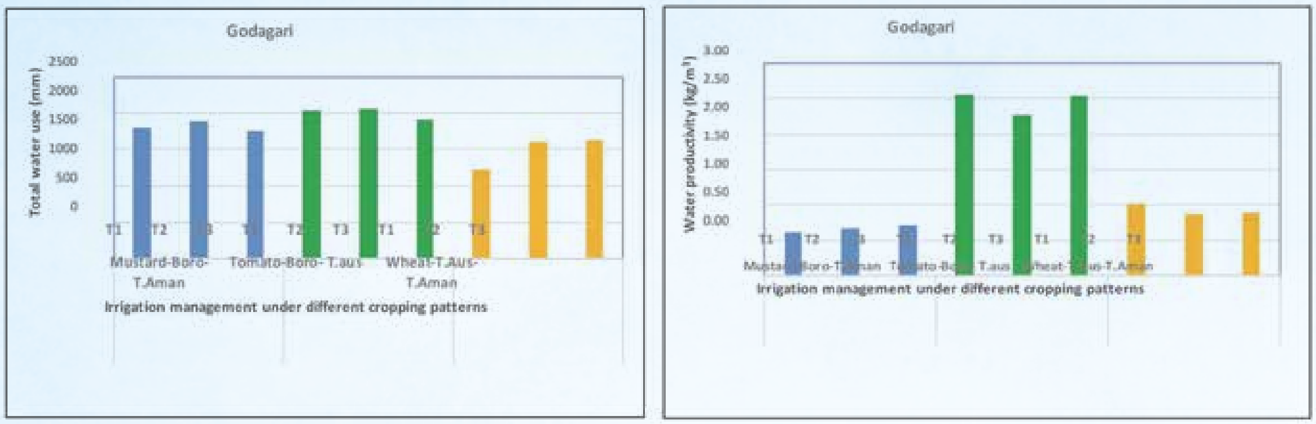


Fig. 11.95. Cropping pattern based Total water use (TWU) and water productivity (WP) at Godagari

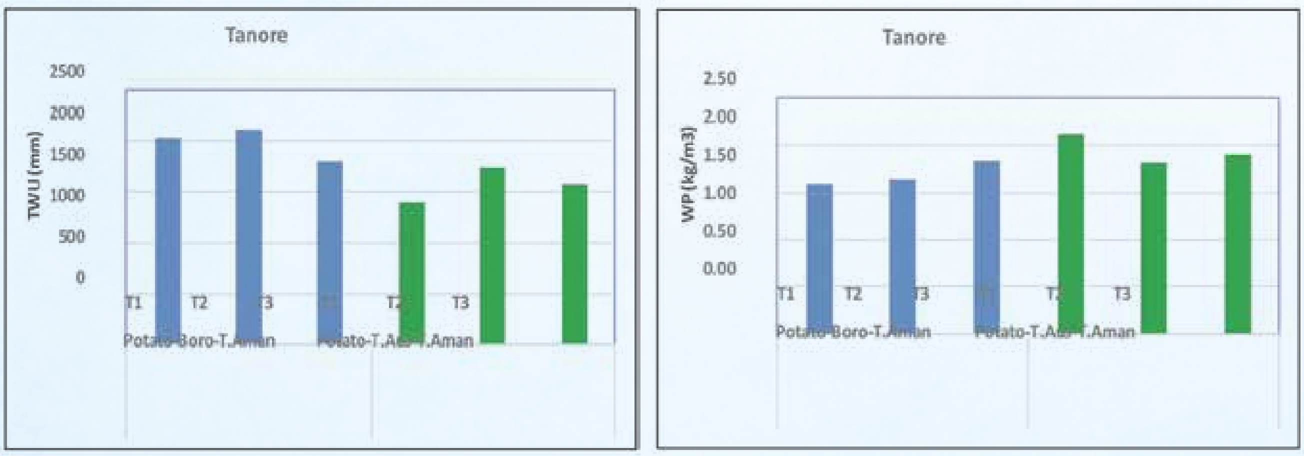
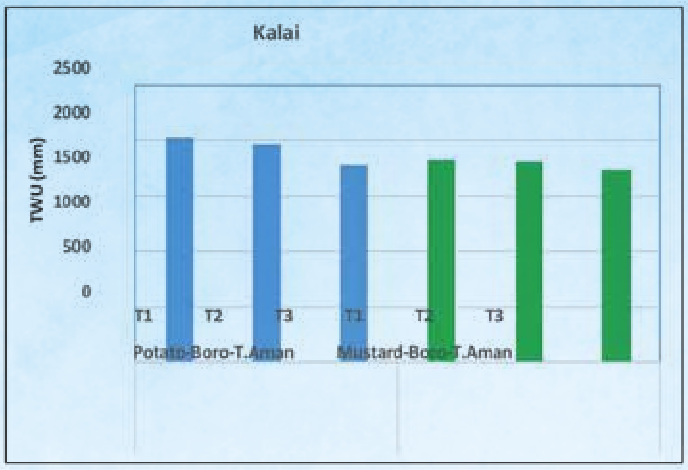


Fig. 11.96. Cropping pattern based Total water use (TWU) and water productivity (WP) at Tanore



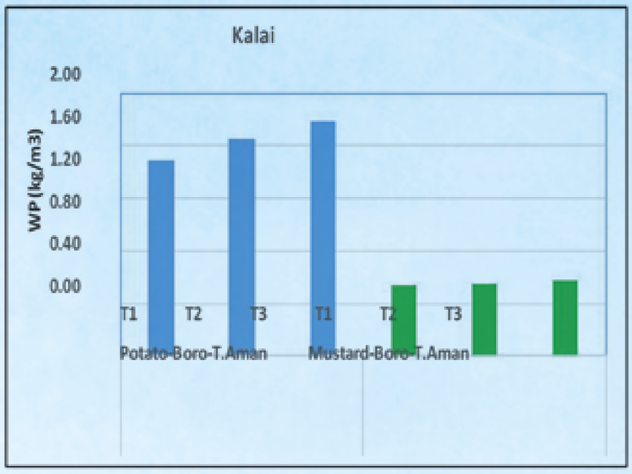


Fig. 11.97. Cropping pattern based Total water use (TWU) and water productivity (WP) at Kalai

11.4.2. Component-2: BRRI

11.4.2.1. Determination of less irrigation requiring cropping patterns for water scarce areas

Five cropping patterns (CP) were tested to find out the best one in terms of water productivity, rice equivalent yield (REY) and economic for the project site. Tested results showed that Aus based CP performed good in terms of water productivity and Boro based CP performed good in terms of REY and economic. Detail results and suggestions for adopting good CP in the project area are given below.

Amount and distribution of rainfall received by cropping patterns

Cropping pattern in a location mostly depends on amount and distribution of annual rainfall of that location. Especially in water scarce area where groundwater problem exists, rainfall amount and its distribution are major factors for establishing CP in that particular location. Considering this matter, monthly amount and distribution of rainfall both in Pabna and Rangpur were analyzed and results are presented in Fig.11.98. Results showed that Rangpur received the higher rainfall than Pabna in each month. July is the wettest month of the year in both the locations. More than 75% of annual rainfall occurred during June to October in both the locations. Though sufficient rainfall occurred during this period, but its uneven distribution and about to cease of it during the last part of October often caused terminal drought in monsoon crop particularly transplanted Aman rice. Besides that sometimes rainfall was not sufficient to meet the consumptive use of crop, thus supplemental irrigations were need to apply to meet the consumptive use of the crop during crop growing period.

Different CP received different amount of rainfall as their establishment and harvesting time were different. Fig. 11.99 and Fig.11.100 represent cropping pattern wise rainfall amount and distribution during 2018-19 and 2019-20, respectively at four different locations of Pabna and Rangpur. During 2018-19 season, T. Aus based cropping pattern such as T. Aman-Wheat-T. Aus and T. Aman- Lentil-T. Aus received the highest rainfall (969 mm) and T. Aman – Fallow- Boro received the lowest rainfall of 715 mm at Ishwardi, Pabna. T. Aman-Wheat-T. Aus received the highest rainfall of 1013 mm followed by 847 mm in T. Aman- Lentil- T. Aus and the lowest 455 mm rainfall was received by T. Aman – Fallow- Boro pattern at Santhia Pabna. Similar results were found in Rangpur where both the pattern T. Aman-Wheat-T. Aus and T. Aman- Lentil- T. Aus received the highest rainfall of 1276 mm at Mithapukur and 1389 mm at Pirgonj.

During 2019-20, rainfall amount was higher than the previous year. The highest 1228 mm and 1108 mm rainfall was observed in T. Aman- Wheat- T. Aus pattern and the lowest 549 mm and 566 mm rainfall was found in T. Aman- Fallow- Boro at Ishwardi and Santhia, respectively. Among the trialed three cropping patterns in Rangpur, T. Aman- Mustard-Boro cropping pattern received the maximum rainfall of 1439 mm and 1314 mm, whereas the lowest 1029 mm and 920 mm rainfall was recorded in T. Aman- Fallow- Boro cropping pattern at Mithapukur and Pirgonj, respectively.

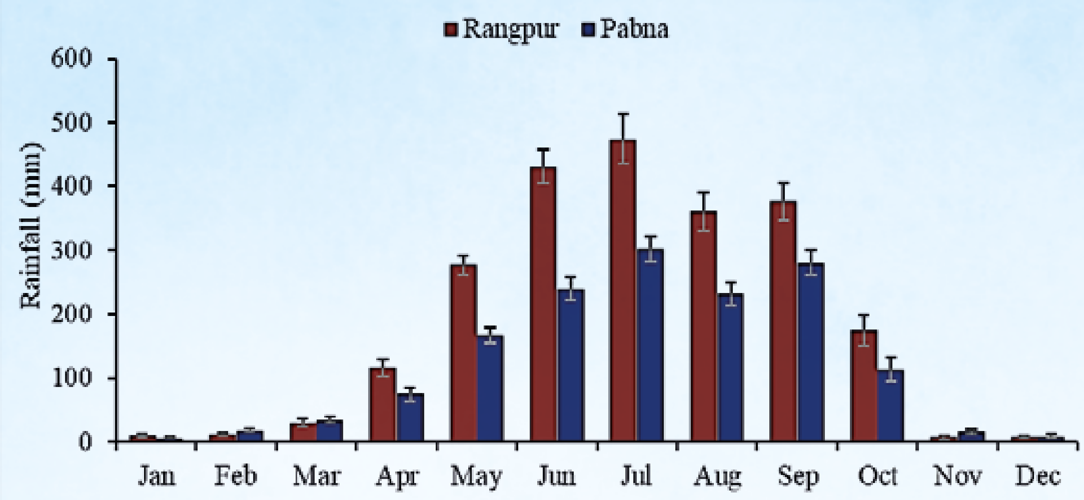


Fig. 11.98. Temporal distribution of monthly normal rainfall in Pabna and Rangpur

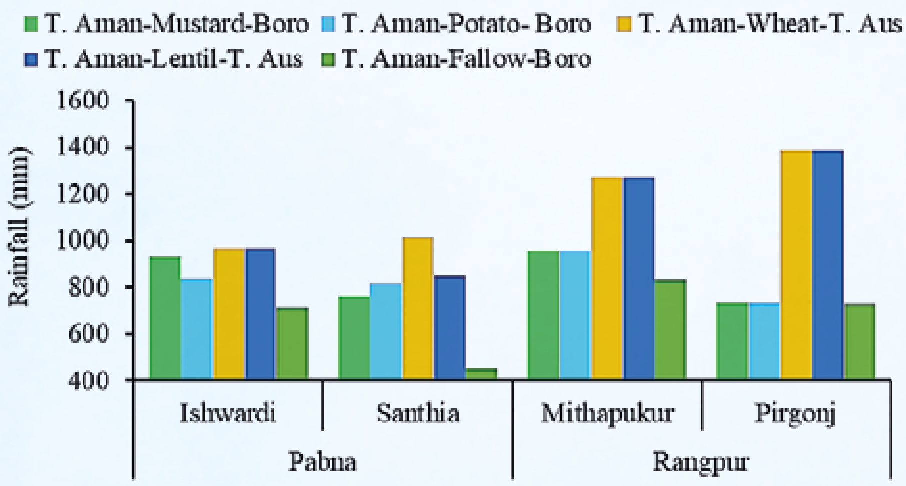


Fig. 11.99. Spatial rainfall distribution for different cropping patterns in Paban and Rangpur during 2018-19

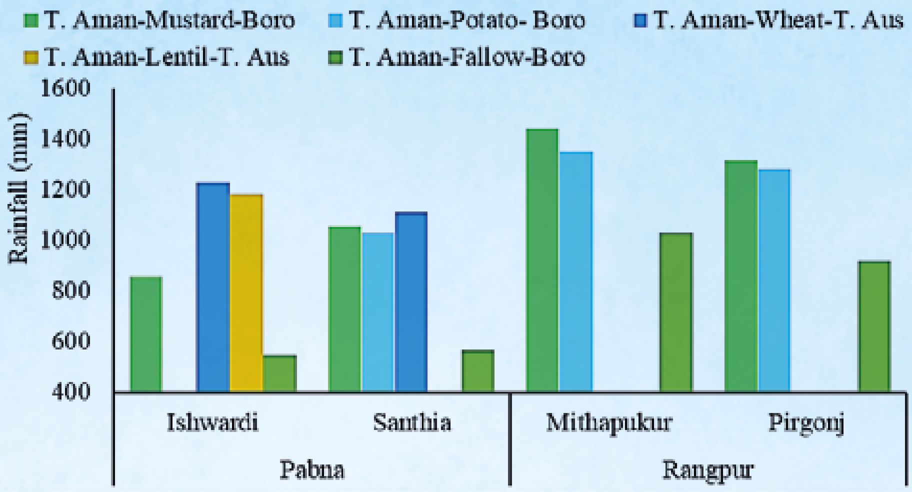


Fig. 11.100. Spatial rainfall distribution for different cropping patterns in Paban and Rangpur during 2019-20

Cropping pattern wise irrigation

Both rainfall and soil moisture when fail to meet the consumptive use of crop then crop suffers from water stress and irrigation becomes essential. This event may happen at any stage of crop growing period in T. Aman and Rabi season. This sub-project experienced such event during its period.

During 2018-19

Applied irrigation for each crop in cropping patterns as well as total amount of irrigation for the cropping pattern were measured during 2018-19 and presented in Table 11.62 and Table 11.63 for Rangpur and Pabna respectively. During 2018-19 period T. Aman rice faced terminal drought as rainfall became almost zero at later part of October, when the crop was at the ripening stage and so supplemental irrigation was applied to mitigate drought in each location. Again only 7 mm, 19 mm and 68 mm rainfall occurred during the Rabi season at Rangpur, Ishwardi and Santhia, respectively which demanded irrigation and about two to four supplemental irrigations were applied. It is mentionable that Boro rice in cropping patterns with three crops required comparatively less irrigation than Boro rice in cropping patterns with two crops (T. Aman-Fallow-Boro). This happened because Boro had less field duration due to Rabi crop delayed Boro transplanting and shifted harvesting time. As a result, delay establishment of Boro crop received more rainfall than timely transplanted Boro. In all the locations, Boro rice was transplanted in March in each year after harvesting of Mustard and Potato, whereas transplanting of Boro rice was completed on January in T. Aman-Fallow-Boro cropping patterns having two crops. However, sufficient rainfall occurred during the reproductive and ripening phase of T. Aus rice, in spite of that supplemental irrigation was applied in the early vegetative phase.

The highest 1537 mm irrigation was applied in T. Aman-Fallow-Boro cropping pattern whereas, only 186 mm irrigation was enough in T.Aman-Lentil-T. Aus cropping pattern in Mithapukur. Which cropping pattern needed less irrigation compared to control or farmer's practiced cropping pattern was determined. The result showed that among the cropping patterns the highest 88% irrigation was saved in T.Aman-Lentil-T. Aus pattern followed by 80%, 33% and 24% in T.Aman-Wheat-T. Aus, T.Aman-Potato-Boro and T.Aman-Mustard-Boro cropping patterns respectively (Table 11.62). The same trend was found in T. Aus based cropping patterns. Such as T.Aman-Lentil-T. Aus and T.Aman-Wheat-T. Aus saved the highest 76% irrigation water and Boro based improved pattern saved more than 20% water over the control T. Aman-Fallow-Boropatterns in Pirgonj, Rangpur.

Since Pabna received comparatively less amount of rainfall than Rangpur therefore, applied irrigation was higher in Pabna than Rangpur in all season. T. Aman required 4 to 6 number of irrigation accounting 133 to 476 mm irrigation at Ishward and Santhia, of Pabna region. No irrigation was applied in Mustard and Lentil, during 2018-19 since a timely rainfall provided sufficient moisture both in Ishwardi and Pabna. Among the cropping patterns, the highest 76% and 58% in T.Aman-Lentil-T. Aus cropping pattern and the lowest 26% and 10% in T. Aman-Fallow-Boro pattern irrigation were saved at Ishward and Santhia, respectively.

Table 11.62. Irrigation applied (mm) for different cropping patterns at Rangpur during 2018-19

Cropping patterns	**Mithapukur, Rangpur**				
	T. Aman	**Rabi**	**Boro/ T. Aus**	**Total**	**Irrigation saved over control (%)**
T.Aman-Mustard-Boro	162	112	890	1164ab	24
T.Aman-Potato-Boro	171	93	758	1023 b	33
T.Aman-Wheat-T. Aus	132	104	68	303 c	80
T.Aman-Lentil-T. Aus	131		55	186 c	88
T.Aman-Fallow-Boro (control)	132		1405	1537 a	
LSD (0.05)				416	
CV (%)				26	
	Pirgonj, Rangpur				
T.Aman-Mustard-Boro	174	63	975	1112 b	23
T.Aman-Potato-Boro	193	61	777	1032 b	29
T.Aman-Wheat-T. Aus	149	108	87	343 c	76
T.Aman-Lentil-T. Aus	211	14	116	341 c	76
T.Aman-Fallow-Boro (control)	208		1240	1448 a	
LSD (0.05)				186	
CV (%)				11.6	

Table 11.63. Irrigation applied (mm) in different cropping patterns at Pabna during 2018-19

Cropping patterns	**Santhia**				
	T. Aman	**Rabi**	**Boro/ T. Aus**	**Total**	**Irrigation saved over control (%)**
T.Aman-Mustard-Boro	456	0	921	1377 ab	10
T.Aman-Potato-Boro	476	37	713	1225 b	20
T.Aman-Wheat-T. Aus	341	71	313	726 c	53
T.Aman-Lentil-T. Aus	302	0	342	644 c	58
T.Aman-Fallow-Boro (control)	313		1219	1532 a	
LSD (0.05)				165	
CV (%)				8.0	
	Ishwardi				
T.Aman-Mustard-Boro	167	0	727	893 b	26

Cropping patterns	Santhia				
	T. Aman	Rabi	Boro/ T. Aus	Total	Irrigation saved over control (%)
T.Aman-Potato-Boro	133	50	600	783 b	35
T.Aman-Wheat-T. Aus	150	40	150	340 c	72
T.Aman-Lentil-T. Aus	133	0	150	283 c	76
T.Aman-Fallow-Boro (control)	150		1050	1200 a	
LSD (0.05)				143	
CV (%)				10.8	

During 2019-20

Sufficient rainfall was observed during 2019-20 cropping season than the previous year in both the locations resulting less irrigation application. Due to uniform rainfall distribution over the T. Aman season no irrigation was required both at Mithapukur and Pirgonj, Rangpur. But, only one irrigation was applied in Rabi crops. The existing (control) T.Aman-Fallow-Boro cropping pattern required the highest 1342 mm and 1272 mm and T.Aman-Potato-Boro pattern required the lowest 764 mm and 803 mm of irrigation at Mithapukur and Pirgonj, respectively (Table 11.64). However, T.Aman-Mustard-Boro and T.Aman-Potato-Boro, these two CPs in Mithapukur saved 26% to 43% irrigation compared to control CP. Again, these two CPs saved 35% and 37% irrigation in Pirgonj.

In Pabna, the control CP also required the highest irrigation water than other CPs. T. Aus based CPs needed less irrigation than Boro based CPs because of more rainfall coverage in T. Aus rice. In terms of water saving, the previous year trend was observed in this year. Such as, T.Aman-Wheat-T. Aus pattern in Santhia and T.Aman-Lentil-T. Aus in Ishwardi saved the highest 67% and 69% irrigation water than control CP, respectively. Again, T.Aman-Mustard-Boro cropping pattern saved the lowest 26% water in both the locations (Table 11.65).

Table 11.64. Irrigation applied (mm) in different cropping patterns at Rangpur during 2019-20

Cropping patterns	Mithapukur, Rangpur				
	T.Aman	Rabi	Boro/ T. Aus	Total	Irrigation saved over control
T.Aman-Mustard-Boro	0	45	954	999 b	26
T.Aman-Potato-Boro	0	39	725	764 c	43
T.Aman-Fallow-Boro (control)	0		1342	1342a	
LSD (0.05)				196	
CV (%)				8.4	
	Pirgonj, Rangpur				
T.Aman-Mustard-Boro	0.0	99.0	727.5	826 b	35
T.Aman-Potato-Boro	0.0	26.4	776.8	803 b	37
T.Aman-Fallow-Boro (control)	0.0		1271.7	1272 c	
LSD (0.05)					
CV (%)					

Table 11.65. Irrigation applied (mm) in different cropping patterns at Pabna during 2019-20

Cropping patterns	Santhia, Pabna				
	T.Aman	Rabi	Boro/ T. Aus	Total	Irrigation saved over control
T.Aman-Mustard-Boro	391	47	893	1330 b	26
T.Aman-Potato-Boro	316	35	819	1170 b	35
T.Aman-Wheat-T. Aus	372	65	163	600 c	67
T.Aman-Fallow-Boro (control)	335		1470	1805 a	
LSD (0.05)				216	
CV (%)				8.8	
	Ishwardi, Pabna				
T.Aman-Mustard-Boro	352	43	676	1072 b	26
T.Aman-Wheat-T. Aus	352	62	150	564 c	61
T.Aman-Lentil-T. Aus	308		143	451 c	69
T.Aman-Fallow-Boro (control)	286		1167	1453 a	
LSD (0.05)				19.0	
CV (%)				341	

Yield performance of different CPs

Acceptance of any CP mostly depends on yield of individual crop and total yield of CP. Sometimes sudden calamities (biotic and abiotic) may damage partially or fully any crop in CP, in this case CP does not reflect its own potentiality. The first year of this project faced such type of problem, however, total yield of CP was converted in rice equivalent yield (REY) in this sub-project.

During 2018-19

Cropping pattern wise grain yields and REYsin Rangpur during 2018-19 season was analyzed and presented in Table 11.66. Almost same grain yield was observed for T. Aman rice in all CPs since variety, water management, transplanting time were the same. It is mentionable that wheat gave the lower grain yield than normal yield due to severe rat damage occurred in both the locations of Rangpur. Lower yield of Lentil than the national average was also observed in Rangpur because of sudden water logging from nearby irrigation channel. Among the cropping patterns the highest REY was observed in T.Aman-Potato-Boro (21 t ha^{-1} and 19.9 t ha^{-1}at Mithapukur and Pirgonj, respectively) and the lowest REY was observed in T. Aus based two cropping patterns in both the locations of Rangpur (10.9 t $ha^{-1}$and 9.7 t ha^{-1}at Mithapukur and Pirgonj, respectively). This was the resultant of the poor yield of Wheat and Lentil crops in these patterns.

Grain yield in T. Aman rice in all CPs were recorded during 2018-19 at Santhia and Ishwardi, Pabna and shown in Table 11.67. Potato gave less yield compared to its potential due to poor germination of seeds lead to less plant per unit area. Lower yield of wheat was due to the severe rat damage in both the fields. T. Aman-Mustard-Boro and T. Aman-Potato-Boro gave statistically the highest grain yield whereas control treatment T. Aman-Fallow-Boro produced the lowest yield at Santhia, Pabna. On the other hand, T. Aman-Mustard-Boro, T. Aman-Potato-Boro and T.Aman-Wheat-T. Aus gave statistically similar yield and other than T. Aman-Potato-Boro yield lowest similar grain yield at Ishwardi, Pabna.

Table 11.66. Total REY of different cropping patterns at Rangpur during 2018-19

Cropping pattern	Mithapukur, Rangpur				Pirgonj, Rangpur			
	T. Aman	Rabi	Boro/ T. Aus	Total REY	T. Aman	Rabi	Boro/ T. Aus	Total REY
T.Aman-Mustard-Boro	5.3	1.4	6.7	15.7 b	5.3	1.24	7.37	16.2b
T.Aman-Potato-Boro	5.4	18.5	6.4	21.0 a	5.3	14.3	7.37	19.9 a
T.Aman-Wheat-T. Aus	5.3	2.5	3.2	11.3 c	4.3	1.8	3.4	9.7d
T.Aman-Lentil-T. Aus	5.2	0.8	3.3	10.9 c	5.1	0.5	3.4	10.0d
T.Aman-Fallow-Boro (control)	5.4		6.8	12.1 c	5.0	-	8.07	13.1c
LSD(0.05)				2.6				1.55
CV (%)				9.7				6.0

Price of Mustard Tk. 55/kg, potato Tk. 10/kg, wheat Tk. 22, lentil Tk. 60, rice Tk. 20/kg

Table 11.67. Total REY of different cropping patterns at Pabna during 2018-19

Cropping pattern	Santhia				Ishwardi			
	T. Aman	Rabi	Boro/ T. Aus	Total REY	T. Aman	Rabi	Boro/ T. Aus	Total REY
T. Aman-Mustard-Boro	4.6	1.8	6.5	16.5 a	5.1	1.6	5.5	13.9 ab
T. Aman-Potato-Boro	4.2	12.0	5.4	15.9 a	4.8	11	5.1	15.7 a
T. Aman-Wheat-T. Aus	4.5	4.8	3.8	14.2 b	5.0	5.1	3.6	14.1 ab
T. Aman-Lentil-T. Aus	4.2	0.6	3.8	12.8 c	4.6	1.5	3.6	12.8 b
T. Aman-Fallow-Boro (control)	4.4		6.5	11.1 d	5.2	0	6.6	11.8 b
LSD(0.05)				1.17				2.75
CV (%)				5				10.7

Price of Mustard Tk. 55/kg, Potato Tk. 10/kg, wheat Tk. 22, lentil Tk. 60/kg, rice Tk. 20/kg

During 2019-20

Farmers in both locations of Rangpur (Mithapukur and Pirgonj) showed less interest for cultivating wheat and lentil this year because they got bad experience of poor yielded wheat and lentil during first year trials (2018-19). Therefore, in this year two cropping patterns, T.Aman-Wheat-T. Aus and T. Aman-Lentil-T.Aus was dropped. For the same reason, T. Aman-Lentil-T.Aus Boro and T. Aman-Potato-Boro patterns were not implemented in this year at Santhia and Ishwardi, respectively.

In Rangpur, T. Aman-Potato-Boro gave the highest REY of 31.3 t $ha^{-1}$and 21.2 t ha^{-1} and the lowest REY was recorded in control T. Aman-Fallow-Boro cropping pattern at Mithapukur and Pirgonj, respectively (Table 11.68).

Following the previous year results, T. Aman-Potato-Boro pattern produced the highest REY (25.2 t ha^{-1}) at Santhia and T. Aman-Lentil-T. Aus pattern gave the maximum 19 t ha^{-1} at Ishwardi (Table 11.69). Boro-Fallow-T. Aman cropping pattern gave the lowest yield at both the locations.

Table 11.68. Total REY of different cropping patterns at Rangpur during 2019-20

Cropping pattern	Mithapukur, Rangpur				Pirgonj, Rangpur			
	T. Aman	Rabi	Boro/ T. Aus	Total REY	T. Aman	Rabi	Boro/ T. Aus	Total REY
T.Aman-Mustard-Boro	5.6	1.5	5.9	15.1 b	5.4	1.2	6.3	15.1
T.Aman-Potato-Boro	5.1	33.6	5.7	31.3 a	4.9	19.6	6.4	21.2
T.Aman-Fallow-Boro	5.3		7.6	12.8 b	5.1		7.8	12.9
LSD (0.05)				2.4				
CV (%)				7.0				

Price of Mustard Tk. 42/kg, potato Tk. 11/kg, rice Tk. 20/kg

Table 11.69. Total REY of different cropping patterns at Pabna during 2019-20

Cropping pattern	Santhia				Ishwardi			
	T. Aman	Rabi	Boro/ T. Aus	Total REY	T. Aman	Rabi	Boro/ T. Aus	Total REY
T. Aman-Mustard-Boro	5.6	1.6	5.6	14.9 b	5.3	1.6	6.0	15.5 b
T. Aman-Potato-Boro	5.9	24.0	4.9	25.2 a				
T. Aman-Wheat-Aus	5.8	3.7	4.8	15.0 b	5.4	4.0	4.9	16.3 b
T. Aman-Lentil-Aus					5.4	1.9	4.7	19.0 a
T. Aman-Fallow-Boro	5.2		6.3	11.5 c	5.6		6.4	12.0 c
LSD (0.05)				1.94				2.3
CV (%)				6.0				7.2

Price of Mustard Tk. 47/kg, potato Tk. 10/kg, wheat Tk. 24, lentil Tk. 82/kg, rice Tk. 18/kg

Irrigation water productivity

Less irrigation application produces higher irrigation water productivity of crop. Rainfall was ignored for calculating irrigation water productivity. But for total water productivity rainfall must be included. Irrigation water productivity of the tested CPs in this project was calculated and results are given below.

During 2018-19

Among the tested CPs three crops containing CP always gave the highest irrigation water productivity than two crops containing CP, because in three crops containing CP the third crop (Rabi) required the less amount of irrigation. Again, in T. Aus rice-based CP, T. Aus rice received good amount of rainfall during its growing period. Thus, T. Aus rice-basedCP always gave the highest irrigation water productivity. But in terms of REY Boro based CP gave the higher yield.

Irrigation water productivity of different cropping patterns in 2018-19 at Rangpur and Pabna has been analyzed and shown in Fig.11.89 and Fig.11.90 respectively. In Rangpur, the highest water productivity 5.96 kg m^{-3} was found in T. Aman- Lentil – T. Aus cropping pattern followed by 3.7 kg m^{-3} in T. Aman-Wheat-T. Aus, 2.12 kg m^{-3} in T. Aman-Potato-Boro and 1.38 kg m^{-3} in T. Aman-Mustard-Boro pattern at Mithapukur. The same scenarios were observed at Pirgonj, Rangpur where T. Aman- Lentil-T. Aus gave the highest water productivity. The lowest water productivity 0.81 kg $m^{-3}$and 0.9 kg m^{-3} were observed at Mithapukur and Pirgonj, respectively in T. Aman-Fallow-Boro cropping pattern. Higher water productivity was observed in Mithapukur compared to Pirgonj.

All most similar trend was observed in Pabna where the highest water productivity 2.0 kg m^{-3} was found in T. Aman- Lentil – T. Aus cropping pattern followed by 1.98 kg m^{-3} in T. Aman-Wheat-T. Aus, 1.32 kg m^{-3} in T. Aman-Potato-Boro at Santhia. The same result was observed at Ishwardi where the maximum irrigation water productivity 4.57 kg $m^{-3}$was in T. Aman- Lentil – T. Aus cropping pattern. In both the locations, T. Aman-Fallow-Boro cropping pattern gave the lowest water productivity.

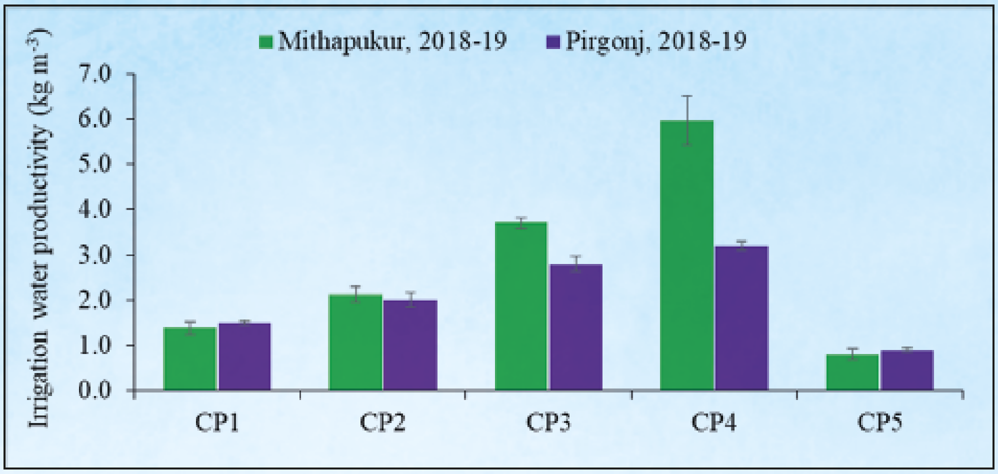


Fig. 11.101. Irrigation water productivity of different cropping patterns at Mithapukur and Pirgonj of Rangpur during 2018-19

Note:
CP_1: T. Aman-Mustard-Boro
CP_2: T. Aman-Potato- Boro
CP_3: T. Aman-Wheat- T. Aus
CP_4: T. Aman-Lentil- T. Aus
CP_5: T. Aman-Fallow-Boro

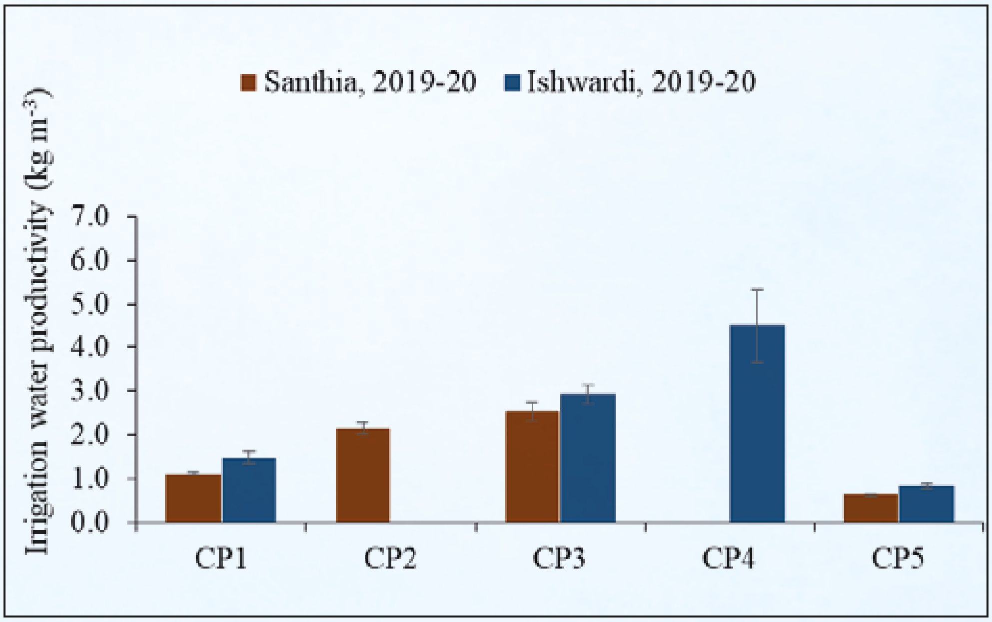


Fig. 11.102. Irrigation water productivity of selected cropping patterns at Ishwardi and Santhia of Pabna district during 2018-19

During 2019-20

Among the tested three patterns, T. Aman-Potato-Boro gave the maximum irrigation water productivity 4.1 kg $m^{-3}$and 2.68 kg m^{-3} at Mithapukur and Pirgonj, respectively (Fig.11.103). Like the previous year study, T. Aman-Fallow-Boro gave the minimum irrigation water productivity at both the locations.

Similar to previous year, T. Aus based pattern T. Aman- Wheat – T. Aus and T. Aman- Lentil – T. Aus gave the highest 2.54 kg $m^{-3}$and 4.5 kg m^{-3}irrigation water productivity at Santhia and Ishwardi, respectively (Fig. 11.104). T. Aman-Fallow-Boro gave the minimum irrigation water productivity at both the locations.

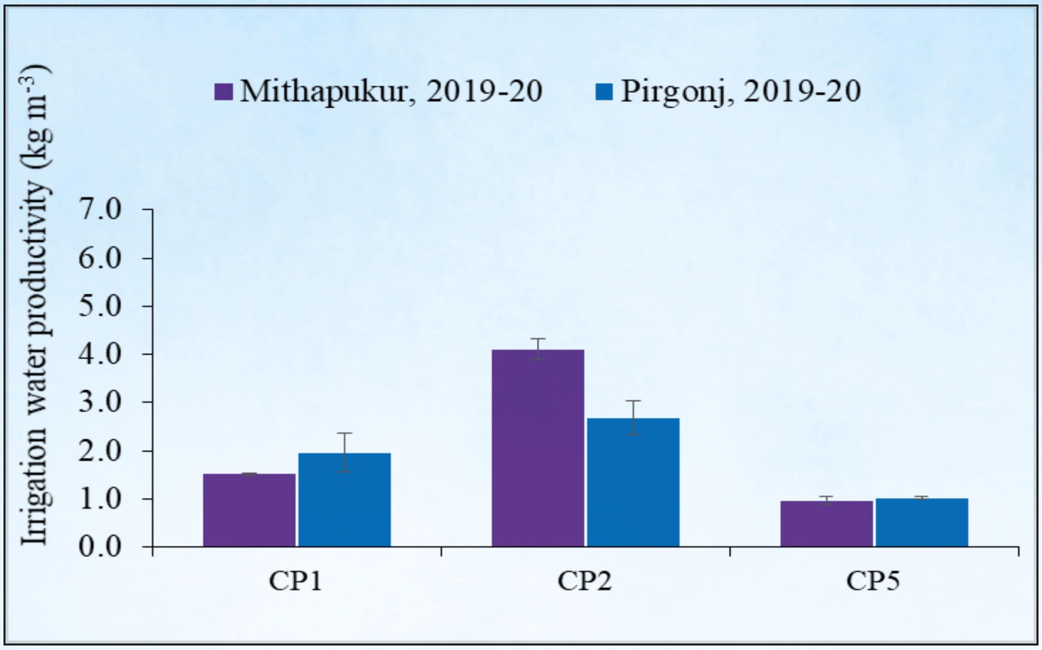


Fig. 11.103. Irrigation water productivity of different cropping patterns at Mithapukur and Pirgonj of Rangpur during 2019-20

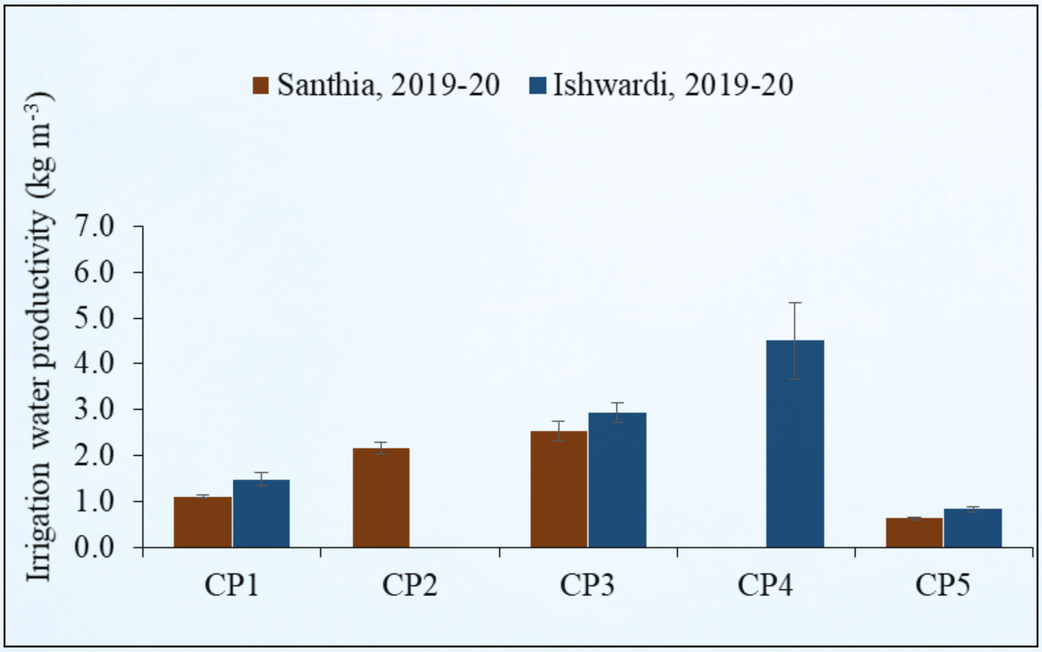


Fig. 11.104. Irrigation water productivity of selected cropping patterns at Ishwardi and Santhia of Pabna district during 2018-19

Economic performance of crops and cropping patterns

The most important factor for accepting a cropping pattern is economic benefit of that CP. Farmers do not easily accept a CP without getting economic benefit from that CP. Therefore, cost of production and returns from different crops and cropping patterns, tested in this project were analyzed and presented in Table 11.70 and Table 11.71. Gross return of T Aman rice included return from grain and straw yield. Gross margin from T. Aman rice was always remarkable since almost its similar yield was obtained in all cropping patterns and in all locations. Rabi crops especially Wheat and Lentil showed negative return as less yield obtained due to rat damage. Timely establishment of Boro rice having good yield resulted good economic return. Whereas, economic return of delay transplanting of Boro crops in cropping pattern having three crop was less because it had to loss grain yield for short field duration.

2018-19 season

During 2018-19, the maximum gross return was found in Potato (Table 11.70) both in Mithapukur and Pirgonj, Rangpur. High yield production led to the maximum return. The highest variable cost was observed in Potato production in each location, since the maximum cost went for seedof the crop. Among the trialed patterns, T. Aman-Potato-Boro gave the highest gross margin of Tk. 145795 followed by Tk. 136713 in T. Aman-Mustard-Boro pattern. The lowest gross margin was found in T. Aus based cropping pattern at Mithapukur. At Pirgonj, the maximum gross return was found in T. Aman-Potato-Boro, but the maximum gross margin was found in T. Aman-Mustard-Boro pattern. This was the result of higher production cost associated with the earlier pattern. Same as Rangpur, T. Aman-Potato-Boro showed the best economic performance at Santhia during 2018-19 and it gave Tk. 147763 gross margin followed by Tk. 86957 in T. Aman-Mustard-Boro cropping pattern. T. Aman-Lentil-Aus gave the lowest gross margin of Tk. 34288 in this location. T. Aman-Wheat-Aus gave the maximum gross margin at Ishwardi during 2018-19.

During 2019-20

Same as the previous year's (2018-19) result the highest gross return and gross margin was found in T. Aman-Potato-Boro pattern both in Mithapukur (Tk. 333995) and Pirgonj (Tk. 198504). T. Aman-Mustard-Boro pattern also gave the second highest gross return in Pirgonj, Rangpur (Table 11.72). T. Aman-Potato-Boro pattern showed the maximum gross return which resulted in the highest gross margin (Tk. 211550) at Santhia, Pabna (Table 11.73). T. Aman-Lentil-Aus gave the highest gross margin of Tk. 200418 at Ishwardi. Aus based cropping pattern performed better at this study location during 2019-20 over control pattern.

Table 11.70. Benefit and cost analysis of different cropping patterns at Mithapukur, Rangpur during 2018-19

Cropping patterns	Gross return (Tk. ha^{-1})				Total variable cost (Tk. ha^{-1})				Gross margin (Tk. ha^{-1})
	T. Aman	Rabi	Boro/ Aus	Total benefit	T. Aman	Rabi	Boro/ Aus	Total cost	
	Mithapukur, Rangpur								
T. Aman-Mustard-Boro	117780	77000	153424	348204	70870	46252	94369	211491	136713
T. Aman-Potato-Boro	121818	185000	146980	453798	70870	142763	94369	308002	145795
T. Aman-Wheat-Aus	125613	55000	75504	256117	70870	57815	73854	202539	53578
T. Aman-Lentil-Aus	118666	48000	78423	245089	70870	36181	73854	180905	64184
T. Aman-Fallow-Boro	122256		152837	275093	70870		94369	165239	109854

Cropping patterns	Gross return (Tk. ha^{-1})				Total variable cost (Tk. ha^{-1})				Gross margin (Tk. ha^{-1})
	T. Aman	Rabi	Boro/ Aus	Total benefit	T. Aman	Rabi	Boro/ Aus	Total cost	
	Pirgonj, Rangpur								
T. Aman-Mustard-Boro	120018	68200	168468	356686	72735	37300	97428	207463	149223
T. Aman-Potato-Boro	122256	143000	159964	425220	72735	146493	97428	316656	108564
T. Aman-Wheat-Aus	103137	39600	81342	224079	72735	46700	76092	195527	28552
T. Aman-Lentil-Aus	116866	30000	80223	227089	72735	29318	76092	178145	48944
T. Aman-Fallow-Boro	116856		175697	292553	72735		97428	170163	122390

Table 11.71. Benefit and cost analysis of different cropping patterns at Santhia, Pabna during 2018-19

Cropping patterns	Gross return (Tk. ha^{-1})				Total variable cost (Tk. ha^{-1})				Gross margin (Tk. ha^{-1})
	T. Aman	Rabi	Boro/ Aus	Total benefit	T. Aman	Rabi	Boro/ Aus	Total cost	
	Santhia, Pabna								
T. Aman-Mustard-Boro	113321	75200	133176	321697	88922	44014	101805	234741	86957
T. Aman-Potato- Boro	105627	240000	118227	463853	87482	130763	97845	316090	147763
T. Aman-Wheat-Aus	107110	88800	95032	290942	88562	64902	63564	217028	73914
T. Aman-Lentil-Aus	106149	36000	95032	237181	87482	51847	63564	202893	34288
T. Aman-Fallow-Boro	109227		148332	257559	88202		101805	190007	67552
	Ishwardi, Pabna								
T. Aman-Mustard-Boro	120521	66000	136076	322597	86246	32078	112082	230406	92191
T. Aman-Potato- Boro	116427	115000	123393	354820	85166	130763	110642	326571	28248
T. Aman-Wheat-Aus	120027	107800	91171	318998	85886	52966	77862	216714	102284
T. Aman-Lentil-Aus	109432	90000	92216	291648	84446	51101	77862	213409	78239
T. Aman-Fallow-Boro	124410		149610	274020	86606		116042	202648	71372

Table 11.72. Benefit and cost analysis of different cropping patterns at Mithapukur, Rangpur during 2019-20

Cropping patterns	Gross return (Tk. ha^{-1})				Total variable cost (Tk. ha^{-1})				Gross margin (Tk. ha^{-1})
	T. Aman	Rabi	Boro/ Aus	Total benefit	T. Aman	Rabi	Boro/A us	Total cost	
	Mithapukur, Rangpur								
T. Aman-Mustard-Boro	134380	63000	150824	348204	70870	46252	94369	211491	136713
T. Aman-Potato- Boro	126618	369600	145780	641998	70870	142763	94369	308002	333995
T. Aman-Fallow-Boro	132856		182437	315293	70870		94369	165239	150054
	Pirgonj, Rangpur								
T. Aman-Mustard-Boro	132618	52080	183208	367906	72735	37300	97428	207463	160443
T. Aman-Potato- Boro	124856	215600	174704	515160	72735	146493	97428	316656	198504
T. Aman-Fallow-Boro	128856		186437	315293	72735		97428	170163	145130

Table 11.73. Benefit and cost analysis of different cropping patterns at Santhia, Pabna during 2019-20

Cropping patterns	Gross return (Tk. ha^{-1})				Total variable cost (Tk. ha^{-1})				Gross margin (Tk. ha^{-1})
	T. Aman	Rabi	Boro/ Aus	Total benefit	T. Aman	Rabi	Boro/ Aus	Total cost	
	Santhia, Pabna								
T. Aman-Mustard-Boro	140721	75200	144376	360297	92362	44014	105407	241783	118514
T. Aman-Potato- Boro	148027	240000	128027	516053	92362	142763	69378	304503	211550
T. Aman-Wheat-Aus	142110	88800	122632	353542	92362	51847	69378	213587	139955
T. Aman-Fallow-Boro	139249		159421	298669	92362		102405	194767	103903
	Ishwardi, Pabna								
T. Aman-Mustard-Boro	134721	75200	157076	366997	89086	32078	119282	240446	126551
T. Aman-Wheat-Aus	140638	96000	132204	368842	89086	52966	73854	215906	152936
T. Aman-Lentil-Aus	137243	155800	121416	414459	89086	51101	73854	214041	200418
T. Aman-Fallow-Boro	142027		161421	303447	89086		119282	208368	95079

Fig. 11.105. Photographic view of field experimental plot

Results of the experiment showed that in terms of irrigation water productivity Aus based CP such asT. Aman- Lentil – T. Aus performed best. But in terms of rice equivalent yield Boro based CP such as T. Aman-Mustard-Boro and T. Aman-Potato-Boro performed well. As REY of these two CPs (Boro based) were good, they were also good in terms of economic benefit (EB). Besides that their irrigation water productivity was also remarkable. Considering a balanced coordination of IWP, REY and EB and farmers' acceptance, this project suggested that T. Aman-Potato-Boro and T. Aman-Mustard-Boro patterns may be the irrigation water saving as well as economically profitable benefited cropping patterns in the project area. The photographic view of field experimental plot are given in Fig. 11.105.

11.4.2.2. Adoption and demonstration of water saving technologies for reducing water use

Some major aims of this project were adoption of technologies for judicial use of ground water to save the groundwater and to face drought in water scarcity areas. This project introduced some technologies and their success are given below.

11.4.2.2.1. Application of supplemental irrigation to mitigate terminal drought in T. Aman rice

Rainfall amount and its distribution are the major determinant of agricultural drought. Therefore, monthly rainfall pattern during T. Aman season of the study period from 2018 to 2020 in Rangpur and Pabna were analyzed and presented in Fig. 11.106. The analysis showed that each year except 2018 the observed rainfall was higher in Rangpur than that in Pabna. July was the wet month than the other months. But heavy rainfall was also observed in September 2020 in Rangpur. The monthly rainfall showed the decreasing trend from July to onward. Almost no rainfall occurred during November in both the locations. Though September and October showed the considerable amount of rainfall, its uneven distribution caused terminal drought and especially supplemental irrigation had to apply at Pabna. But more rainfall events reduced the supplemental irrigation demand in Rangpur.

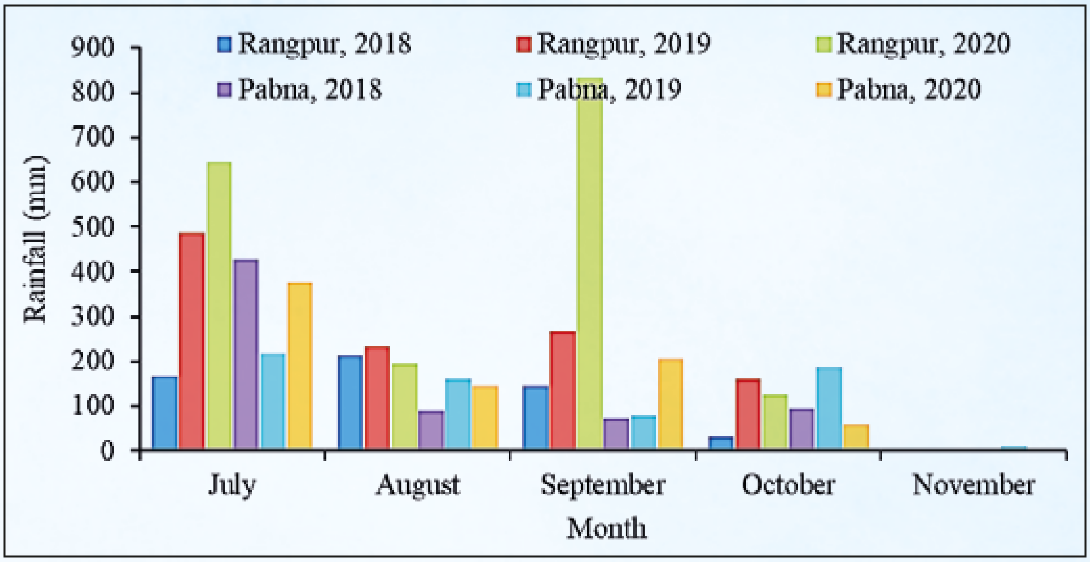


Fig. 11.106. Monthly rainfall distribution in T.Aman season during 2018 to 2020 in Rangpur and Pabna

The role of supplemental irrigation on T. Aman rice cultivation were assessed both in Pabna and Rangpur from 2018 to 2020. The major findings from the experiments were analyzed and presented below.

T. Aman, 2018

Rainfall was sufficient during vegetative phase of T.Aman rice both in Mithapukur and Pirgonj, Rangpur, but at the later part crop faced terminal drought. Supplemental irrigation was applied to mitigate drought effect. About 156 mm and 232 mm irrigation was applied in Mithapukur and Pirgonj respectively. Yield advantage of supplemental irrigation was observed (Table 11.74). Table 11.74 showed that BRRI dhan52 produced 5.3 t/ha yield for supplemental irrigation at Mithapukur site resulting 10.6% yield increased over rainfed condition (4.79 t/ha). At Pirgonj, 4.39 t/ha and 4.1 t/ha yield were observed in supplemental irrigated and rainfed condition respectively.

T. Aman crop experienced about 439 mm rainfall in Ishwardi, whereas 249 mm rainfall was found in Santhia. This was the results of late transplanting of T. Aman crop in Santhia (end of August) than Ishwardi (End of July to mid-August). Because of this, the applied supplemental irrigation was 140 mm and 248 mm at Ishwardi and Santhia, respectively. Thus, T. Aman crop showed about 35% and 32% yield advantages in supplemental irrigation treatment over rainfed condition (Table 11.75).

Table 11.74. Irrigation amount and yield of different treatments in Rangpur during T.Aman 2018

Treatment	Mithapukur, Rangpur				Pirgonj, Rangpur			
	Rainfall (mm)	Irrigation applied (mm)	Yield (t/ha)	Yield increase over rainfed (%)	Rainfall (mm)	Irrigation applied (mm)	Yield (t/ha)	Yield increase over rainfed (%)
Supplemental irrigation	486	156	5.3	10.6	445	232	4.39	7.1
Rainfed condition		0	4.79			0	4.10	
LSD(0.05)			0.33				0.88	
CV (%)			2.5				6	

Table 11.75. Irrigation amount and yield of different treatments in Pabna during T.Aman 2018

Treatment		Ishwardi, Pabna				Santhia, Pabna		
	Rainfall (mm)	Irrigation applied (mm)	Yield (t/ha)	Yield increase over rainfed (%)	Rainfall (mm)	Irrigation applied (mm)	Yield (t/ha)	Yield increase over rainfed (%)
Supplemental Irrigation	439	140	5.6 [a]	35	249	248	4.7 [a]	32
Rainfed condition		0	4.1 [b]			0	3.5 [b]	
LSD(0.05)			6.4				5.9	
CV (%)			0.34				0.28	

T. Aman, 2019

Rainfall was sufficient and its distribution was even during the growing period of T.Aman rice both in Mithapukur and Pirgonj, Rangpur. Hence, no supplemental irrigation was required as there was no water stress. Similar yield was observed in both supplemental irrigation and rainfed condition treatments. At Mithapukur BRRI dhan52 produced 5.75 t/ha in supplemental irrigation treatment where rainfed condition gave yield of 5.69 t/ha. At Pirgonj, Rangpur BRRI dhan52 gave 5.64 t/ha yield in supplemental irrigation treatment with only 2.4% yield advantages over rainfed condition (5.51 t/ha) (Table 11.76).

The opposite scenario was observed in Pabna where terminal drought occurred due to less rainfall in the later period of the crop. About 414 mm and 440 mm rainfall was recorded and the applied amount of supplemental irrigation was 350 mm and 250 mm at Ishwardi and Santhia, respectively. Thus, 18% yield advantages were observed in Santhia and that was 22% in Ishwardi over rainfed condition (Table 11.77).

Table 11.76. Irrigation amount and yield of different treatments in Rangpur during T.Aman 2019

Treatment	Mithapukur, Rangpur				Pirgonj, Rangpur			
	Rainfall (mm)	Irrigation applied (mm)	Yield (t/ha)	Yield increase over rainfed (%)	Rainfall (mm)	Irrigation applied (mm)	Yield (t/ha)	Yield increase over rainfed (%)
Supplemental Irrigation	690	0	5.75	1.8	640	0	5.64	2.4
Rainfed condition		0	5.69			0	5.51	
LSD(0.05)			ns				0.88	
CV (%)			2.5				6	

Table 11.77. Irrigation amount and yield of different treatments in Pabna during T.Aman 2019

Treatment	Ishwardi, Pabna				Santhia, Pabna			
	Rainfall (mm)	Irrigation applied (mm)	Yield (t/ha)	Yield increase over rainfed (%)	Rainfall (mm)	Irrigation applied (mm)	Yield (t/ha)	Yield increase over rainfed (%)
Supplemental Irrigation	414	350	5.1^{a}	22	440	250	5.35	18
Rainfed condition		0	4.17^{b}			0	4.57	
LSD(0.05)			0.84					0.56
CV (%)			6.4					4.0

T. Aman, 2020

T. Aman crop experienced huge amount of rainfall both in Mithapukur and Pirgonj, during T. Aman, 2020. About 1182 mm and 1088 mm rainfall occurred during the growing period at Mithapukur and Pirgonj, respectively (Table 11.78). As a result, no supplemental irrigation was required in Rangpur. Similar yield performance was observed for both the treatments as no water stress was found in rainfed treatment.

Similar trend was observed in Pabna where, the rainfall was the highest among the last three seasons. A total of 673 mm and 596 mm rainfall was found in Ishwardi and Santhia, respectively. One supplemental irrigation at Ishwardi and two irrigations in Santhia were applied in later part of the growing period. The supplemental irrigation resulted 11% and 10% yield increase over rainfed treatment at Ishwardi and Santhia, respectively (Table 11.79).

Table 11.78. Amount of irrigation and yield of different treatments in Rangpur during T. Aman, 2020

Treatment	Mithapukur, Rangpur				Pirgonj, Rangpur			
	Rainfall (mm)	Irrigation applied (mm)	Yield (t/ha)	% Yield increase over rainfed (%)	Rainfall (mm)	Irrigation applied (mm)	Yield (t/ha)	Yield increase over rainfed (%)
Supplemental Irrigation	1182	0	5.4	0	1088	0	5.2	2
Rainfed condition		0	5.7			0	5.1	
LSD (0.05)								
CV (%)								

Table 11.79. Irrigation amount and yield of different treatments in Pabna during T.Aman 2020

Treatment	Ishwardi, Pabna				Santhia, Pabna			
	Rainfall (mm)	Irrigation applied (mm)	Yield (t/ha)	% Yield increase over rainfed (%)	Rainfall (mm)	Irrigation applied (mm)	Yield (t/ha)	%Yield increase over rainfed (%)
Supplemental Irrigation	673	45	5.3	11	596	98	5.6	10
Rainfed condition		0	4.8			0	5.1	
LSD(0.05)								
CV (%)								

It is obvious that benefit of supplemental irrigation depends on severity of drought. Supplemental irrigation brought more benefit for more severity of drought. It was clear that if rainfall meet the consumptive use of crop, no supplemental irrigation is required. In that case supplemental irrigation treatment and rainfed condition treatment give the same result. Since amount and distribution of rainfall were different in different years and locations during the project period, so, benefit of supplemental irrigation was different in different years in both locations (Rangpur and Pabna) for example, in 2018 rainfall was comparatively lower than that in 2009 and 2020 in both locations. Inherently the highest benefit of supplemental irrigation was found in both locations in 2018. In 2018 supplemental irrigation treatment gave 10.6% higher yield than rainfed condition at Mithapukur of Rangpur which was highest in Rangpur during the project period. In the same year, at Ishwardi of Pabna supplemental irrigation treatment plot was benefited by 35% higher yield over rainfed condition plot. It was apparent that there was scope of supplemental irrigation technology in both Rangpur and Pabna districts. But this technology was more suitable and adoptable in Pabna than Rangpur.

11.4.2.2.2. Rainwater harvesting through levee management around the rice field

An improved levee management (ILM) can contain more rainwater and hold it longer. Hence, this management can mitigate light or medium drought that occurs during T. Aman season. In ILM levee height was kept 15 cm, its inner side is well clay coated and it is repaired immediately when crack is shown on its body. Farmers were either not familiar with ILM or they ignored ILM. The survey showed that farmers in the project area maintained levee height 7 to 10 cm and they never repaired their levee during crop growing period. Through experiment ILM technology was demonstrated in farmers' field both in Rangpur and Pabna and found effective for rainwater harvesting. Thus, more rainfall was stored in researcher management plot for ILM than farmers' levee management (FLM) plot.

T. Aman, 2018

During T. Aman, 2018, number of standing water days in ILM plot were 55 days whereas 44 days were observed in FLM plot at Mithapukur, Rangpur. That is ILM could hold 11 days more standing water in the plot. Similarly ILM showed 7 days more standing water in Pirgonj, Rangpur (Table 11.80). It was conceivable that excess standing water in ILM could mitigate short spell drought resulting 6% and 7% yield advantages at Mithapukur and Pirgonj, respectively over FLM.Similarly, during T. Aman 2018, 13% and 11% yield advantages was observed in ILM at Ishwardi and Santhia, respectively (Table 11.81).

Table 11.80. Number of standing water days and yield under improved levee and farmer's levee management in Rangpur, 2018

Treatment	Mithapukur, Rangpur			Pirgonj, Rangpur		
	Standing water days	Yield (t/ha)	Yield increase over FM (%)	Standing water days	Yield (t/ha)	Yield increase over FM (%)
Levee management	55	5.2	6	64	4.8	7
Farmers management	44	4.9		57	4.5	
LSD(0.05)		0.6			0.4	
CV (%)		8.4			5.5	

Table 11.81. Number of standing water days and yield under improved levee and farmer's levee management in Pabna, 2018

Treatment	Ishwardi, Pabna			Santhia, Pabna		
	Standing water days	Yield (t/ha)	Yield increase over FM (%)	Standing water days	Yield (t/ha)	Yield increase over FM (%)
Levee management	67	4.4 [a]	13	53	4.0 [a]	11
Farmers management	54	3.9[b]		41	3.6[b]	
LSD (0.05)		0.45			0.38	
CV (%)		6.9			7.8	

T. Aman, 2019

Sufficient rainfall occurred during T. Aman, 2019 in Rangpur. T. Aman crop suffered from no water stress in its critical stages. However, ILM stored 8 days more standing water (73 days) over FLM (65 days) and parallel yield was found in both the managements at Mithapukur, Rangpur (Table 11.82). No significant yield advantage was observed in Pirgonj also.

Again, ILM had 18 days more standing water than FLM at Ishwardi and on the other hand 13 days more stored water was found in ILM at Santhia. Since difference of standing water days between the two managements was substantial a significant yield difference was observed between the managements. ILM showed 17% and 14% yield advantages over FLM at Ishwardi and Santhia, respectively (Table 11.83).

Table 11.82. Number of standing water days and yield under improved levee and farmer's levee management in Rangpur, 2019

Treatment	Mithapukur, Rangpur			Pirgonj, Rangpur		
	Standing water days	Yield (t/ha)	Yield increase over FM (%)	Standing water days	Yield (t/ha)	Yield increase over FM (%)
Levee management	73	5.2	0	69	5.4	2
Farmers management	65	5.2		63	5.3	
LSD (0.05)		0.3			0.62	
CV (%)		4.3			7.8	

Table 11.83. Number of standing water days and yield under improved levee and farmer's levee management in Pabna, 2019

Treatment	Ishwardi, Pabna			Santhia, Pabna		
	Standing water days	Yield (t/ha)	Yield increase over FM (%)	Standing water days	Yield (t/ha)	Yield increase over FM (%)
Levee management	75	4.9 [a]	17	68	4.3 [a]	14
Farmers management	57	4.2 [b]		55	3.8 [b]	
LSD (0.05)		0.28			0.35	
CV (%)		4.6			5.7	

T. Aman, 2020

Adequate rainfall and its uniform distribution created no drought in both the sites of Rangpur. About 1182 mm and 1088 mm rainfall occurred during T. Aman, 2020 at Mithapukur and Pirgonj, respectively. Thus, almost similar yield was observed in both the treatment at Rangpur (Table 11.84).

Among the three years' trial, T. Aman, 2020 experienced more rainfall than the other two years. But the uneven distribution of rainfall in 2020 in Pabna caused drought at the later part of the crop growing period. However, more stored rainfall in ILM triggered 11% and 9% yield advantage over FLM at Ishwardi and Santhia, respectively (Table 11.85).

Table 11.84. Number of standing water days and yield under improved levee and farmer's levee management in Pabna, 2020

Treatment	Mithapukur, Rangpur			Pirgonj, Rangpur		
	Standing water days	Yield (t/ha)	Yield increase over FM (%)	Standing water days	Yield (t/ha)	Yield increase over FM (%)
Levee management	78	5.5	4	80	5.0	0
Farmers management	69	5.3		71	5.1	
LSD (0.05)		0.56			0.59	
CV (%)		6.9			7.8	

Table 11.85. Number of standing water days and yield under improved levee and farmer's levee management in Pabna, 2020

Treatment	Ishwardi, Pabna			Santhia, Pabna		
	Standing water days	Yield (t/ha)	Yield increase over FM (%)	Standing water days	Yield (t/ha)	Yield increase over FM (%)
Levee management	78	5.1 [a]	11	74	5.0 [a]	9
Farmers management	63	4.6[b]		59	4.6 [b]	
LSD (0.05)		0.5			0.57	
CV (%)		7.1			8.0	

It was clear that rain water harvesting capacity of improved levee management was more than that of farmer's levee management. But benefit of ILM was visible at scare or uneven distribution rainfall. For example, the maximum yield advantage (17% higher) was obtained in ILM at Pabna in 2019 (Table 11.83) as rainfall was lower in 2019 than 2020. However, the highest standing water in ILM was 78 days and found at Mithapukur and Ishwardi in 2020. Nevertheless, in the same year in FLM the highest standing water were 69 and 63 at Mithapukur and Ishwardi respectively. But the standing water in ILM remained 18 days more than that in FLM at Ishwardi in 2019 and it was the maximum achievement for ILM during the project period. 17% more yield was obtained in ILM compared to FLM at Ishwardi during the project period. It may be concluded that improved levee management technology was beneficial for the project area.

11.4.2.2.3. Alternate wetting and drying irrigation method for Boro rice cultivation

Undoubtedly Alternate Wetting and Drying (AWD) irrigation method was one of the best water saving technology. The benefit of this technology was highlighted to the farmers by demonstration of this technology through this project. So that farmers be enthusiastic with this technology. Positive results were found in all locations of the project area.

Water saved in AWD irrigation method

During Boro, 2018-19

In Boro season, 2018-19, about 762 mm water was applied in AWD irrigation method whereas 1125 mm water was applied in farmers practice at Mithapukur (Fig. 11.107). That is 32% water was saved in AWD method over farmer's practice and the rice variety was BRRI dhan58. In this wayirrigationwaterwas saved by 16% in Pirgonj for BRRI dhan29, 15% in Ishwardi for BRRI dhan28 and 25% in Santhia for BRRI dhan58 in AWD method over farmers' management practice.

Boro, 2019-20

Alternate wetting and drying irrigation method required also less irrigation water in each location during Boro, 2019-20. Among the study locations, the highest 22% water saving was found for BRRI dhan28 cultivation at Ishwardi, Pabna and the lowest 17% water was saved in Santhia for BRRI dhan58 (Fig. 11.108).

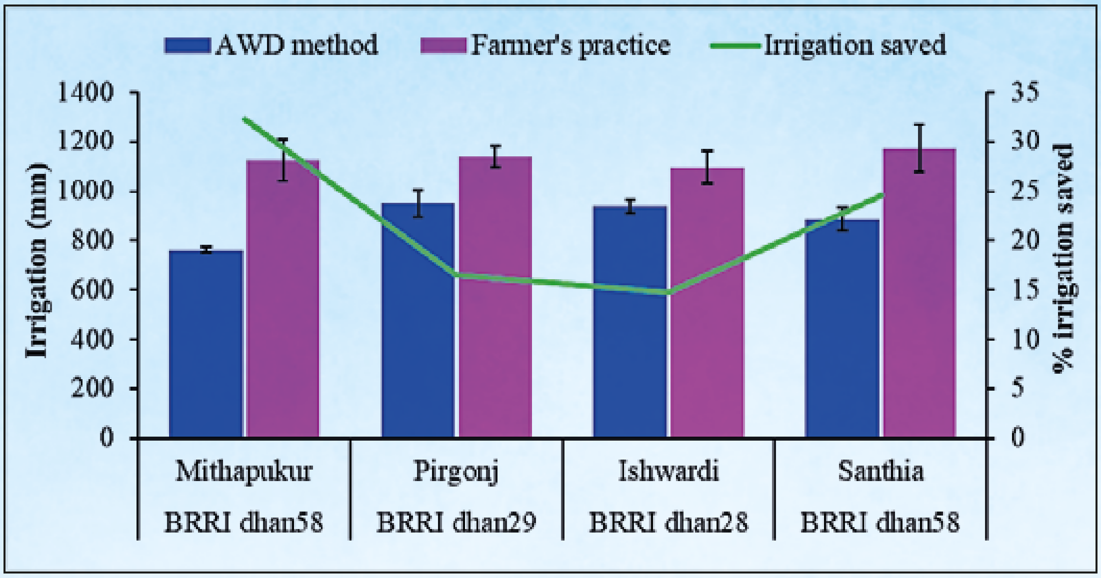


Fig. 11.107. Irrigation applied at AWD method and farmers practice in Rangpur and Pabna sites during Boro, 2018-19

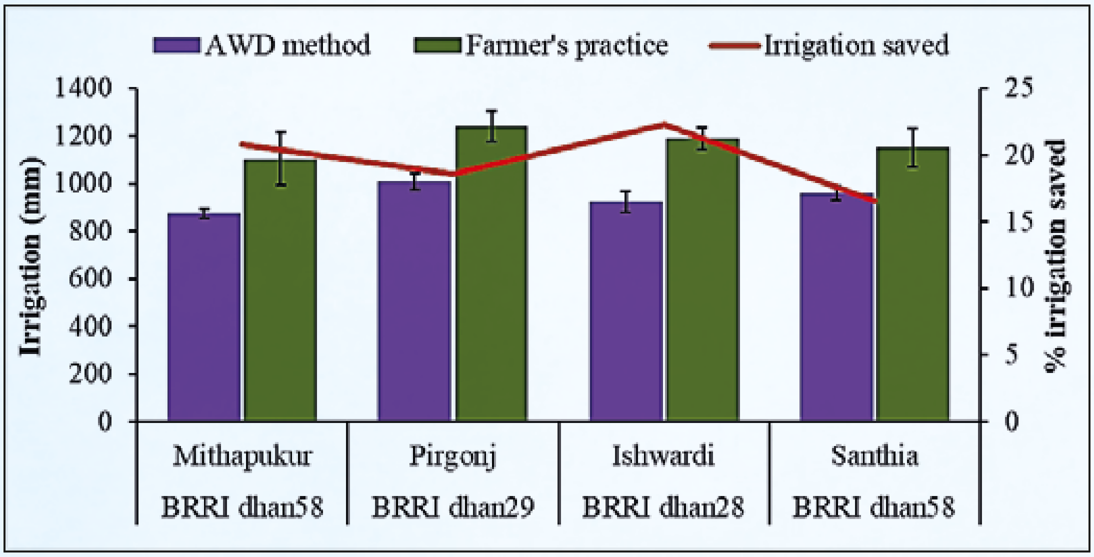


Fig. 11.108. Irrigation applied at AWD method and farmers practice in Rangpur and Pabna sites during Boro, 2019-20

Yield performance

AWD method cannot bring always yield advantage but it definitely reduces number of irrigation and saves irrigation water. More reduction in irrigation number is more reduction in irrigation cost.

2018-19

AWD irrigation method gave similar grain yield with the farmers' management practices during Boro, 2018-19 (Fig. 11.109). No significant yield difference was observed between the two methods. BRRI dhan29 gave the highest grain yield in both the treatments due to since its higher growth duration at Mithapukur. Similarly, BRRI dhan28 gave lowest yield at Ishwardi Pabna.

2019-20

In 2019-20, no significant yield difference was observed between AWD practice and farmers management practice (Fig. 11.110). Due to varietal variation BRRI dhan29 produced the highest grain yield and BRRI dhan28 gave the lowest among all the varieties.

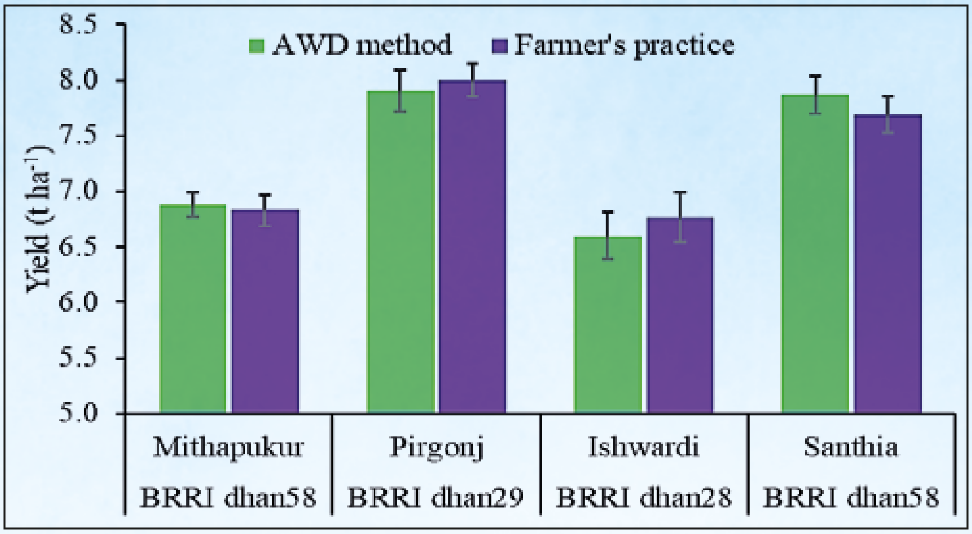


Fig. 11.109. Yield performance in AWD method and farmer's practice in Pabna and Rangpur during Boro, 2018-19

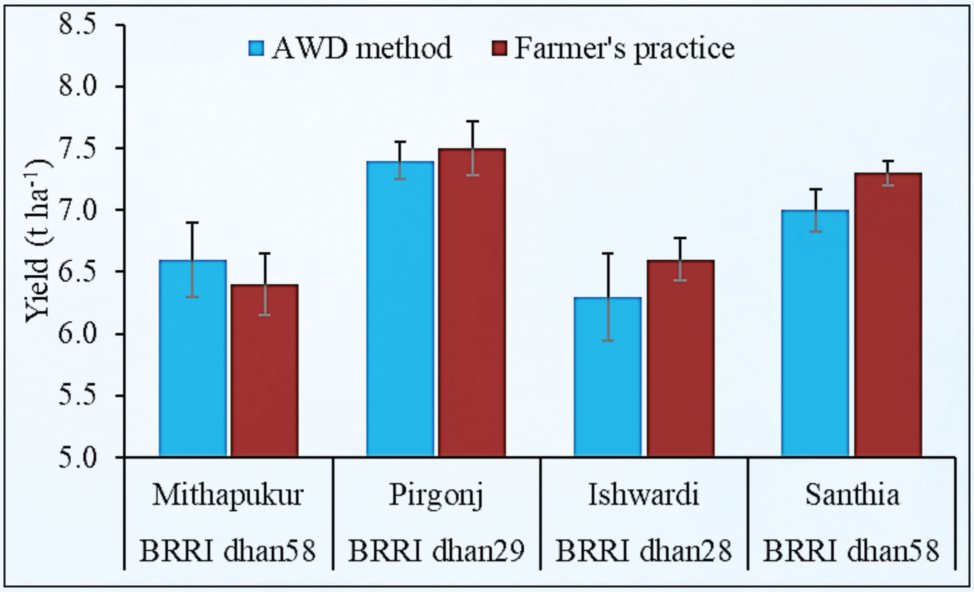


Fig. 11.110. Yield performance in AWD method and farmer's practice in Pabna and Rangpur during Boro, 2019-20

Irrigation water productivity

Boro, 2018-19

Irrigation water productivity of Boro rice both in AWD and farmers management practices during Boro, 2018-19 has been analyzed and shown in Fig.11.111. AWD method showed higher irrigation water productivity in all the locations. This was due to the similar grain yield in both the practices but, comparatively less irrigation application in AWD method than the farmers practice. Among the tested cultivar BRRI dhan58 gave the highest irrigation water productivity at Mithapukur and BRRI dhan28 gave the lowest water productivity at Ishwardi Pabna.

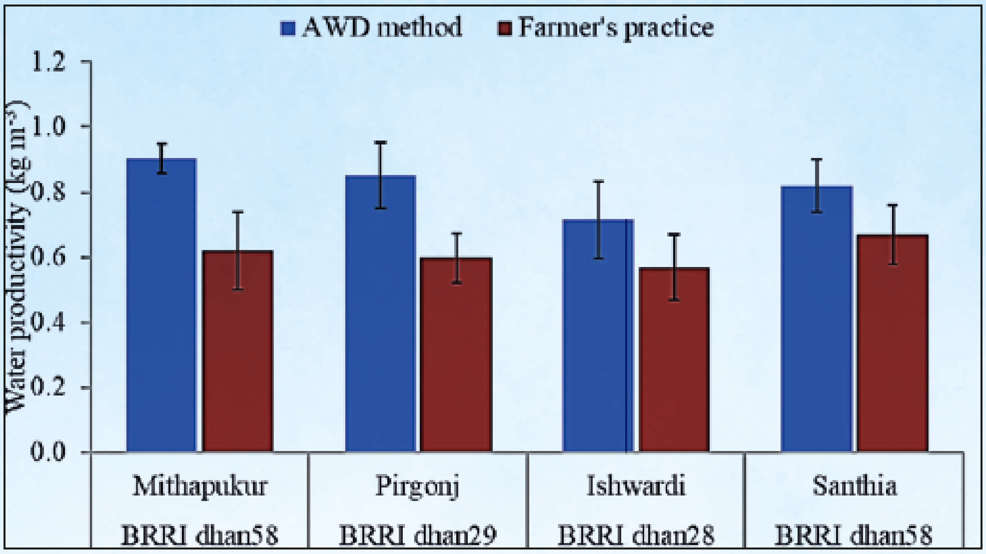


Fig. 11.111. Water productivity of different varieties under AWD and farmers practice at different locations of Rangpur and Pabna districts during Boro 2018-19

Boro, 2019-20

Similar to the previous year's results AWD method gave the highest irrigation water productivity than the existing farmers' management in all locations. The highest irrigation water productivity was found in Mithapukur for BRRI dhan58 and BRRI dhan28 gave the lowest irrigation water productivity and that was found in Ishwardi (Fig. 11.112).

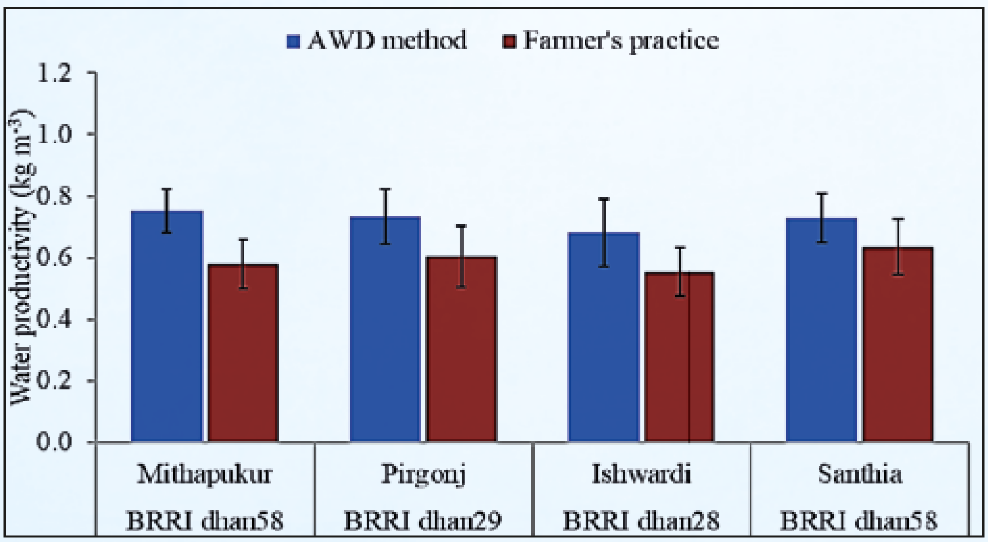


Fig. 11.112. Water productivity of different varieties under AWD and farmers practice at different locations of Rangpur and Pabna districts during Boro 2019-20

AWD technology successively saved irrigation water than conventional irrigation method. During Boro 2018-19, AWD method saved 15% to 32% irrigation water over farmers practice in the study locations. Similarly, 17% to 22% irrigation saved in AWD method during Boro, 2019-20. No significant yield difference was observed between the two practices in all the locations. Less irrigation application in AWD method led to higher irrigation water productivity. BRRI dhan58 gave the highest irrigation water productivity (0.90 kg m^{-3}) at Mithapukur and BRRI dhan28 (0.71 kg m^{-3}) gave the lowest water productivity at Ishwardi Pabna under AWD method during Boro, 2018-19. The highest 0.67 kg m^{-3} and the lowest 0.57 kg m^{-3} irrigation water productivity was found for the same variety under farmers management practices. Similar results were observed in the following years. To sum up, AWD method have potentiality to save irrigation water in all locations without sacrificing grain yield.

Farmers' awareness building to irrigation water saving technologies

A good awareness among the farmers was developed regarding groundwater issues, water saving technologies, water management, modern varieties of crop, pest management, balance fertilizer, use cropping patterns etc. from demonstrations, field day, training and direct contact with the farmers through this project.

Water saving technologies, improved crops and cultivars have been demonstrated among the farmers of the project locations from 2018 to 2020. In addition to the field demonstration activities, some promotional activities have been performed among the directly engaged farmers and associated farmers in the project area. Field day and farmers training activities have been conducted in different cropping seasons. During the project period, 7 farmers training (day long) were conducted where 210 farmers were trained about improved water management and crop production practices. About 50 female and 160 male farmers participated in the training programs. After completion of each training farmers opined that the training was very useful and mentioned that it was the first time they heard about the present and future status of groundwater. They gathered good knowledge on modern crop and variety selection, improved water and agronomic management, pest management, etc. They assured to implement the acquired knowledge in their field.

Eight farmers field day were arranged in the project areas in different seasons and about 560 farmers participated. Among the participated farmers 150 were female and 410 were male. The respective resource persons, scientists from Bangladesh Rice Research Institute, Upazila Agriculture Officer of Department of Agriculture Extension, Local representative were present in the programs. The resource persons described the benefits and operations of the demonstrated technology to the farmers (Fig. 11.113).

Fig. 11.113. Photographic view of promotional activities of the project

11.4.3. Component-3: BINA

11.4.3.1. Cropping pattern study for identifying water-saving cropping pattern

Nachole upazila

Year round crop production at Charmanpara and Jonakipara location of Nachole Upazila are presented in Table 11.86. Existing Aman and Boro rice were actually high yielding but long duration as well as more water consuming than that of new intervention. Yield of existing T. Aman and Boro rice were found respectively, 5.67 t/ha to 5.97 t/ha and 6.12 t/ha to 6.35 t/ha. Yield of proposed new T. Aman rice was observed 4.63 t/ha to 5.27 t/ha under water optimizing condition. Yield of T. Aus rice was comparatively lower than that of T. Aman and it was found 4.19 t/ha to 4.93 t/ha under water optimization. In case of rabi crop, the yield of Mustard, lentil and wheat were observed respectively, 1.64 to 1.88 t/ha, 1.31 to 1.45 t/ha and 3.33 to 3.79 t/ha.

Table 11.86. Year-wise yield (t/ha) of year round crop at Charmanpara and Jonakipara, Nachole

Year	Location	Year wise yield (t/ha) of year round crop at Nachole							
		T. Aus (New)	T.Aman (New)	T. Aman (Existing)	Mustard	Lentil	Wheat	Boro (New)	Boro (Existing)
2018-19	Char.	4.19	4.63	5.76	1.68	1.43	3.69	5.67	6.17
	Jonaki.	4.46	5.02	5.97	1.88	1.36	3.79	5.97	6.35
2019-20	Char.	4.65	4.51	5.67	1.71	1.31	3.47	5.54	6.21
	Jonaki.	4.93	5.18	5.89	1.85	1.42	3.62	5.87	6.27
2020-21	Char.	3.74	5.15	5.87	1.64	1.38	3.33	5.54	6.12
	Jonaki.	3.93	5.27	5.97	1.82	1.45	3.72	5.87	6.26

From 2018 to 2021, year-wise irrigation requirement of different crops of new and existing practices are presented in Table 11.87. Based on existing climatic condition, only residual soil profile moisture was enough for lentil cultivation. So, no irrigation was needed for lentil crop. In case of Mustard and wheat, sometimes pre-sowing irrigation was needed. Available moisture condition during sowing time with 5 to 8 cm and 10 to 15 cm irrigation water, respectively for Mustard and Wheat was enough to produce optimum yield.

Irrigation requirement of existing T. Aman and Boro rice were found respectively, 24 to 30 cm and 82 to 86 cm. Irrigation requirement of new proposed T. Aman rice was observed 12 to 18 cm under water optimizing condition. Irrigation requirement of T. Aus rice was comparatively higher than that of T. Aman, and it was found 30 to 36 cm under water optimization. Pictorial view of Aman, Aus and Rabi crops in experimented fields are given in Fig. 11.114.

Table 11.87. Year wise irrigation requirement (cm) of year round crop at Nachole area

Year	Location	Year wise irrigation requirement (cm) of year round crop at Nachole							
		T. Aus (New)	T.Aman (New)	T. Aman (Existing)	Mustard	Lentil	Wheat	Boro (New)	Boro (Existing)
2018-19	Char.	34	18	30	8	0	12	66	86
	Jonaki.	30	14	30	8	0	10	64	84
2019-20	Char.	36	18	30	5	0	15	68	84
	Jonaki.	32	12	30	5	0	10	60	82
2020-21	Char.	30	12	24	8	0	10	66	84
	Jonaki.	30	12	24	5	0	10	64	82

Aman Rice

Rabi Crop

Aus Rice

Fig. 11.114. Pictorial view of Aman, Aus and Rabi crop in experimental field at Nachole

Economic Analysis

For each pattern, the crops other than rice the yields were transformed to equivalent rice yield. Year-wise (2018 to 2021) rice-equivalent yield, water productivity, net income, BCR, and irrigation water saving in different cropping patterns at Nachole are presented in table 11.88.

Rice-equivalent yield of all introduced cropping patterns was higher than that of existing pattern (T. Aman-Fallow-Boro). In case of Aus based cropping pattern, maximum rice-equivalent yield (12.87 to 15.52 t/ha) was found in Pattern -1 (T. Aman-Mustard-T. Aus) and total seasonal irrigation amount, water productivity, BCR and Net income were respectively, 41 to 57 cm, 226 to 358 kg/ha/cm, 1.42 to 1.61 and 85340 to 121725 Tk/ha. On the other hand, rice-equivalent yield (12.04 to 12.18 t/ha) was found in existing Pattern -5 (T. Aman-Fallow-Boro) and total seasonal irrigation amount, water productivity, BCR and net income were respectively, 112 to 115 cm, 106 to 107 kg/ha/cm, 1.40 to 1.61 and 68269 to 109113 Tk/ha. But in boro based cropping Pattern-4 (T. Aman-Mustard-Boro), rice-equivalent yield (14.76 to 16.56 t/ha) was maximum among five cropping patterns and total seasonal irrigation amount, water productivity, BCR and Net income were respectively, 84 to 88 cm, 172 to 193 kg/ha/cm, 1.50 to 1.69 and 105726 to 146089 Tk/ha. Having Boro rice and additional rabi crop (Mustard) in Pattern-4 (T. Aman-Mustard-Boro), irrigation water requirement was less than that of existing Pattern-5 (T. Aman-Fallow-Boro). Because, high yielding and short duration Aman rice (i.e. Binadhan-17, Binadhan-22 and BRRI dhan71), Mustard (i.e. Binasarisha-9, Binasarisha-10 and BARI Sarisha-14) and Boro rice (i.e. Binadhan-14) were used in Pattern-4 (T. Aman-Mustard-Boro). All introduced new cropping patterns were water saving as well as profitable than that of existing pattern. Percent yield as well as net income increased was comparatively lower in year (2020-2021) because of high market price of rice during that time.

Table 11.88. Rice-equivalent yield, water productivity, net income, BCR, and irrigation water saving in different cropping patterns at Nachole (Year wise from 2018 to 2021)

Year	Cropping Pattern	Rice-equivalent yield (t/ha)	Irri. Amount, cm (seasonal total)	Water Productivity, kg/ha/cm	Net Income (Tk/ha)	BCR	% Irrigation Saving	% Yield Increase	% Net income Increase
2018-19	Pattern-1	14.66	41	358	85340	1.42	64	21	25
	Pattern-2	13.73	37	371	77668	1.40	68	13	14
	Pattern-3	13.60	47	289	80006	1.42	59	12	17
	Pattern-4	16.27	84	189	105726	1.50	25	34	55
	Pattern-5	12.13	112	106	68269	1.40	-	-	-
2019-20	Pattern-1	15.52	56	277	110315	1.54	51	29	49
	Pattern-2	14.45	51	283	97916	1.50	55	20	33
	Pattern-3	13.96	61	229	91309	1.47	46	16	24
	Pattern-4	16.56	86	193	122225	1.58	25	38	66
	Pattern-5	12.04	116	106	73790	1.43	-	-	-
2020-21	Pattern-1	12.87	57	226	121725	1.61	50	6	12
	Pattern-2	12.28	52	236	112317	1.59	54	1	3
	Pattern-3	12.30	62	198	115622	1.60	46	1	6
	Pattern-4	14.76	88	172	146089	1.69	25	21	34
	Pattern-5	12.18	115	107	109113	1.61	-	-	-

Note: Price of different crops in (Tk/kg) of

(2018-19): T. Aman rice (18/-), Mustard (50/-), Wheat (20/-), Lentil (54/-), Boro rice (18/-), T. Aus (18/-)

(2019-20): T. Aman (18.75/-), Mustard (52.5/-), Wheat (20/-), Lentil (55/-), Boro rice (18/-), T. Aus (18.5/-)

(2020-21): T. Aman (25/-), Mustard (52.5/-), Wheat (21.25/-), Lentil (54/-), Boro rice (19/-), T. Aus (19/-)

Three years average rice-equivalent yield, water productivity, net income, BCR, and irrigation water saving in different cropping patterns at Nachole are presented in Table 11.88. Cultivation of Rabi crops like mustard, lentil or wheat, and Aus rice instead of Boro, requires less amount of irrigation water, but produces higher annual yield (REY) and net profit. Instead of the traditional two cropped "Aman-Fallow-Boro" pattern, the three-cropped "Aman-Rabi (lentil /mustard /wheat)-Aus" pattern saved an average of about 55 percent irrigation water and increased the equivalent rice yield to about 10-19 percent (Table 11.89).

Table 11.89. Rice-equivalent yield, water productivity, net income, BCR, and irrigation water saving in different cropping patterns at Nachole (3 years average)

Cropping Pattern	Rice-equivalent yield (t/ha)	Irri. Amount, cm (seasonal total)	Water Productivity, kg/ha/cm	Net Income (Tk/ha)	BCR	% Irrigation Saving	% Yield Increase	% Net income Increase
Pattern-1 (T.Aman-Mustard-T.Aus)	14.35	51	281.10	106254	1.53	55	19	29
Pattern-2 (T.Aman-Lentil-T.Aus)	13.49	47	289.71	96383	1.50	59	11	17
Pattern-3 (T.Aman-Wheat-T.Aus	13.28	57	234.88	96062	1.50	50	10	16
Pattern-4 (T.Aman-Mustard-Boro)	15.87	86	185.57	124725	1.59	25	31	52
Pattern-5 (T.Aman-Fallow-Boro)	12.12	114	106.27	83724	1.48	-	-	-

Note: Price of different crops in (Tk/kg) of

(2018-19): T. Aman (18/-), Mustard (50/-), Wheat (20/-), Lentil (54/-), Boro rice (18/-), T. Aus (18/-)

(2019-20): T. Aman (18.75/-), Mustard (52.5/-), Wheat (20/-), Lentil (55/-), Boro rice (18/-), T. Aus (18.5/-)

(2020-21): T. Aman (25/-), Mustard (52.5/-), Wheat (21.25/-), Lentil (54/-), Boro rice (19/-), T. Aus (19/-)

Irrigation water requirement of "Aman-Rabi-Aus" cropping pattern was less than that of the traditional practice of "Aman-Fallow-Boro" cropping pattern. It was possible to get good yield in Rabi season without irrigation in case of Lentil (e.g. Binamasur-8), with one or two irrigations in Mustard (Binasarisha-9, Binasarisha-10 or BARI Sarisha-14) and, with two or three irrigations in Wheat (BARI Gom-33, BARI Gom-35 or BARI Gom-26) after harvesting of short-duration Aman rice variety (Binadhan-7, Binadhan-17, Binadhan-22 or BRRI dhan71) in that area. After harvesting wheat or lentil or mustard, cultivation of Aus rice (Binadhan-19 or Binadhan-21) with 3-4 irrigations were sufficient which was given from planting to vegetative stage, and the rest of the time was covered by natural rainfall. The yield of cultivated Aus rice was about 4.79 t/ha. Groundwater abstraction was relatively low as the demand for irrigation water was largely met by rainwater. As a result, cultivation of Rabi crop and Aus rice instead of Boro rice, required less withdrawal of groundwater, which was environment-friendly. On the other hand, this pattern increased the annual rice-equivalent yield (REY) as well as net profit or income.

Cropping pattern study for identifying water-saving pattern (Niamatpur upazila)

Year-round crops at Verendibazar and Sirajpur locations of Niamatpur upazila are presented in Table. 11.90. Existing Aman and Boro rice were actually high yielding but long duration as well as more water consuming than that of new intervention. Yield of existing T. Aman and Boro rice were found 5.67 t/ha to 6.10 t/ha and 6.17 t/ha to 6.34 t/ha, respectively. Yield of new proposed T. Aman rice was observed as 4.82 t/ha to 5.22 t/ha under water optimizing condition. Yield of T. Aus rice was comparatively lower than that of T. Aman and it was found to be 3.75 t/ha to 4.46 t/ha under water optimization. In case of Rabi crop, the yield of mustard, lentil and wheat were observed 1.64 to 1.76 t/ha, 1.43 to 1.75 t/ha and 3.89 to 4.38 t/ha, respectively.

Table 11.90. Year-wise yield (t/ha) of year-round crops at Verendibazar and Sirajpur, in Niamatpur upazila

Year	Location	Year wise yield (t/ha) of year round crop at Niamatpur							
		T. Aus (New)	T.Aman (New)	T. Aman (Existing)	Mustard	Lentil	Wheat	Boro (New)	Boro (Existing)
2018-19	Verendi.	4.13	4.63	5.76	1.69	1.48	3.89	5.67	6.17
	Siraj.	4.22	5.02	5.97	1.76	1.56	3.97	5.97	6.34
2019-20	Verendi.	4.46	4.82	5.67	1.64	1.59	3.96	6.12	6.21
	Siraj.	4.39	5.01	5.89	1.71	1.75	4.20	5.96	6.33
2020-21	Verendi.	3.92	5.21	5.87	1.65	1.43	4.22	6.02	6.21
	Siraj.	3.75	5.22	6.10	1.74	1.67	4.38	5.91	6.33

From 2018 to 2021, year-wise irrigation requirement of different crops of new and existing practices are presented in Table 11.91. Based on existing climatic condition, only residual soil profile moisture was enough for lentil cultivation. So, no irrigation was needed for lentil crop. In case of mustard and wheat, sometimes pre-sowing irrigation was needed. Pre-sowing irrigation, water of 4 to 5 cm and 10 to 15 cm, respectively for mustard and wheat was enough to produce optimum yield.

Irrigation requirement of existing T. Aman and Boro rice were found as 24 to 30 cm and 82 to 90 cm, respectively. Irrigation requirement of new proposed T. Aman rice was observed as 12 to 18 cm under water optimizing condition. Irrigation requirement of T. Aus rice was comparatively higher than that of T. Aman, and it was found to be 30 to 36 cm under water optimization. The pictorial view of Aman, Aus and Rabi crops in experimental field (Niamatpur) is given in Fig. 11.115.

Table 11.91. Year-wise irrigation requirement (cm) of year round crop at study area

Year	Location	Year wise irrigation requirement (cm) of year round crop at Niamatpur							
		T. Aus	T.Aman (New)	T. Aman (Existing)	Mustard	Lentil	Wheat	Boro (New)	Boro (Existing)
2018-19	Verendi.	32	18	30	4.5	0	10	72	90
	Siraj.	30	15	30	5	0	10	60	78
2019-20	Verendi.	30	12	24	4	0	10	60	78
	Siraj.	36	15	24	5	0	10	66	84
2020-21	Verendi.	30	12	24	4	0	10	65	80
	Siraj.	30	14	24	5	0	10	66	82

Aman Rice

Rabi Crop

Aus Rice

Fig. 11.115. Pictorial view of Aman, Aus and Rabi crop in the experimental field at Niamatpur

Economic Analysis

For each pattern, the crops other than rice the yields were transformed into equivalent rice yield. Year-wise rice-equivalent yield, water productivity, net income, BCR, and irrigation water saving in different cropping patterns at Niamatpur are presented in Table 11.92.

Rice-equivalent yield of all introduced cropping patterns was higher than that of existing pattern (T. Aman-Fallow-Boro). In case of Aus based cropping pattern, maximum rice-equivalent yield (13.55 to 14.41 t/ha) was found in Pattern -1 (T. Aman-Mustard-T. Aus). Total seasonal irrigation amount, water productivity, BCR and Net income were 41 to 50 cm, 288 to 347 kg/ha/cm, 1.41 to 1.71 and 81388 to 139197 Tk/ha,respectively.

But in Boro based cropping Pattern-4 (T. Aman-Mustard-Boro), rice-equivalent yield (15.57 to 16.03 t/ha) was maximum among the five cropping patterns and total seasonal irrigation amount, water productivity, BCR and Net income were respectively, 80 to 86 cm, 185 to 200 kg/ha/cm, 1.49 to 1.77 and 102355 to 163293 Tk/ha.

Having Boro rice and additional rabi crop (Mustard) in Pattern-4 (T. Aman-Mustard-Boro), irrigation water requirement was less than that of existing Pattern-5 (T. Aman-Fallow-Boro). Because, high yielding and short duration Aman rice (i.e. Binadhan-17, Binadhan-22 and BRRI dhan71), Mustard (i.e. Binasarisha-9, Binasarisha-10 and BARI Sarisha-14) and Boro rice (i.e. Binadhan-14) were used in Pattern-4 (T. Aman-Mustard-Boro). All introduced new cropping patterns were water saving as well as profitable than that of existing pattern. Percent yield as well as 'net income increased' was comparatively lower in year 2020-2021 because of high market price of rice during that time.

Table 11.92. Rice-equivalent yield, water productivity, net income, BCR, and irrigation water saving in different cropping patterns at Niamatpur (Year wise from 2018 to 2021)

Year	Cropping Pattern	Rice-equivalent yield (t/ha)	Irri. Amount, cm (seasonal total)	Water Productivity, kg/ha/cm	Net Income (Tk/ha)	BCR	% Irrigation Saving	% Yield Increase	% Net income Increase
2018-19	Pattern-1	14.23	41	347	81388	1.41	64	17	27
	Pattern-2	14.02	37	379	79597	1.40	68	16	24
	Pattern-3	13.75	47	293	79520	1.40	59	13	24
	Pattern-4	15.94	86	185	102355	1.49	25	31	59
	Pattern-5	12.13	114	106	64272	1.37	-	-	-
2019-20	Pattern-1	14.41	50	288	91751	1.46	53	20	25

Year	Cropping Pattern	Rice-equivalent yield (t/ha)	Irri. Amount, cm (seasonal total)	Water Productivity, kg/ha/cm	Net Income (Tk/ha)	BCR	% Irrigation Saving	% Yield Increase	% Net income Increase
	Pattern-2	14.75	45	328	89954	1.44	57	22	23
	Pattern-3	14.10	55	256	84298	1.41	48	17	15
	Pattern-4	16.03	80	200	114393	1.55	24	33	56
	Pattern-5	12.05	105	115	73345	1.43	-	-	-
2020-21	Pattern-1	13.55	47	288	139197	1.71	56	11	30
	Pattern-2	13.57	42	323	136962	1.69	60	11	28
	Pattern-3	13.62	52	262	139640	1.70	50	11	31
	Pattern-4	15.57	80	195	163293	1.77	24	27	53
	Pattern-5	12.26	107	117	106804	1.59	-	-	-

Note: Price of different crops in (Tk/kg) of

(2018-19): T. Aman rice (18/-), Mustard (50/-), Wheat (20/-), Lentil (54/-), Boro rice (18/-), T. Aus (18/-)

(2019-20): T. Aman (18.75/-), Mustard (52.5/-), Wheat (20/-), Lentil (55/-), Boro rice (18/-), T. Aus (18.5/-)

(2020-21): T. Aman (25/-), Mustard (52.5/-), Wheat (21.25/-), Lentil (54/-), Boro rice (19/-), T. Aus (19/-)

Three years average rice-equivalent yield, water productivity, net income, BCR, and irrigation water saving in different cropping patterns at Niamatpur are presented in Table 11.93. Cultivation of Rabi crops like mustard, lentil or wheat, and Aus rice instead of Boro, requires less amount of irrigation water, but produces higher annual yield (REY) and net profit.

Instead of the traditional two cropped "Aman-Fallow-Boro" pattern, the three-cropped "Aman-Rabi (lentil /mustard /wheat)-Aus" pattern saves an average of about 57 percent irrigation water and increased the equivalent rice yield to about 14-16 percent (Table 11.83).

Table 11.93. Rice-equivalent yield, water productivity, net income, BCR, and irrigation water saving in different cropping patterns at Niamatpur

Cropping Pattern	Rice-equivalent yield (t/ha)	Irri. Amount, cm (seasonal total)	Water Productivity, kg/ha/cm	Net Income (Tk/ha)	BCR	% Irrigation Saving	% Yield Increase	% Net income Increase
Pattern-1 (T.Aman-Mustard-T.Aus)	14.06	46	307.54	104112	1.53	57	16	27
Pattern-2 (T.Aman-Lentil-T.Aus)	14.12	41	342.43	102171	1.51	62	16	25
Pattern-3 (T.Aman-Wheat-T.Aus	13.82	51	269.87	101153	1.51	52	14	23
Pattern-4 (T.Aman-Mustard-Boro)	15.84	82	194.40	126680	1.60	24	30	56
Pattern-5 (T.Aman-Fallow-Boro)	12.14	108	112.44	81474	1.46	-	-	-

Note: Price of different crops in (Tk/kg) of

(2018-19): T. Aman rice (18/-), Mustard (50/-), Wheat (20/-), Lentil (54/-), Boro rice (18/-), T. Aus (18/-)

(2019-20): T. Aman (18.75/-), Mustard (52.5/-), Wheat (20/-), Lentil (55/-), Boro rice (18/-), T. Aus (18.5/-)

(2020-21): T. Aman (25/-), Mustard (52.5/-), Wheat (21.25/-), Lentil (54/-), Boro rice (19/-), T. Aus (19/-)

Irrigation water requirement of “Aman-Rabi-Aus” cropping pattern was less than that of the traditional practice of “Aman-Fallow-Boro” cropping pattern. It was possible to get good yield in Rabi season without irrigation in case of Lentil (e.g. Binamasur-8), with one or two irrigations in Mustard (Binasarisha-9, Binasarisha-10 or BARI Sarisha-14) and, with two or three irrigations in wheat (BARI Gom-33, BARI Gom-35 or BARI Gom-26) after harvesting of short-duration Aman rice variety (Binadhan-7, Binadhan-17, Binadhan-22 or BRRI dhan71) at that area. After harvesting wheat or lentil or mustard, cultivation of Aus rice (Binadhan-19 or Binadhan-21) with 3-4 irrigations were sufficient which was given from planting to vegetative stage, and the rest of the time was covered by natural rainfall. The yield of cultivated Aus rice was about 4.49 t/ha. Groundwater abstraction was relatively low as the demand for irrigation water was largely met by rainwater. As a result, cultivation of Rabi crops and Aus rice instead of Boro rice, required less withdrawal of groundwater, which was environment-friendly. On the other hand, this pattern increased the annual rice-equivalent yield (REY) as well as net profit or income.

12. Research highlight (title of the sub-project, background, objectives, methodology, key findings, and key words):

Title of the sub-project: Groundwater resources management for sustainable crop production in northwest hydrological region of Bangladesh

Background

The sustainable use and management of groundwater is now a great challenge, especially in the northwest region of Bangladesh. Due to cultivation of water intensive crops, irrational irrigation management, indiscriminate installation of pumps and non-availability of modern technologies, the use of groundwater is much higher in this region compared to other parts of the country leading to declination of groundwater table at an alarming rate. Lowering of groundwater table during dry months has created many problems such as drying up of wells, ponds and tanks, non-functioning of shallow tube wells or low discharge (less than design discharge), causing threat to the sustainability of water use for irrigation, domestic use as well as for the livestock population in the region. In addition, global climate change effects and reduced water flow in major rivers due to upstream water diversion by India has made the situation worse. Because of this threat, it is important not to exploit groundwater annually exceeding the replenished amount from annual seasonal rainfall. Therefore, the key challenges are now to increase agricultural productivity without deteriorating the groundwater resources. This is possible through safe extraction of groundwater resources. The irrigation water should be utilized judicially by implementing appropriate irrigation methods, and practicing water saving technologies with low water consuming cropping patterns simultaneously. Thus, sustainable groundwater resources management will sustain agricultural production in this region.

Sub-project general objective(s)

- To assess groundwater availability and recharge pattern in different districts of northwest hydrological region of Bangladesh
- To optimize groundwater abstraction for irrigation
- To suggest plan for sustainable use of groundwater for crop production

Methodology

The study locations were in the north-west hydrological region of Bangladesh as follows: Component-1: BARI – Rajshahi (Godagari and Tanore upazila), Joypurhat (Joypurhat sadar and Kalai upazila); Component-2: BRRI – Rangpur (Mithapukur and Pirganj upazila), Pabna (Ishwardi and Santhia upazila) and Component-3: BINA –Chapainawabganj (Nachole upazila) and Naogaon (Niamatpur upazila) districts. Recharge to groundwater was assessed using tracer technique, water balance and water-table fluctuation method. Trend of water-table was determined using MAKSENSE and discrete space-state model. Trend of rainfall was determined through non-parametric method (*Rho*-test). Historical weekly groundwater level data of 29 years (1980 – 2018) from observation wells in the study areas were collected and used to predict the trend of change of groundwater level by using discrete Space-state modeling approach. Irrigation, domestic and municipal water requirement were assessed to predict long term yearly groundwater abstraction pattern. Groundwater abstraction, recharge pattern, withdrawal rate and deficit and positive recharge were calculated and analyzed. A relationship between groundwater recharge deficit and withdrawal rate of water was developed. Recharge to groundwater was assessed using tracer technique, water balance and water-table fluctuation method. Although artificial recharge is a sensitive matter, still its importance and demands of age is inevitable in the country, for artificial recharge to groundwater, if necessary. Three prototypes of artificial groundwater recharge method (AGRM) consisting of three different types filters were tested. Groundwater samples were collected before starting (November/December) and at the end (February/March) of dry season irrigation to examine its suitability for irrigation over the season.

A hydrologic model MODFLOW was used to optimize of groundwater abstraction. MODFLOW simulation model was calibrated using field data and used to develop scenario of water-table position under different cropping patterns. Simulating withdrawal rate, total deficit recharge after a long period and safe withdrawal rate per year for recovering deficit was determined using conceptual model known as Towfiqul Islam (TI) model.

Based on an extensive investigation on the existing cropping patterns in the study areas, four to five promising cropping patterns from each study area were selected and cropping pattern based field trials with rice and non-rice crops were conducted with adoption of water saving AWD technology. Levee management practices, Farmers Levee Management (FLM) and Improved Levee Management (ILM) in rice cultivation, were evaluated to capture rain water to reduce supplemental irrigation. Cropping pattern of low water requirement of economic yield was identified using low water demanding crops.

Key Findings

Groundwater level declination was found more in Tanore upazila than other three upazilas of Rajshahi and Joypurhat district. The rate of GW level declination was on average 27.43 cm/yr at Tanore, 14.02 cm/yr at Godagari, 11.28 cm/yr at Joypurhat sadar, 15.83 cm/yr at Kalai. It will be almost double by the year 2040 in Tanore. A declining trend of groundwater table persists in Rangpur and Pabna upazilas except at Pirganj. The maximum total depletion was 205 cm with the maximum 6.6 cm per year depletion. The number of years of negative recharge was more than that of positive recharge during 32 years. The maximum groundwater table remained below suction limit at Ishwardi causes inoperative (no or less discharge of shallow tubewell, STW) during dry season. A declining trend in annual rainfall was observed in Pabna district. A linear relationship between rainfall and recharge was found at two locations of the study area. Yearly recharge (Naogaon and Nawabganj districts) at Nachole area varied from 106.6 to 211.7 mm/year under different methods (7.68 – 15.3% of yearly rainfall) for the study period. When averaged over years, it was found as 195.8, 122.8, and 102.6 mm under tracer technique, water balance method, and water-table fluctuating method, respectively. At Niamatpur area, yearly recharge was found as 210 mm, 149.1 mm, and 137.6 mm under tracer technique, water balance method, and water-table fluctuating method, respectively. In terms of annual rainfall, it was about 15.14%, 10.7%, and 9.92 % of rainfall. Aquifer properties provided sustainable groundwater abstraction of the area and all the values were suitable for sustainable groundwater development. The properties determined as of hydraulic conductivity (K), Transmissibility (T) and Specific Yield (S_y) at Nachole were found as 17.34 to 55.35 m^3/m^2/day, 433.41 to 1383.69 m^2/m/day and 4.03 to 5.03%, respectively, under different methods. For Niamatpur area, the K, T and S_y were found as 37.12 to 54.71 m^3/m^2/day, 733.20 to 1299.47 m^3/m/day and 4.04 to 9.30%, respectively. The water quality indices, in north-west hydrological region of studied districts, such as SAR, SSP, RSC and KR indicated that quality of groundwater samples fall into excellent and good categories for irrigation use. As per water quality index (WQI), a combined water quality index to better assess suitability of groundwater for irrigation, all the samples were "good" except few were found "poor" in post-irrigation season. In respect of all evaluating criteria, groundwater of the study area was found suitable and can safely be used for irrigation purpose. Tested results showed that groundwater in the project area was suitable for drink and irrigation according to FAO recommendation.

As the increasing demand of water is triggering more in Rajshahi than in Joypurhat, so more groundwater need to be abstracted in future from Barind area of Rajshahi. Abstraction will be increasing by 33-35% in Joypurhat study areas while it will be increasing by 40-45% in Rajshahi in the next 20 years. The results revealed that the computed groundwater heads at the three observation wells varied noticeably as a result of the changes in the recharge scenarios. In the business-as-usual case, the MODFLOW computed heads at the three observation wells GT 8194046, GT8194048, and GT8194049 on 24 September 2018 (based on the available groundwater head data obtained from the BWDB) were 16.388m, 18.133m, and 22.215m, respectively. When the abstraction was reduced to 90%, the computed heads rose significantly, and the values were 7.970m, 11.150m, and 18.106m, respectively at the three observation wells. On the other hand, if the abstraction would be increased to 110%, the MODFLOW computed heads at the observation wells were found as 20.707m, 21.745m, and 24.413m, respectively which indicated a substantial increase (drop) in the quantity of head development. The model (TI model) quantified that maximum 66.67 percent deficit recharge occurred in aquifer of Rangpur and Pabna districts and maximum reduced utilization of groundwater per year should be 13.33 percent if it is targeted to recover deficit recharge within five years. The maximum coverage (69.44 % of Boro area) by the alternate wetting and drying (AWD) technology will be able to recover deficit recharge within five years in the study area through retarding declination of groundwater per year. It was obvious that groundwater declination can be retarded and groundwater deficit can be recovered by proper management after assessment of groundwater behaviour. In terms of groundwater availability and safe yield for Naogaon and Nawabganj districts, from the simplified hydrological balance equation, the safe yield of aquifer at Nachole and Niamatpur was found to be 291 and 326 mm, respectively. The model quantified that maximum 72.89 and 87.57 percent deficit recharge occurred in aquifer of Nachole and Niamatpur and maximum reduced utilization of groundwater per year should be 14.58 and 17.51 percent, respectively, if it is targeted to recover deficit recharge within five years.

In Rajshahi and Joypurhat, rice equivalent yield (REY) and water productivity (WP) were found higher in cropping patterns where high yielding rabi crops like tomato, potato and maize were included and water saving irrigation technologies (AWD, etc.) were adopted. Among the cropping patterns, the highest REY and WP were obtained from Tomato-Boro-T.Aus followed by Potato-Boro-T.Aman pattern while the lowest was from Mustard-Boro-T.Aman pattern. Use of water saving irrigation technologies increased REY by 8-24% and saved about 20-25% water over existing farmers' practice. In Pabna and Rangpur, in terms of irrigation water productivity (IWP), rice equivalent yield (REY) and economic for the project site, Aus based CP such as T. Aman- Lentil – T. Aus performed best. But in terms of rice equivalent yield, Boro based CP such as T. Aman-Mustard-Boro and T. Aman-Potato-Boro performed well. As REY of these two CPs (Boro based) were good, they were also good in terms of economic benefit (EB). Besides that their irrigation water productivity was also remarkable. Benefit of ILM was visible at scare or uneven distribution of rainfall. For example, the maximum yield advantage (26% higher) was obtained in ILM at Pabna in

2018 as rainfall was lower than in 2019 and 2020. In Naogaon and Nawabganj districts, the pattern "Aman-Rabi (lentil /mustard /wheat)-Aus" saved an average of about 55 and 57 percent irrigation water and increased the equivalent rice yield to about 10-19 and 14-16 percent (along with higher benefit-cost ratio), compared to existing two cropped pattern "Aman-Fallow-Boro" at Nachole and Niamatpur, respectively.

Key Words: Aquifer, cropping pattern, water-table, sustainability, economics, Barind area, groundwater.

B. Implementation Status

1. Procurement (component wise):

1.1. Coordination Component: BARC

Description of equipment and capital items	PP Target		Achievement		Remarks
	Physical (No.)	Financial (Tk.)	Physical (No.)	Financial (Tk.)	
(a) Office furniture (Computer Table, Computer Chair, Visitor Chair, File Cabinet, Almirah, Revolving Chair, Office Table)	11	139500.00	11	139500.00	
(b) Office equipment (Desktop Computer, Monitor, UPS, Printer, Laptop, Camera, Scanner)	07	198592.00	07	198592.00	

1.2. Component-1: BARI

Description of equipment and capital items	PP Target		Achievement		Remarks
	Physical (No.)	Financial (Tk.)	Physical (No.)	Financial (Tk.)	
Furniture (Guest chair, office table, computer table, file cabinet)	16	136,000.00	16	136,000.00	
Office equipment (Scanner, multimedia, computer, printer, camera)	4	230,000.00	4	230,000.00	
Lab equipment (EC meter, WQ kit, canopy meter, turbidity meter, refrizerator, avometer)	9	10,50,000.00	7	6,90,000.00	Water contact gauge not procured due to higher market price than reserve value
Field equipment (Rain gauge, soil auger, moisture meter)	7	279,000.00	7		
Transport (1motor cycle, 2-bicycle)	3	180,000.00	3		

1.3. Component-2: BRRI

Description of equipment and capital items	PP Target		Achievement		Remarks
	Physical (No.)	Financial (Tk.)	Physical (No.)	Financial (Tk.)	
1) Laboratory equipment					
a) Turbidity meter	01	144000	01	144000	
b) pH meter	01	76000	01	76000	
c) Freezer	01	38000	01	38000	
2) Computer equipment					
a) Desktop	01	70000	01	70000	
b) Laptop	01	70000	01	70000	
c) Camera	01	25000	01	25000	
3) Small transport					
a) Motor cycle	01	150000	01	150000	
b) Bi-cycle	01	15000	01	15000	
4) Furniture					
a) Official Table	02	50000	02	50000	
b) Chair	08	34000	08	34000	
c) File cabinet	02	40000	02	40000	

1.4. Component-3: BINA

Description of equipment and capital items	PP Target		Achievement		Remarks
	Physical (No.)	Financial (Tk.)	Physical (No.)	Financial (Tk.)	
(a) Office equipment	10	344000.00	10	328400	
(b) Lab &field equipment	8	360000.00	8	348650	
(c) Other capital items	1	155523	1	155523	

2. **Establishment/renovation facilities:** Not applicable for all components

3. **Training/study tour/ seminar/workshop/conference organized:**

3.1 Coordination Component: BARC

Item/Topics	No. of Participants			Duration (Days)	Venue & Date
	Male	Female	Total		
Inception Workshop	28	5	33	1 day	Training Building, BARC 30 July 2018
First Annual Workshop	35	3	38	1 day	Training Building, BARC 23 April 2019
Second Annual Review Workshop	34	6	40	1 day	Training Building Auditorium, BARC 11 October 2020
Project Completion Workshop	47	3	50	1 day	Training Building Auditorium, BARC 12 January 2022
Coordination Meeting (Total=08)	82	21	103	1 day/ meeting	BARC Conference Room 1 & 2 15/03/2018, 25/06/18, 22/11/2018, 23/04/2019, 01/08/2019, 26/12/2019, 21/06/2020

3.2. Component-1: BARI

Description	Number of participants			Duration (Days/weeks/ months)	Remarks
	Male	Female	Total		
(a) Training	151	49	200	01 day x 8= 8 days	Farmers' Training (8-batch@ 25 farmers/batch)
(b) Workshop				1+1+1= 3 days	Inception and Annual Workshop arranged by BARC
(c) Others (if any)	148	52	200	01 day	Field day at each site

3.3. Component-2: BRRI

Description	Number of participants			Duration (Days)	Remarks
	Male	Female	Total		
a) Farmer's training	160	50	210	1 day	7 training
b) Field day	150	410	560	1 day	8 Field day

3.4 Component-3: BINA

Description	Number of participants			Duration (Days/weeks/ months)	Remarks
	Male	Female	Total		
(a) Training	25	00	25	01 Day (29 December 2020)	Farmer's (01)
	21	04	25	01 Day (23 February 2021)	Officers (01)
(b) Workshop	-	-	-		
(c) Others: Field Day	512	88	600	Rabi, Aus and Aman rice	6 nos

C. Financial and Physical Progress (combined & component wise)

Combined

Item of expenditure/ activities	Total approved budget	Fund received	Actual expenditure	Balance/ unspent	Physical progress (%)	Reasons for deviation
Contractual staff salary	12047528	12103571	12103571	0.00	100.00	
Field Research/Lab expenses and supplies	11313796	9425978	9425978	0.00	100.00	
Operating expenses	2603503	2477042	2477042	0.00	100.00	
Vehicle Hire and Fuel, Oil and maintenance	2063042	1874512	1874512	0.00	100.00	
Training/Workshop/Seminar etc.	2263000	2243100	2243100	0.00	100.00	
Publications and printing	482500	346766	346766	0.00	100.00	
Miscellaneous	950724	739531	739531	0.00	100.00	
Capital Expenses	3055747	4521747	4521747	0.00	100.00	
Grand total	34779840	33732247	33732247	0.00	100.00	

Coordination Component: BARC

Item of expenditure/ activities	Total approved budget	Fund received	Actual expenditure	Balance/ unspent	Physical progress (%)	Reasons for deviation
Contractual staff salary	5966458	5966458	5966458	0.00	100.00	
Field Research/Lab expenses and supplies	0	0	0	0.00	100.00	
Operating expenses	397452	397452	397452	0.00	100.00	
Vehicle Hire and Fuel, Oil and maintenance	89990	89990	89990	0.00	100.00	
Training/Workshop/Seminar etc.	393300	393300	393300	0.00	100.00	
Publications and printing	200000	199500	199500	0.00	100.00	
Miscellaneous	389629	389629	389629	0.00	100.00	
Capital Expenses	338092	338092	338092	0.00	100.00	
Grand total	7774921	7774421	7774421	0.00	100.00	

Component-1: BARI

Item of expenditure/ activities	Total approved budget	Fund received	Actual expenditure	Balance/ unspent	Physical progress (%)	Reasons for deviation
Contractual staff salary	2483611	2498088	2498088	0.00	100.00	
Field Research/Lab expenses and supplies	4168961	2711664	2711664	0.00	100.00	
Operating expenses	572124	580934	580934	0.00	100.00	
Vehicle Hire and Fuel, Oil and maintenance	673555	652955	652955	0.00	100.00	
Training/Workshop/Seminar etc.	567200	567200	567200	0.00	100.00	
Publications and printing	20000	20000	20000	0.00	100.00	
Miscellaneous	65773	29983	29983	0.00	100.00	
Capital Expenses	1288000	2754000	2754000	0.00	100.00	
Grand total	9839224	9814824	9814824	0.00	100.00	

Component-2: BRRI

Item of expenditure/ activities	Total approved budget	Fund received	Actual expenditure	Balance/ unspent	Physical progress (%)	Reasons for deviation
Contractual staff salary	2261487	2332503	2332503	0.00	100.00	
Field Research/Lab expenses and supplies	4323919	4319733	4319733	0.00	100.00	
Operating expenses	723222	742815	742815	0.00	100.00	
Vehicle Hire and Fuel, Oil and maintenance	488385	431962	431962	0.00	100.00	
Training/Workshop/Seminar etc.	905400	905400	905400	0.00	100.00	
Publications and printing	50000	40000	40000	0.00	100.00	
Miscellaneous	142980	122980	122980	0.00	100.00	
Capital Expenses	707232	707232	707232	0.00	100.00	
Grand total	9602625	9602625	9602625	0.00	100.00	

Component-3: BINA

Item of expenditure/ activities	Total approved budget	Fund received	Actual expenditure	Balance/ unspent	Physical progress (%)	Reasons for deviation
Contractual staff salary	1335972	1306522	1306522	0.00	100.00	
Field Research/Lab expenses and supplies	2820916	2394581	2394581	0.00	100.00	
Operating expenses	910705	755841	755841	0.00	100.00	
Vehicle Hire and Fuel, Oil and maintenance	811112	699605	699605	0.00	100.00	
Training/Workshop/Seminar etc.	397100	377200	377200	0.00	100.00	
Publications and printing	212500	87266	87266	0.00	100.00	
Miscellaneous	352342	196939	196939	0.00	100.00	
Capital Expenses	722423	722423	722423	0.00	100.00	
Grand total	7563070	6540377	6540377	0.00	100.00	

D. Achievement of Sub-project by Objectives (Tangible form): Technology generated/developed

Coordination Component: BARC: Not applicable

Component-1: BARI:

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output (i.e. product obtained, visible, measurable)	Outcome (short term effect of the research)
To suggest plan for sustainable use of groundwater for crop production	➢ Field trials with rabi/boro crops and water saving irrigation technologies at farmers field ➢ GW samples from selected DTWs and STWs were collected and analyzed	In terms of REY and WP, Tomato-Boro-T.Aus was the most profitable pattern for Godagari while Potato-Boro-T.Aman pattern was profitable for Tanore, Kalai and Joypurhat sadar upazilas.	Profitable cropping patterns with water saving technologies for sustainable groundwater use in Rajshahi and Joypurhat areas

Component-2: BRRI

General/Specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output (i.e. product obtained, visible measurable)	Outcome (short term effect of the research)
➢ To optimize groundwater abstraction for irrigation	➢ This project has developed a model for quantifying groundwater deficit compared to previous years and	➢ The model quantified that maximum 66.67 percent deficit recharge occurred in aquifer in the study area and withdrawal level in other word maximum reduced utilization	➢ Farmers' awareness development about safe withdrawal and measured use of

General/Specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output (i.e. product obtained, visible measurable)	Outcome (short term effect of the research)
	safe withdrawal of groundwater per year to retard GWT declining as well as to recover the deficit recharge.	of groundwater per year should be 13.33 percent if it is targeted to recover deficit recharge within five years.	groundwater.
➢ To suggest plan for sustainable use of groundwater for crop production	➢ Four cropping patterns were tested and compared with existing cropping pattern ➢ Three water saving technologies were up scaled in the selected farmers' field	➢ Considering a balanced coordination of irrigation water productivity, rice equivalent yield and economic benefit T. Aman-Potato-Boro and T. Aman-Mustard-Boro patterns may be the irrigation water saving as well as economically benefited cropping patterns in the project area. ➢ Supplemental irrigation gave 10-35% yield advantages over rainfed condition. ➢ Improved levee management (15 cm levee height) conserved 18 days more standing water and gave 9-26% yield advantages over farmers management ➢ Alternate wetting and drying irrigation method saved 20-20% water than farmers management without yield loss.	➢ Farmers' getting benefit by cultivating low irrigation requiring cropping pattern. ➢ Farmers' getting benefit by mitigating any severity of drought through supplemental irrigation. ➢ Farmers' getting benefit by mitigating moderate drought through this management. ➢ Farmers' getting benefit by reducing irrigation cost.

Component-3: BINA

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output (i.e. product obtained, visible, measurable)	Outcome (short term effect of the research)
➢ To optimize groundwater abstraction for irrigation	➢ Safe yield was estimated based on hydrologic equation and TI model ➢ Model simulation	➢ The TI model quantified that maximum 72.89 percent deficit recharge occurred in aquifer at Nachole and maximum reduced utilization of groundwater per year should be 14.58 percent if it is targeted to recover deficit recharge within five years. ➢ For Niamatpur, 87.57 percent deficit recharge occurred in aquifer in the study area and maximum reduced utilization of groundwater per year should be 17.51 percent if it is targeted to recover deficit recharge within five years.	➢ Sustainable groundwater withdrawal

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output (i.e. product obtained, visible, measurable)	Outcome (short term effect of the research)
		➢ The simulation results also indicated that with the incremental replacement of Boro by Aus (30%, 50%, 100%), the declination of WT will be reduced, and hence the WT situation will be improved. If the recharge rate is reduced from its present condition (e.g. to 80% or 90%), the depth to WT will also be increased.	
➢ To suggest plan for sustainable use of groundwater for crop production	➢ Field experiments with different cropping patterns were conducted	➢ The pattern "Aman-Rabi (lentil /mustard /wheat)-Aus" saved an average of about 55 percent irrigation water and increased the 'equivalent rice yield' to about 10-19 percent (along with higher benefit-cost ratio) compared to existing pattern "Aman-Fallow-Boro" at Nachole area. ➢ At Niamatpur area, instead of the traditional two cropped "Aman-Fallow-Boro" pattern, the three-cropped "Aman-Rabi (lentil /mustard /wheat)-Aus" pattern saved an average of about 57 percent irrigation water and increased the equivalent rice yield to about 14-16 percent.	➢ Use of water saving technologies and profitable cropping pattern

E: Information/Knowledge generated/Policy generated

Coordination Component: BARC: Not applicable

Component-1: BARI

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output	Outcome (short term effect of the research)
➢ To assess groundwater availability and recharge pattern in different district of northwest hydrological region of Bangladesh	➢ Collection of long-term groundwater level, rainfall and other meteorological data, lithological data, etc. and present and future availability of groundwater was determined by discrete space state model ➢ GW samples from	➢ The rate of GW level declination was on average 18 cm/yr at Tanore, 9 cm/yr at Godagari, 6 cm/yr at Joypurhat sadar. In Godagari, Joypurhat sadar, and Kalai upazila, the groundwater level declination was found obvious in few observation wells, the groundwater levels showed increasing trends in some observation wells. ➢ In respect of all evaluating	➢ Long-term groundwater level trend was predicted (Present and future trend of groundwater level in northwest region) ➢ Water quality was determined and suggested for agricultural use (Groundwater quality for irrigation in the northwest region)

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output	Outcome (short term effect of the research)
	selected DTWs and STWs were collected and analysed for quality evaluation	criteria (SAR, SSP, RSC, KR, and WQI) groundwater of the study area was found suitable and can safely be used for irrigation purpose	
➢ To optimize groundwater abstraction for irrigation	➢ Calibration and validation of groundwater model ➢ Scenario development for sustainable groundwater use for crop production using groundwater model	➢ Abstraction will be increasing by 33-35% in Joypurhat study areas while it will be increasing by 40-45% in Rajshahi in the next 20 years. ➢ In the business-as-usual case, the MODFLOW computed heads at the three observation wells GT 8194046, GT8194048, and GT8194049 on 24 September 2018 were 16.388m, 18.133m, and 22.215m, respectively. When the abstraction was reduced to 90%, the computed heads rose significantly to 7.970m, 11.150m, and 18.106m, respectively. If the abstraction would be increased to 110%, the computed heads were found as 20.707m, 21.745m, and 24.413m, respectively which indicated a substantial increase (drop) in the quantity of head development.	➢ Future groundwater abstraction pattern was assessed (Present and future patterns of groundwater abstraction in northwest region) ➢ Three different scenarios (business-as-usual, abstraction<recharge, abstraction>recharge) were developed using MODFLOW groundwater model (Optimization of groundwater abstraction for different recharge scenarios)
➢ To suggest plan for sustainable use of groundwater for crop production	➢ Field trials with rabi/boro crops and water saving irrigation technologies at farmers' field	The highest REY and WP were obtained from Tomato-Boro-T.Aus followed by Potato-Boro-T.Aman pattern while the lowest was from Mustard-Boro-T.Aman pattern. Use of water saving irrigation technologies increased REY by 8-24% and saved about 20-25% water over existing farmers' practice.	Rice equivalent yield (REY) and water productivity (WP) were found higher in cropping patterns where high yielding rabi crops like tomato, potato and maize were included and water saving irrigation technologies were adopted.

Component-2: BRRI

General/Specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output	Outcome (short term effect of the research)
➢ To assess groundwater availability and recharge pattern in different districts of northwest hydrological region of Bangladesh	➢ Historical (about 32 years) groundwater table (GWT) data, collected from Bangladesh water development board were analyzed namely average per year depletion, trend of GWT and relationship between rainfall and GWT.	➢ Average per year groundwater table depletion was 6.6 cm at Ishwardi and it was highest in the sub-project area. The trend line indicated that at present (in 2019) there is no groundwater table depletion at Mithapukur	➢ Long-term groundwater level trend was predicted
➢ To optimize groundwater abstraction for irrigation	➢ Primary and secondary data was analyzed using model study for optimizing groundwater abstraction ➢ Determination of suitable method for safe groundwater recharge and quality of groundwater	➢ Development and validation of TI model. About thirteen percent per year withdrawal should be reduced to return groundwater level in its previous level ➢ About 70 percent Boro area should be brought under AWD method to retard groundwater level depletion.	➢ Farmer's awareness development about safe withdrawal and measured use of groundwater.
➢ To suggest plan for sustainable use of groundwater for crop production	➢ Identification of less irrigation requiring cropping pattern ➢ Application of water saving technologies for crop production	➢ In terms of irrigation water productivity Aus based CP such as T. Aman- Lentil – T. Aus performed better best compared to Boro based CP such as T. Aman-Mustard-Boro and T. Aman-Potato-Boro. ➢ Use of water saving technologies saved water, increased productivities and crop yield.	➢ Farmer's awareness development about Aus based cropping pattern. ➢ Farmers were benefited

Component-3: BINA

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output	Outcome
➢ To assess groundwater availability and recharge pattern in different districts of northwest hydrological region of Bangladesh	➢ Hydraulic properties of Aquifer were determined. ➢ Groundwater recharge were estimated using tracer and water balance method ➢ Trend of GWT was determined ➢ Quality of groundwater at Nachole and Niamatpur was evaluated.	➢ The hydraulic conductivity (K), Transmissibility (T) and Specific yield (Sy) of aquifer were found as 17.34 to 55.35 m^3/m^2/day, 433.41 to 1383.69 m^3/m/day and 4.03 to 5.03%, respectively at Nachole and 37.12 to 54.71 m^3/m^2/day, 733.20 to 1299.47 m^3/m/day and 4.04 to 9.30%, respectively at Niamatpur upazila ➢ Average recharge at Nachole was found as 195.8, 122.8, and 102.6 mm under tracer technique, water balance method, and water-table fluctuating method, respectively. ➢ At Niamatpur area, yearly recharge was found as 210 mm, 149.1 mm, and 137.6 mm under tracer technique, water balance method, and water-table fluctuating method, respectively. In terms of annual rainfall, it was about 15.14%, 10.7%, and 9.92 % of rainfall. ➢ The trend was declining and the magnitude between maximum and minimum depth to water-table was decreasing over time, meaning that the recharge rate is decreasing. ➢ In some cases, average annual declining rate was about 0.5 – 1.0 m. ➢ The quality of groundwater at Nachole and NiamatpurUpazila were found within permissible limit for irrigation and drinking purposes according to FAO, GOB and WHO guidelines.	➢ Aquifer properties provide sustainable groundwater abstraction of the area and all the values were suitable for sustainable groundwater development. ➢ Farmers' awareness development about groundwater declination. ➢ The groundwater quality was found safe as per FAO, GoB and WHO guidelines.
➢ To optimize groundwater abstraction pattern	➢ Safe yield was estimated based on hydrologic equation and analytical model.	➢ The analytical model quantified that maximum 72.89 percent deficit recharge occurred in aquifer at Nachole and maximum reduced utilization of groundwater per year should be 14.58 percent if it is targeted to recover deficit recharge	➢ Sustainable groundwater withdrawal ➢ Simulation model forcasts Boro replacement by

General/specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output	Outcome
	➢ Simulation model was used for developing scenario under different withdrawal situation and suggestions were made	within five years. For Niamatpur, 87.57 percent deficit recharge occurred in aquifer in the study area and maximum reduced utilization of groundwater per year should be 17.51 percent if it is targeted to recover deficit recharge within five years. ➢ The predicted scenario of GWT for 2050 and 2075 indicated that in 2050, the depth to water-table would be about 1.5 times and that in 2075, would be nearly double of those in 2018. The simulation results also indicate that with the incremental replacement of Boro by Aus (30%, 50%, 100%), the declination of WT will be reduced, and hence the WT situation will be improved. If the recharge rate is reduced from its present condition (e.g. to 80% or 90%), the depth to WT will also be increased.	Aus will increase the recovery rate of GWT.
➢ To suggest plan for sustainable use of groundwater for crop production	➢ Trail of low water demanding cropping patterns for sustainable groundwater resource in Nachole and Niamatpur upazila	➢ The pattern "Aman-Rabi (lentil /mustard /wheat)-Aus" saved an average of about 55 percent irrigation water and increased the 'equivalent rice yield' to about 10-19 percent (along with higher benefit-cost ratio) compared to existing pattern "Aman-Fallow-Boro" at Nachole area. ➢ At Niamatpur area, instead of the traditional two cropped "Aman-Fallow-Boro"pattern, the three-cropped "Aman-Rabi (lentil /mustard /wheat)-Aus" pattern saved an average of about 57 percent irrigation water and increased the equivalent rice yield to about 14-16 percent.	➢ Identified water-saving and economic cropping patterns

F. Materials Development/Publication made under the Sub-project

Coordination Component: BARC

Publication	Number of publications		Remarks (e.g. paper title, name of journal, conference name, etc.)
	Under preparation	Completed and published	
Booklet	-	01	Groundwater resources management for sustainable crop production in northwest hydrological region of Bangladesh (বাংলাদেশের উত্তর-পশ্চিম হাইড্রোলজিক্যাল অঞ্চলে টেকসই ফসল উৎপাদনের জন্য ভূগর্ভস্থ পানি সম্পদের টেকসই ব্যবস্থাপনা)
Policy paper	-	01	Policy paper on Groundwater resources management for northwest hydrological region of Bangladesh.
Video Documentation	-	01	বাংলাদেশের উত্তর-পশ্চিম হাইড্রোলজিক্যাল অঞ্চলে টেকসই ফসল উৎপাদনের জন্য ভূগর্ভস্থ পানিসম্পদ ব্যবস্থাপনা
News Paper/Popular Article	-	08	Published in BARC newsletter

Component-1: BARI

Publication	Number of publications		Remarks (e.g. paper title, name of journal, conference name, etc.)
	Under preparation	Completed and published	
Leaflet	-	01	1. Cropping pattern based water management with water saving irrigation technologies in barind area
Journal publication	-	01	1. Roy, D.K., Biswas, S.K., Saha, K.K. et al. (2021). Groundwater Level Forecast Via a Discrete Space-State Modelling Approach as a Surrogate to Complex Groundwater Simulation Modelling. Water Resources Management volume 35, pages1653–1672.
News Paper/Popular Article	-	02	Report on field day

Component-2: BRRI

Publications	Number of publications		Remarks (e.g. paper title, name of journal, conference name, etc)
	Under preparation	Completed and published	
Technology bulletin/booklet /leaflet/flyer etc.	-	03	১। পাবনা ও রংপুর অঞ্চলের জন্য সেচ সাশ্রয়ী উন্নত ফসল বিন্যাস ২। ভূগর্ভস্থ পানির উত্তোলন কমাতে বোরো ধানে সেচ প্রয়োগে পর্যায়ক্রমে ভেজানো ও শুকানো (AWD) পদ্ধতির ব্যবহার ৩। ভূগর্ভস্থ পানির টেকসই ও নিরাপদ ব্যবহার নির্ধারণে TI মডেল
Journal publication	-	02 (Submitted)	1. Cropping system intensification: An approach to increase yield, water productivity and profitability in North-west Bangladesh. Submitted to International Journal of Agronomy. 2. Behavior of Groundwater Table with Rainfall in Northwest Region of Bangladesh. Paper submitted to Bangladesh Rice Journal.

Component-3: BINA

Publications	Number of publications		Remarks (e.g. paper title, name of journal, conference name, etc)
	Under preparation	Completed and published	
Technology bulletin/booklet/ leaflet/flyer etc.	-	02	1. Water Saving and Economic Cropping Pattern for Nachol upazila for Sustaining Groundwater Resource. 2. Water saving and Economic Cropping Pattern for Niamatpur upazila for Sustaining Groundwater Resource.
Journal publication	-	02	1. M. H. Ali1, M. H. Zaman, M. A. Islam, P. Biswas, N. N. Karim and M. A. Kader. (2021). Quality Assessment of Barind Groundwater Area in Bangladesh, Using Integrated Hydrochemical Method. Asian Journal of Advances in Agricultural Research. 16(4): 18-27; Article no.AJAAR.75120. 2. M. H. Ali1, M. H. Zaman, M. A. Islam, P. Biswas, N. N. Karim and M. A. Kader. (2021). Recent Trend of Precipitation and Crop Planning at Rajshahi Region of Bangladesh. Asian Journal of Advances in Agricultural Research. 16(4): 28-39; Article no. AJAAR. 75121.
Newspaper/Popular Article	-	06	Report on field day/farmers training

G. Description of generated Technology/Knowledge/Policy

Component-1: BARI:

i. Technology Factsheet

Title of the technology: Cropping pattern based water management with water saving irrigation technologies for Rajshahi district (under North-West hydrological region)

Introduction
Huge groundwater has been withdrawn in Rajshahi district for boro rice production without considering annual replenishment from rainfall that caused declination of groundwater table at an alarming rate. Low rainfall, cultivation of water intensive boro rice, irrational irrigation management, and non-use of available irrigation technologies leading use of water resources sustainability is at risk. This situation will progressively be aggravated by climate change in future. Special attention should be given for safe use of water resources and save environment of the region. The rational use of water with advanced irrigation strategies and practicing irrigation water saving technologies with low water consuming crops in the cropping patterns may be the management practice to save water resources in the area.

Description
Cropping pattern based water management means each crop of a pattern receives irrigation only at critical stages, previously determined, except rice. Rice receives irrigation by AWD method, that is, farmers will apply irrigation to rice field when water reached at the bottom of 30 cm long and 7.5 cm diameter plastic pipe used for AWD method. Different cropping patterns, observed in the study area, from Rabi crops - Boro - T.Aman pattern have been tested in the study area to find out irrigation water requirement for the patterns. A pattern, Rabi crops - Boro - T.Aman rice; rabi (winter) crops like mustard, potato/maize and wheat will receive irrigation one, three and two-times, respectively, at its critical stages. Different patterns were tested with different rabi crops as stated. Short duration mustard (BARI sharisha-14) to be irrigated only at pre-flowering stage; potato at stolonization, tuberization and bulking stages and maize at seedling, silking and grain filling stages; wheat at CRI and heading stages while Boro and T.Aman rice are irrigated by AWD method. Alternate furrow irrigation (AFI) technology is used for tomato, potato and maize while drip irrigation is used only for tomato. Special emphasis is given to use residual soil moisture of previous crops so that sowing time irrigation for germination of succeeding crop can be omitted. Thus, total irrigation requirement reduces markedly for the pattern adopting water saving technologies (e.g., deficit irrigation and AFI for row crops, and AWD for rice) without any loss in crop yield and thereby water productivity increases largely.

Suitabile location
Godagari and Tanoreupazilas of Rajshahi district

Benefits
Inclusion of rabi crops in the cropping pattern instead of boro rice, a water intensive crop, certainly have reduced the requirement of irrigation water. As rice plays a pivotal role meeting the food security and as the major share of rice production comes from boro cultivation, it is not always possible and even not pragmatic supplementing boro rice with other non-rice crops. Boro rice is supplemented by Aus or Aman rice that receives rain that reduces irrigation need compared to boro rice. Rather, use of water saving technologies for crop production keeping the crops in a pattern unchanged but with short duration can reduce the irrigation water requirement and thereby reduce the withdrawal of groundwater. In this way, system crop productivity (i.e., rice equivalent yield) is

increased by 13 – 28% with the water saving of about 9 – 18% and increase of farmers' net income by 15 – 50%. As a result, it will save groundwater as well as reduce the fuel cost of extraction, and will also conserve the environment and biodiversity of the area.

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ii. Effectiveness in policy support (if applicable): Not applicable

Component-2: BRRI

i. Technology Factsheet-1

Title of the technology: Modeling for quantifying groundwater deficit recharge and safe withdrawal for sustainable crop production in North-West region of Bangladesh

Introduction

Water is one of the most important inputs for targeted and sustainable crop production. Bangladesh has two different sources of water, categorically surface and groundwater, for irrigating the crop land mainly for cereal rice production. Boro rice is mainly grown during dry season (December - May) utilizing / pumping groundwater. Surface water is very scarce during dry season in most of the agro-ecological zones of the country with the exception of southern parts of the country. Because of huge withdrawal of groundwater during dry season causes decline of groundwater table. So, micro level such as for a particular area or zone, ground water declining simulation and groundwater safe utilization mechanism should be developed for retarding groundwater declining and ensuring future crop production through groundwater irrigation. In this study a conceptual mathematical model for the studied location has been developed which can simulate groundwater declining trend and estimate groundwater withdrawal rate for retarding groundwater declining as well as gives direction for which management is suitable for safe utilization of groundwater.

Description

- This Model quantifies groundwater deficit recharge at any year compare to any previous year(s)
- It measures the groundwater withdrawal limit per year to recover the deficit recharge within targeted coming years
- It also calculates the amount of area to be brought per year under water saving technology to recover the deficit recharge
- The model has been applied for the studied locations.

Suitable location

North-West hydrological region. Groundwater declining area is also a potential for using/applying developed the model.

Benefits

Retarding groundwater declining as well as recovering groundwater deficit in the aquifer.

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ii. Effectiveness in policy support (if applicable)

The model will help in policy making by a. identifying present status of groundwater, b. quantifying safe groundwater withdrawal and c. determining coverage of water saving technology in agriculture.

i. Technology Factsheet-2

Title of the technology: Low irrigation demand cropping pattern to mitigate groundwater level declination in Rangpur and Pabna districts (under North-West hydrological region)

Introduction

Increasing cropping intensity is creating more irrigation demand in Bangladesh. Moreover, crops are suffering from drought due to less rainfall and its uneven distribution. Thus, more dependency of groundwater irrigation is causing water table declination especially in water scarce north-west. Immediate actions should be taken to arrest groundwater table declination for sustaining agriculture production and livelihood. Since agriculture is the largest consumer of groundwater in the study area, demonstration and adoption of on-farm water management technologies can play a significant role to judicious water use. However, social constraints often restrict implementation of water saving technologies. To avoid the issue, cultivation of less irrigation intensive profitable cropping pattern would the preferable water saving solution and easily acceptable to farmer.

Description

Two cropping patterns, T. Aman- Potato-Boro and T. Aman-Mustard-Boro are suitable for medium high land to high land instead of T. Aman-Fallow-Boro patterns. BRRI and BARI developed modern high yielding varieties (BRRI dhan49 and similar varieties in T. Aman, BARI Potato-25 for Potato, BARI Shorisha-14 for Mustard, BRRI dhan58 and similar variety for Boro) are cultivated along with recommended agronomic practices. Potato/Mustard should be established as early as possible after T. Aman harvesting (within 15th December). For Boro rice irrigation should be applied following alternate wetting and drying (AWD) method or after disappearing standing water. Two to three irrigation need to apply at critical stages for mustard and Potato.

Suitable location

Medium highland to highland of Pabna and Rangpur districts

Benefits

Both the cropping patterns saves 25-30% irrigation water covering more rainfall and gave higher rice equivalent yield than T. Aman-Fallow-Boro cropping pattern. Besides, higher gross margin of average Tk. 25000 $ha^{-1}$and Tk. 40000 ha^{-1} can be achieved in T. Aman- Potato-Boro and T. Aman-Mustard-Boro cropping pattern, respectively over T. Aman-Fallow-Boro pattern.

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ii. Effectiveness in policy support (if applicable)
This technology will help for the policy planner to increase land and water productivity improvement. It has a great potentiality to save irrigation water, thus groundwater abstraction can be reduced by adopting it. Massive demonstration is required to adopt the technology.

Component-3: BINA

i. Technology Factsheet

Title of the technology
Water saving and economic cropping pattern for sustaining groundwater resource in Chapainawabganj and Naogoan district (under North-West hydrological region)

Introduction
Groundwater levels in the study are declining faster than that of other parts of the country. Due to low rainfall in this area, the amount of water that is being pumped out is not being refilled or recharged to the aquifer. If this situation continues, there will be a time when water will not be available even with the help of deep tube-wells. As a result, lack of water can lead to environmental disasters in the future. To get rid of this situation, groundwater have to be withdrawn in such a way that the water level does not go down too much, that is, sustainability is maintained. In most of the lands, two crops are cultivated in a year following the cropping pattern "Aman-Fallow-Boro". Local farmers usually cultivate long-duration Aman variety and after harvesting Aman rice, they keep the land fallow for about 2-3 months and then cultivate long-duration Boro rice. As a result, they are dependent on groundwater for partial irrigation (2-4 nos) of Aman rice, and complete irrigation (12-14 nos) of Boro rice.

Description
This has been observed from the study in the area that irrigation water requirement of “Aman-Rabi-Aus” cropping pattern is less than the traditional practice of “Aman-Fallow-Boro” cropping pattern. It is possible to get good yield in Rabi season without irrigation in case of Lentil (e.g. Binamasur-8), with one or two irrigations in Mustard (Binasarisha-9, Binasarisha-10 or BARI Sarisha-14) and, with two or three irrigations in Wheat (BARI Gom-33, BARI Gom-35 or BARI Gom-26) after harvesting of short-duration Aman rice variety (Binadhan-7, Binadhan-17, Binadhan-22 or BRRI dhan71) at that area. After harvesting wheat or lentil or mustard, cultivation of Aus rice (Binadhan-19 or Binadhan-21) with 3-4 irrigations are sufficient which should be given from planting to vegetative stage, and the rest of the time is covered by natural rainfall. The yield of cultivated Aus rice is about 4.79 t/ha. Groundwater abstraction is relatively low as the demand for irrigation water is largely met by rainwater. As a result, cultivation of Rabi crop and Aus rice instead of Boro rice, requires less withdrawal of groundwater, which is environment-friendly. On the other hand, this pattern increases the annual rice-equivalent yield (REY) as well as net profit or income.

Suitable Area/Location for Application
Chapainawabganj and Naogoan district

Benefits
Cultivation of Rabi crops like mustard, lentil or wheat, and Aus rice instead of Boro, requires less amount of irrigation water, but produces higher annual yield (REY) and net profit. Instead of the traditional two cropped “Aman-Fallow-Boro” pattern, the three-cropped “Aman-Rabi (lentil /mustard /wheat)-Aus” pattern saves 50 - 59 percent irrigation water and increases the equivalent rice yield to about 10-19 percent at Nachol, Chapainawabganj; and saves 52-62 percent irrigation water and increases the equivalent rice yield to about 16-14 percent at Niamatpur, Naogoan district.

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ii. Effectiveness in Policy Support (if applicable)
To minimize groundwater abstraction, the technology may play a significant role at study area. But substantial demonstrations are required to accept the technology among the local farmers. In addition, awareness building among the farmers is required regarding the adverse effect of excessive declination of groundwater level. The findings will be helpful to the policy planner to take relevant policy actions for sustainable groundwater resource management at that area.

H. Technology/Knowledge generation/Policy Support (as applied)

Component-1: BARI

i. **Immediate impact of generated technology (commodity & non-commodity)**
Cropping pattern based water management with water saving irrigation technologies save about 20-25% of irrigation water and thereby 20-25% less water need to be drafted for irrigation. These technologies will have a positive impact on reducing irrigation cost and groundwater declination rate as well.

ii. **Generation of new knowledge that help in developing more technology in future**
Forecasted groundwater abstraction and declination pattern will give a new insight in developing more technology in future to conserve groundwater for sustaining our agriculture.

iii. **Technology transferred that help increased agricultural productivity and farmers' income**
Cropping pattern based irrigation technology will help increase crop productivity which ultimately will enhance farmers' income as well as improve their livelihood.

iv. **Policy support**
Policy and strategic support need to popularize of these irrigation technologies at farmers' level. This initiative can reduce pressure on groundwater as well as energy consumption.

Component-2: BRRI

i) **Immediate impact on generated technology (commodity and non-commodity)**
About 20 ha of lands in the project area has been brought under improve cropping patterns and it save both irrigation water and groundwater withdrawal. Farmers earned average Tk. 25000 to Tk. 40000 per hectare over their previous years by applying the improved cropping patterns. Adoption of AWD technology saved about 25-30% irrigation water than the farmers' practices. Supplemental irrigation and levee management gave about 10-30% higher yield than control practice. Promotional activity including field demonstration, farmers training, field and direct advisory to farmers increased farmer's knowledge about the technology

ii) **Generation of new knowledge that help in developing more technology in future**
Not applicable

iii) **Technology transferred that help increased agricultural productivity and farmers income**
a. Cropping patterns developed by this sub-project
b. Supplemental irrigation demonstrated during monsoon period

c. Improved levee management demonstrated during monsoon period
d. AWD method demonstrated during dry period

iv) Policy support
Not applicable

Component-3: BINA

i) Immediate impact on generated technology (commodity and non-commodity)
Field demonstration, farmers training and field days tended to motivate local farmers to take the water saving and profitable technology. Skilled farmers as well as their followers were changing their existing cropping pattern and DAE personnel are now capable to train them easily to adopt new technologies in different fields

ii) Generation of new knowledge that help in developing more technology in future
Location specific hydraulic properties, long term prediction of GW dynamics and sustainable use of groundwater resources by water saving technologies will help DAE and BMDA personnel to conduct their future project activities.

iii) Technology transferred that help increased agricultural productivity and farmers income
a. Water saving and profitable cropping patterns at study area
b. Groundwater resources availability and its proper utilization techniques

iv) Policy support
Policy support is required to implement the water-saving and profitable cropping pattern in the study area.

I. Information regarding Desk and Field Monitoring

Coordination Component: BARC

i. Desk Monitoring [description & output of consultation meeting, monitoring workshops/seminars etc.)

Visited component institutes: BARI, BRRI, BINA and discussed on the adoption of methods of data analysis for having uniformity in conclusion.

Component institutes followed the instructions of desk monitoring and reported outputs of the sub project.

ii. Field Monitoring (date& no. of visit, name and addresses of team visit and output)

Date	No. of visit	Name and addresses of team visit	Output
20/01/2021 (BARI, BRRI, Gazipur)	02	Dr. Sultan Ahmmed, MD, NRM, BARC Dr. Nazmun Nahar Karim, MD (Livestock), BARC Md. Abdul Kader, SSO, PBRG Sub-project (ID: 002)	Developed methodology
14/12/2020 BARI, Gazipur	01	Dr. Nazmun Nahar Karim, MD (Livestock), BARC Dr. Ahmad Ali Hassan, Consultant (Part time), PBRG Sub-project (ID: 002) Md. Abdul Kader, SSO, PBRG Sub-project (ID: 002)	Seen model output
21/12/2020 BINA, Mymensingh	01	Dr. Nazmun Nahar Karim, MD (Livestock), BARC	Instructed to use BARI and BRRI used model

Date	No. of visit	Name and addresses of team visit	Output
		Dr. Ahmad Ali Hassan, Consultant (Part time), PBRG Sub-project (ID: 002) Md. Abdul Kader, SSO, PBRG Sub-project (ID: 002)	
14/12/2020 (BRRI, Gazipur)	01	Dr. Nazmun Nahar Karim, MD (Livestock), BARC Dr. Ahmad Ali Hassan, Consultant (Part time), PBRG Sub-project (ID: 002) Md. Abdul Kader, SSO, PBRG Sub-project (ID: 002)	Instructed to use BARI used model
25-27/01/2020 (Chapai Nawabganj, Rajshahi and Pabna)	01	Dr. Sultan Ahmmed, MD, NRM, BARC Dr. Nazmun Nahar Karim, MD (Livestock), BARC Dr. Ahmad Ali Hassan, Consultant (Part time), PBRG Sub-project (ID: 002) Md. Abdul Kader, SSO, PBRG Sub-project (ID: 002)	Visited field experiments and gave necessary suggestions
21-23/12/2019 (Joypurhat)	01	Md. Abdul Kader, SSO, PBRG Sub-project (ID: 002)	Visited field experiments and gave necessary instructions
09-11/02/2020 (Pirganj and Mithapukur)	01	Dr. Ahmad Ali Hassan, Consultant (Part time), PBRG Sub-project (ID: 002) Md. Abdul Kader, SSO, PBRG Sub-project (ID: 002)	Visited field experiments and inspired farmers using water saving technologies

iii. Weather data, flood/salinity/drought level (if applicable) and natural calamities
Not applicable

Output: Valuable and effective directions were provided by the team for making the project work more effective.

J. Sub-project Auditing (covers all types of audits performed)

Coordination Component: BARC

Types of audits	Major observation/ issues/ objections raised; if any	Amount of Audit (Tk.)	Status at the sub-project end	Remarks
Internal	None	14,14,499.00	July/2018 to June/2019	
FAPAD	None	14,14,499.00	July/2018 to June/2019	
FAPAD	None	6,42,829.00	July/2019 to June/2020	
FAPAD	None	7,40,208.00	July/2012 to June/2021	

Component-1: BARI

Types of audits	Major observation/ issues/ objections raised; if any	Amount of Audit (Tk.)	Status at the sub-project end	Remarks
FAFAD	None	33,17,603.00	July/2018 to June/2019	
FAFAD	None	33,07,105.00	July/2019 to June/2020	

Component-2: BRRI

Types of audits	Major observation/ issue/objections raised; if any	Amount of Audit (Tk.)	Status at the sub-project end	Remarks
FAPAD	None	30,70,294.00	July/2018 to June/2019	
FAPAD	None	24,89,388.00	July/2019 to June/2020	

Component-3: BINA

Types of audits	Major observation/ issues/ objections raised; if any	Amount of Audit (Tk.)	Status at the sub-project end	Remarks
FAFAD	None	29,05,144.00	July/2018 to June/2019	
FAFAD	None	20,64,707.00	July/2019 to June/2020	

K. Lessons Learned:

Component-1: BARI

i. Cropping pattern based water management with adoption of water saving irrigation technologies which saved about 20-25% of irrigation water and thereby reduced the groundwater use for crop irrigation;

ii. In terms of REY and WP, Tomato-Boro-T.Aus was the most profitable pattern for Godagari while Potato-Boro-T.Aman pattern was the profitable for Tanore, Kalai and Joypurhat sadar upazilas. Farmers can save irrigation cost if they adopt water saving irrigation technologies;

iii. While the groundwater level declination is obvious in some observation wells and will be doubled in the next 22 years (by 2041), if the present rate of abstraction continues. The groundwater levels showed rising trends in some observation wells. The rising trend in groundwater levels in some observation wells indicated the recent initiatives adopted by the authority in imposing the constraints of the maximum withdrawal limits.

iv. In respect of all evaluating criteria (SAR, SSP, RSC, KR, and WQI) groundwater of the study area was found to be suitable and can safely be used for irrigation and drinking purposes.

Component-2: BRRI

i. Huge prospect exists both in Pabna and Rangpur to increase cropping intensity and income.

ii. Aus based cropping patterns saved huge water, though it had comparatively less economic return.

iii. Groundwater level declination can be contrled by massive adoption of water saving technology.
iv. Technology demonstration should be on block wise instead of single field.

Component-3: BINA

i. Including mustard, lentil or wheat in Aus-based cropping pattern, it is possible to increase cropping intensity as well as sustainable use of groundwater resources.
ii. Preliminary, it may be difficult to adopt Aus-based cropping pattern instead of Boro based, but not impossible if we develop awareness of farmers through BMDA and DAE personnel with water saving and economic cropping pattern technology.

L. Challenges (if any):

Coordination Component: BARC

Groundwater is a valuable resource for crop production and other utilizations (domestic, industry, fisheries, etc.). The water resources should be used properly so that groundwater is not mined/ over exploited and thus environment is saved for future generation. Following measures can be adopted for safe utilization of groundwater resources.

- Adoption of appropriate irrigation technology by the farmers;
- Timely crop establishment sometimes hampered due to untimely pump operation
- Policy intervention to create awareness among the farmers and other stakeholders about the consequences of indiscriminate use of groundwater.

M. Suggestions for Future Planning (if any):

Coordination Component: BARC

To safeguard groundwater resources the following measures can be adopted:

- Massive demonstration work should be done regarding improved cropping patterns and water saving technologies.
- Demonstration work may be done regarding improved cropping patterns and water saving technologies.
- Policy plan should be developed to quick adoption of water saving technology in about 60% Boro growing areas in north west region of Bangladesh, and
- Policy plan should be taken to replace Boro based cropping pattern by Aus based cropping pattern to replenish groundwater table.

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Annexure I

a. Farmer's Survey Questionnaire

Sub-project Title: Groundwater resources management for sustainable crop production in northwest hydrological region of Bangladesh Baseline Survey/Study

ক্রমিক নং ঃ

কৃষকের নামঃ বয়সঃ

শিক্ষাঃ পেশা

গ্রামঃ ইউনিয়নঃ

মৌজাঃ উপজেলাঃ জেলাঃ

১। সাক্ষাৎকার দানকারী কৃষকের পারিবারিক তথ্যাবলী:

পরিবারে আপনার উপর নির্ভরশীল সদস্যদের সংখ্যা, শিক্ষা ও পেশা সম্পর্কে কিছু বলুন।

পরিবারের অন্যান্য সদস্যের বিবরণ					
ক্রমিক নং	বয়স	লিঙ্গ (পু/ম)	শিক্ষা	পেশা	সম্পর্ক
১					
২					
৩					
৪					
৫					
৬					

২। পরিবারের বিবরণীঃ

আপনার পরিবারের জমির পরিমাণ, বসতবাড়ী ও অন্যান্য সম্পদের বিবরণ:

জমির ধরন ও পরিমাণ (স্থানীয় একক)		অন্যান্য সম্পদের বিবরণ
নিজ আবাদী	বর্গা দেয়া	বাড়ীর প্রকৃতিঃ
বর্গা নেয়া	বন্ধক	
বন্ধক নেয়া	বাগান	
বসত বাড়ী	মাছের ঘের	
পুকুর	পতিত	

৩। বাৎসরিক আয়ঃ
আপনার বার্ষিক আয়ের বিবরণ দিন

ক্র. নং	আয়ের উৎস	মোট মূল্য	মোট উৎপাদন খরচ	নীট মুনাফা
১	কৃষি খাত: ক) শস্য খাত			
	আমন ধান			
	আউস ধান			
	বোরো ধান			
	গম			
	তেল জাতীয় ফসল			
	ডাল জাতীয় ফসল			
	শাক-সবজি			
	অন্যান্য			
মোট টাকা				
	খ) গৃহপালিত পশু খাত			
	গ)মৎস খাত			
	ঘ)হাঁস ও মুরগী খাত			
মোট টাকা (কৃষি খাত)				
২)	অকৃষি খাত:			
	কৃষি দিনমজুর			
	চাকুরী			
	ব্যবসা			
	কৃষি দিনমজুর নয়			
	অন্যান্য			
মোট টাকা (অকৃষি খাত)				
সর্বমোট টাকা (কৃষি এবং অকৃষি খাত)				

৪। জমির ধরনঃ
আপনার চাষকৃত জমিগুলো কোন্ ধরনের কতটুকু?

জমির ধরন	পরিমাণ (স্থানীয় একক)	পরিমাণ (হেক্টর)
১। উচু জমি		
২। মাধ্যম উচু জমি		
৩। মধ্যম নিচু জমি		
৪। নীচু জমি		
৫। বেশী নীচু জমিঃ		

৫। **শস্য পরিক্রমা:**
আপনার চাষকৃত জমিগুলোতে আপনি কি ধারাবাহিকতায় (কোন্টির পর কোন্টি) শস্য চাষাবাদ করেন ?

	আমন মৌসুম	রবি /বোরো মৌসুম	আউশ মৌসুম	জমির পরিমাণ
১ম শস্য				
২য় শস্য				
৩য় শস্য				
৪র্থ শস্য				

৬। চাষাবাদকৃত জমির পরিমাণ এবং ফলন

গতবছর আপনি কি কি ফসল করেছেন, কতটুকু জমিতে চাষাবাদ করেছেন এবং কতটুকু ফলন হয়েছে।

শস্যের নাম	বপন/রোপন থেকে মাড়াই পর্যন্ত সময়	জমির পরিমাণ (স্থানীয় একক)	ফলন (স্থানীয় একক)
১। আমন মৌসুমঃ			
২। রবি মৌসুমঃ			
৩। বোরো মৌসুম:			
৪। আউশ মৌসুম:			
মোট চাষাবাদকৃত জমির পারিমাণ			

৭। জলবায়ু পরিবর্তনে শস্য উৎপাদনে সমস্যাঃ

আপনি যেসব শস্য উৎপাদন করেন, আবহাওয়া পরিবর্তনের ফলে উৎপাদনে কোন সমস্যা সম্মুখীন হচ্ছেন কি?

মৌসুম	শস্য	সমস্যাসমূহ	হ্যাঁ/না
১। আমন মৌসুম			
২। রবি মৌসুম			
৩। বোরো মৌসুম			
৪। আউশ মৌসুম			
৫। খরিফ-১ মৌসুম			

৮। বৃষ্টির পানি নির্ভর শস্য উৎপাদন:

আপনি যেসব শস্য উৎপাদন করেন, তা উৎপাদনের জন্য বৃষ্টির পানি পর্যাপ্ত কি?

মৌসুম	শস্য	হ্যাঁ	না	হ্যাঁ হলে সমস্যার সমাধান কিভাবে করেন
১। আমন মৌসুম				
২। রবি মৌসুম				
৩। বোরো মৌসুম				
৪। আউশ মৌসুম				
৫। খরিফ-১ মৌসুম				

৯। সেচকৃত শস্য:

সেচ দিলে কোন ফসলে কি পরিমাণ এবং কতবার সেচ দেন তার বিবরণ দিন

মৌসুম	সেচকৃত শস্য	সেচ সংখ্যা	জমির পরিমাণ (স্থানীয় একক)	জমির পরিমান (হে.)
১। আমন মৌসুম				
২। রবি মৌসুম				
৩। বোরো মৌসুম				
৪। আউশ মৌসুম				
৫। খরিফ-১ মৌসুম				

১০। সেচ প্রদানে সমস্যা:

আপনার সেচকৃত শস্যে সেচ প্রদান আপনি কোন সমস্যার সম্মুখীন হচ্ছেন কিনা? সমস্যা থাকলে সমস্যা সমূহের বিবরণ দিন

মৌসুম	শস্য	হ্যাঁ	না	সমস্যা সমূহ
১। আমন মৌসুম				
২। রবি মৌসুম				
৩। বোরো মৌসুম				
৪। আউশ মৌসুম				
৫। খরিফ-১ মৌসুম				

১১। সেচ ছাড়া শস্য

আপনি সেচ ছাড়া কি ফসল করেন তার বিবরণ দিন

ক্রমিক নং	সেচ ছাড়া শস্য	মৌসুম	পরিমাণ (স্থানীয় একক)	পরিমাণ (হেক্টর)
১।				
২।				
৩।				
৪।				

১২। আপনার সেচ পানির উৎস

আপনার সেচ পানির উৎস কি

নদী/খালের পানি	পুকুরের পানি	নলকুপের পানি	অন্যান্য

১৩। বিভিন্ন সেচ ব্যবস্থায় জমির পরিমাণ:

গতবছর কোন ব্যবস্থায় কতটুকু জমিতে সেচ দিয়েছেন?

	সেচ ব্যবস্থা				
	গভীর নলকুপ(DTW)	অগভীর নলকুপ (STW)	লো লিফট পাম্প (LLP)	হ্যান্ড টিউবয়েল(HTW)	ট্রাডিশনাল সিস্টেম (TS)
জমির পরিমাণ (স্থানীয় একক)					
জমির পরিমাণ হেক্টর)					

১৪। সেচ ব্যবস্থাপনা মালিকানা

নিচের যে কোনটিতে টিক চিহ্ন দিন:

নিজস্ব সেচ ব্যবস্থা	ভাড়ায় সেচ ব্যবস্থা	উভয়
		নিজস্ব (বিঘা/হেক্টর): ভাড়ায় (বিঘা/হেক্টর):

১৫। সেচ যন্ত্র

নিজস্ব সেচ ব্যবস্থা হলে আপনার কি কি সেচ যন্ত্র আছে ?

১।	২।
৩।	৪।

১৬। সেচ পানির বিতরণ ব্যবস্থা

সেচের পানি যে পদ্ধতিতে জমিতে প্রয়োগ করেন তাতে টিক চিহ্ন দিন:

সেচ পদ্ধতি		**সেচ পদ্ধতি**	
১। কাঁচা সেচ নালা		২। পাকা সেচ নালা	
৩। অর্ধ পাকা সেচ নালা		৪। ফেরোসিমেন্ট সেচ নালা	
৫।পলিথিন বিছানো সেচ নালা		৬। প্লাস্টিক/পলিথিন হোস পাইপ	
৭। ভুগর্ভস্থ সেচ নালা		৮। অন্যান্য	

১৭।

(ক) পানি সাশ্রয়ী শস্য শস্যবিন্যাস সম্পর্কে ধারণা আছে কি না?

(খ) ভূ- গর্ভস্থ পানিস্তর ক্রমোন্বয়ে নীচে এ সম্পর্কে ধারণা আছে কি না?

১৮। সেচ খরচ

মৌসুম	**সেচ খরচ (বিঘা প্রতি)**	**সেচ খরচ বিষয়ে মন্তব্য**			
		খুব বেশী	**বেশী**	**মধ্যম**	**মোটামুটি**
১। আমন					
২। রবি:					
বোরো					
৩। আউশ/					
খরিফ-১					

স্বাক্ষর:

সাক্ষাৎ গ্রহণকারীর নাম:

তারিখ :

b. Pump Owner's Survey Questionnaire

Sub-project Title: Groundwater resources management for sustainable crop production in northwest hydrological region of Bangladesh Baseline Survey/Study

ক্রমিক নং ঃ

কৃষকের নামঃ বয়সঃ

শিক্ষাঃ পেশা

গ্রামঃ ইউনিয়নঃ

মৌজাঃ উপজেলাঃ জেলাঃ

১। সাক্ষাৎকার দানকারী কৃষকের পারিবারিক তথ্যাবলী:

পরিবারে আপনার উপর নির্ভরশীল সদস্যদের সংখ্যা, শিক্ষা ও পেশা সম্পর্কে কিছু বলুন।

পরিবারের অন্যান্য সদস্যের বিবরণ					
ক্রমিক নং	বয়স	লিঙ্গ (পু/ম)	শিক্ষা	পেশা	সম্পর্ক
১					
২					
৩					
৪					
৫					
৬					

২। পরিবারের বিবরণীঃ

আপনার পরিবারের জমির পরিমাণ, বসতবাড়ী ও অন্যান্য সম্পদের বিবরণ:

জমির ধরন ও পরিমাণ (স্থানীয় একক)		অন্যান্য সম্পদের বিবরণ
নিজ আবাদী	বর্গা দেয়া	বাড়ীর প্রকৃতিঃ
বর্গা নেয়া	বন্ধক	
বন্ধক নেয়া	বাগান	
বসত বাড়ী	মাছের ঘের	
পুকুর	পতিত	

৩। বাৎসরিক আয়ঃ

আপনার বার্ষিক আয়ের বিবরণ দিন

ক্র. নং	আয়ের উৎস	মোট মূল্য	মোট উৎপাদন খরচ	নীট মুনাফা
১	কৃষি খাত: ক) শস্য খাত			
	আমন ধান			
	আউস ধান			
	বোরো ধান			
	গম			
	তেল জাতীয় ফসল			
	ডাল জাতীয় ফসল			
	শাক-সবজি			
	অন্যান্য			
মোট টাকা				

ক্র. নং	আয়ের উৎস	মোট মূল্য	মোট উৎপাদন খরচ	নীট মুনাফা
	খ) গৃহপালিত পশু খাত			
	গ)মৎস খাত			
	ঘ)হাঁস ও মুরগী খাত			
মোট টাকা (কৃষি খাত)				
২)	অকৃষি খাত:			
	কৃষি দিনমজুর			
	চাকুরী			
	ব্যবসা			
	কৃষি দিনমজুর নয়			
	অন্যান্য			
মোট টাকা (অকৃষি খাত)				
সর্বমোট টাকা (কৃষি এবং অকৃষি খাত)				

৪। জমির ধরনঃ

আপনার চাষকৃত জমিগুলো কোন্ ধরনের কতটুকু?

জমির ধরন	পরিমাণ (স্থানীয় একক)	পরিমাণ (হেক্টর)
১। উচু জমি		
২। মাধ্যম উচু জমি		
৩। মধ্যম নিচু জমি		
৪। নীচু জমি		
৫। বেশী নীচু জমিঃ		

৫। শস্য পরিক্রমা:

আপনার চাষকৃত জমিগুলোতে আপনি কি ধারাবাহিকতায় (কোন্টির পর কোন্টি) শস্য চাষাবাদ করেন ?

	আমন মৌসুম	রবি /বোরো মৌসুম	আউশ মৌসুম	জমির পরিমাণ
১ম শস্য				
২য় শস্য				
৩য় শস্য				
৪র্থ শস্য				

৬। চাষাবাদকৃত জমির পরিমাণ এবং ফলন

গতবছর আপনি কি কি ফসল করেছেন, কতটুকু জমিতে চাষাবাদ করেছেন এবং কতটুকু ফলন হয়েছে।

শস্যের নাম	বপন/রোপন থেকে মাড়াই পর্যন্ত সময়	জমির পরিমাণ (স্থানীয় একক)	ফলন (স্থানীয় একক)
১। আমন মৌসুমঃ			
২। রবি মৌসুমঃ			
৩। বোরো মৌসুম:			
৪। আউশ মৌসুম:			
মোট চাষাবাদকৃত জমির পারিমাণ			

৭। জলবায়ু পরিবর্তনে শস্য উৎপাদনে সমস্যাঃ

আপনি যেসব শস্য উৎপাদন করেন, আবহাওয়া পরিবর্তনের ফলে উৎপাদনে কোন সমস্যা সম্মুখীন হচ্ছেন কি?

মৌসুম	শস্য	সমস্যাসমূহ	হ্যাঁ/না
১। আমন মৌসুম			
২। রবি মৌসুম			
৩। বোরো মৌসুম			
৪। আউশ মৌসুম			
৫। খরিফ-১ মৌসুম			

৮। বৃষ্টির পানি নির্ভর শস্য উৎপাদন:

আপনি যেসব শস্য উৎপাদন করেন, তা উৎপাদনের জন্য বৃষ্টির পানি পর্যাপ্ত কি?

মৌসুম	শস্য	হ্যাঁ	না	হ্যাঁ হলে সমস্যার সমাধান কিভাবে করেন
১। আমন মৌসুম				
২। রবি মৌসুম				
৩। বোরো মৌসুম				
৪। আউশ মৌসুম				
৫। খরিফ-১ মৌসুম				

৯। সেচকৃত শস্য:

সেচ দিলে কোন ফসলে কি পরিমাণ এবং কতবার সেচ দেন তার বিবরণ দিন

মৌসুম	সেচকৃত শস্য	সেচ সংখ্যা	জমির পরিমাণ (স্থানীয় একক)	জমির পরিমান (হে.)
১। আমন মৌসুম				
২। রবি মৌসুম				
৩। বোরো মৌসুম				
৪। আউশ মৌসুম				
৫। খরিফ-১ মৌসুম				

১০। সেচ প্রদানে সমস্যা:

আপনার সেচকৃত শস্যে সেচ প্রদান আপনি কোন সমস্যার সম্মুখীন হচ্ছেন কিনা? সমস্যা থাকলে সমস্যা সমূহের বিবরণ দিন

মৌসুম	শস্য	হ্যাঁ	না	সমস্যা সমূহ
১। আমন মৌসুম				
২। রবি মৌসুম				
৩। বোরো মৌসুম				
৪। আউশ মৌসুম				
৫। খরিফ-১ মৌসুম				

১১। সেচ ছাড়া শস্য

আপনি সেচ ছাড়া কি ফসল করেন তার বিবরণ দিন

ক্রমিক নং	সেচ ছাড়া শস্য	মৌসুম	পরিমাণ (স্থানীয় একক)	পরিমাণ (হেক্টর)
১।				
২।				
৩।				
৪।				

১২। আপনার সেচ পানির উৎস

আপনার সেচ পানির উৎস কি

নদী/খালের পানি	পুকুরের পানি	নলকুপের পানি	অন্যান্য

১৩। বিভিন্ন সেচ ব্যবস্থায় জমির পরিমাণ:

গতবছর কোন ব্যবস্থায় কতটুকু জমিতে সেচ দিয়েছেন?

	সেচ ব্যবস্থা				
	গভীর নলকুপ(DTW)	অগভীর নলকুপ (STW)	লো লিফট পাম্প (LLP)	হ্যান্ড টিউবয়েল(HTW)	ট্রাডিশনাল সিস্টেম (TS)
জমির পরিমাণ (স্থানীয় একক)					
জমির পরিমাণ হেক্টর)					

১৪। সেচ ব্যবস্থাপনা মালিকানা

নিচের যে কোনটিতে টিক চিহ্ন দিন:

নিজস্ব সেচ ব্যবস্থা	ভাড়ায় সেচ ব্যবস্থা	উভয়
		নিজস্ব (বিঘা/হেক্টর): ভাড়ায় (বিঘা/হেক্টর):

১৫। সেচ যন্ত্র

নিজস্ব সেচ ব্যবস্থা হলে আপনার কি কি সেচ যন্ত্র আছে ?

১।	২।
৩।	৪।

১৬। সেচ পানির বিতরণ ব্যবস্থা

সেচের পানি যে পদ্ধতিতে জমিতে প্রয়োগ করেন তাতে টিক চিহ্ন দিন:

সেচ পদ্ধতি		সেচ পদ্ধতি	
১। কাঁচা সেচ নালা		২। পাকা সেচ নালা	
৩। অর্ধ পাকা সেচ নালা		৪। ফেরোসিমেন্ট সেচ নালা	
৫।পলিথিন বিছানো সেচ নালা		৬। প্লাস্টিক/পলিথিন হোস পাইপ	
৭। ভুগর্ভস্থ সেচ নালা		৮। অন্যান্য	

১৭।

(ক) পানি সাশ্রয়ী শস্য শস্যবিন্যাস সম্পর্কে ধারণা আছে কি না?

(খ) ভূ- গর্ভস্থ পানিস্তর ক্রমোম্বয়ে নীচে এ সম্পর্কে ধারণা আছে কি না?

১৮। সেচ খরচ

মৌসুম	সেচ খরচ (বিঘা প্রতি)	সেচ খরচ বিষয়ে মন্তব্য			
		খুব বেশী	বেশী	মধ্যম	মোটামুটি
১। আমন					
২। রবি:					
বোরো					
৩। আউশ/					
খরিফ-১					

স্বাক্ষর:

সাক্ষাৎ গ্রহণকারীর নাম:

তারিখ :

গণপ্রজাতন্ত্রী বাংলাদেশ সরকার

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