The impact of the proposed rubber dam facilitated surface water irrigation on adjacent groundwater at Chapai Nawabganj district, Bangladesh

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Abstract

The dry season irrigation primarily depends on groundwater in Bangladesh. The over-abstraction, along with decreasing recharge, is depleting the groundwater resource across the country. Consequently, the government of Bangladesh is planning to switch from groundwater to surface water irrigation. In line with this, Bangladesh Water Development Board has proposed to construct a rubber dam on the Mohananda river at the Chapai Nawabganj district. This work investigated the impact of the proposed reservoir facilitated surface water irrigation on the adjacent groundwater in the study area. A coupled river–groundwater modeling technique was used to predict the long-term groundwater condition. Results showed that the groundwater lowering rate reduced to 50 mm/year inside the irrigation zone compared to 87 mm/year outside the zone. Also, the augmented surface water irrigation raised the groundwater over an area of 141 km² and 242 km² in 2029 relative to the base condition of 2013 and existing irrigation practice if continued, respectively. Besides, the raised groundwater resulted in a higher discharge from the aquifer to the river. The study concludes that increased surface water irrigation successfully lowered the groundwater declination rate, especially in the surface water irrigation zone.

Keywords Groundwater model · Rainfall–runoff model · River model · Coupled river–groundwater modeling · Surface water irrigation

Introduction

Bangladesh is an agricultural and densely populated country that heavily relies on domestic crop production to feed a population of more than 140 million (Streatfield and Karar 2008). Cultivation of high-yield varieties of rice such as Boro during the dry season entirely depends on irrigation water. This water comes from mainly two sources—surface water from rivers and groundwater. In Bangladesh, farmers primarily depend on groundwater for irrigation purposes during the dry period due to low flow in the perennial rivers and lack of storage facility (Krupnik et al. 2017). The

contribution of groundwater to irrigation has increased from 41% in 1982–1983 to 77% in 2006–2007, and surface water has declined accordingly (Dey et al. 2017; Shahid 2008; Shahid and Behrawan 2008). The ratio of groundwater to surface water use is even higher in the northwest region of Bangladesh compared to other parts of the country. Therefore, the over-abstraction of groundwater and declination of recharge due to urbanization is increasingly lowering the groundwater heads in the region, rendering severe problems for both domestic water supply and irrigation.

To improve the groundwater condition across the country, the government of Bangladesh has decided to increase surface water irrigation because it not only reduces the over-extraction of groundwater but also contributes to groundwater recharge. Besides, it is more environmental-friendly since if the river water is not stored and utilized, it gets wasted. Consequently, the government has planned to construct barrages and dams on the potential rivers across the country to facilitate surface water irrigation along the bank by storing water during the dry season. On this ground, Bangladesh Water Development Board (BWDB) has planned to

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construct a rubber dam on the Mohananda river located in Chapai Nawabganj—a northwest district of Bangladesh (IWM 2015).

Chapai Nawabganj falls under the driest part of the country, where mean monthly average rainfall varies 12–20 mm only from November to April. However, the annual rainfall varies from a minimum of 1250 mm to a maximum of 2000 mm (Akram et al. 2012). Shahid and Hazarika (2010) analyzed groundwater hydrographs and rainfall time series for the study area and reported that groundwater extraction for irrigation in the dry season and recurrent droughts are the leading causes of groundwater declination in the region. Besides, a thick clay layer lying above the aquifer also restricts the percolation of rainwater to the aquifer (IWM 2006). IWM (2015) reported that the stored water by the dam from November to May could increase surface water irrigation coverage from 4200 to 7000 hectares (ha). However, the study did not analyze the effect of the proposed rubber dam facilitated surface water irrigation on the adjacent groundwater.

This work uses a groundwater model coupled with rainfall–runoff and river models to simulate the integrated surface water and groundwater flow system in the study area. The model predicts the groundwater condition in the study area with and without the proposed rubber dam facilitated surface water irrigation schemes incorporating the long-term effect of climate change. Besides, the river–aquifer interaction is analyzed to determine the exchange of water between aquifer and river. This study can help the authorities involved in groundwater management to evaluate the effect of the proposed storage reservoir and planned surface water irrigation on the overall groundwater condition in the study area. Besides, the concerned authorities can adopt and apply the presented methodology of this work to make informed decisions while planning future surface water irrigation schemes across the country.

Methodology

Study area and data collection

The study area lies in the Barind tract located in the northwest region of Bangladesh, as shown in Fig. 1. It covers an area of 462 km² extending over Nawabganj Sadar, Shibganj, Nachole, Gomastapur Upazilas of Nawabganj District, and Godagari Upazila of Rajshahi district. The east and north-east of the study area are called high Barind areas, while the west and south are called the low Barind areas. The Mohananda, a trans-boundary river, is the only perennial river in the study area. It enters Bangladesh at Bholahat Upazila of Chapai Nawabganj district and then flows toward the south and meets with the Ganges river near Sultanganj of

Godagari Upazila. The Mohananda river has two tributaries called Punarbhaba and Pagla, which become dry during the summer (IWM 2015). The area has a low groundwater potential compared to other parts of the northwest region. An aquifer of 15–30 m thick, sandwiched between thick clay layer, is the primary source of groundwater within 80 m depth from the ground surface (IWM 2012). Hydrological and hydrogeological data needed for the study are collected from the Bangladesh Water Development Board (BWDB). Supplementary data are also collected from the Institute of Water Modelling (IWM), Barind Multipurpose Development Authority (BMDA), and Soil Research and Development Institute (SRDI). Table 1 lists all the data collected during this study with the corresponding sources and model application.

The dry season irrigation along the banks of the Mohananda river is provided using low lift pumps (LLP) to grow Boro and other related crops from November to May. Figure 2 shows the locations of LLP schemes and their coverage areas. A total of 43 LLP schemes exist along the bank of the Mohananda river that irrigates approximately 4200 ha of land (IWM 2015). Thirty-six of the total LLP schemes are located upstream of the proposed rubber dam site that irrigates approximately 3245 ha area. The remaining seven LLP schemes are located more than eight kilometers downstream of the proposed rubber dam site and cover nearly 956 ha of land. Besides, some LLPs are installed during the irrigation season and have no permanent installation location. They disappear at the end of the irrigation season. IWM (2015) reported that the proposed rubber dam would increase surface irrigation coverage from 4200 to 7000 ha.

Mathematical modeling

Conceptual model

The collected topography data suggests that most of the area is flat land except for the high Barind area, where land elevation becomes relatively higher. The land surface slopes from northeast to southwest, and ground elevation varies from 37 mPWD (meter above Public Works Department datum) in the high Barind areas to 14 mPWD in the low Barind areas inside the model area. The soils of the area are primarily floodplain and terrace soils. The terrace soil is Modhupur clay, where the Ganges alluvium forms the floodplain soil. The groundwater of the area follows the topography and flows from northeast to southwest from the high to the low Barind areas. The aquifer beneath the study area shows two distinct aquifer systems—the Mohananda floodplain aquifer system and the Barind terrace aquifer system (IWM 2006). The Mohananda floodplain aquifer system contains a moderate groundwater gradient, where the Barind terrace aquifer

Fig. 1 Study area map showing the model boundary, boundary and calibration wells for groundwater model, discharge and water level measuring stations for the river model and the rainfall stations. The Mohananda river is flowing through the central region of the model domain from north to south. The Ganges river is located to the south of the study area and flowing from west to east. The Mohananda and the Ganges rivers meet at Godagari Upazila, located to the south of the map. It also shows the location of the proposed rubber dam to be used for creating a storage reservoir during the dry season

system possesses a steep groundwater gradient. Mohananda, the only perennial river inside the model area, also flows from north to south.

The aquifer beneath the study area is called the shallow aquifer, which 15–30 m thick within the 80-m depth. Clay layers bound it at the top and bottom. Besides, an intermittent clay layer divides the aquifer into two distinct parts—upper and lower shallow aquifers. Therefore, five hydrogeological layers exist within the modeled depth based on the available borelog data: top clay, upper shallow aquifer, middle clay, lower shallow aquifer, and bottom clay. The upper aquifer is composed of very fine-to-fine sand with lenses of fine to medium-grained sand and occasionally with clay, silt, and trace mica lenses (IWM 2006). Its average thickness ranges from five to eight meters inside the modeled area. The

lower aquifer is the principal source of groundwater in the study area. It has an average thickness range from 6 to 16 m and is composed of medium to coarse-grained sand with occasional fine sediment lenses. The specific yield varies from 0.01 to 0.27, the hydraulic conductivity varies from 12 to 67.44 m/day, and the transmissivity varies from 300 to 1000 m²/day in the study area.

The mean annual rainfall varies between 1250 and 2000 mm in the study area (Akram et al. 2012). The potential recharge of the area varies from 400 to 700 mm (Karim 1984). The study area's groundwater recharge sources are mainly rainfall, floodwater, and return flow of irrigated water. Generally, recharge from rainfall starts in May and continues to the end of October. However, the thick clay layer at the top in some parts of the study area restricts

Table 1 List of collected data and their period, interval, and sources with application in model construction under the study

Data type	Duration	Source	Interval	Model application
Rainfall	1980–2015	BWDB and http://globalweather.tamu.edu/	Daily	RR and GW
Surface water level	1985–2015	BWDB	3-h	SW
Discharge	1985–2015	BWDB		SW
River cross section	25 nos	IWM		SW
LLP schemes	43 nos	IWM		SW
Groundwater level	2000–2015	BWDB	Weekly	GW
Land use		SRDI		GW
Soil type		SRDI		GW
Borelog	139 nos	BMDA		GW
Aquifer test	8 nos	IWM, BWDB, and BMDA		GW
Topography		IWM	100-m resolution	RR and GW
Evaporation	1980–2015	BWDB	Daily	RR and GW

RR Rainfall–runoff, GW groundwater, SW surface water

Fig. 2 The permanent LLP structure locations along the Mohananda river. The polygon inside model boundary surrounds the LLP irrigation areas that are irrigated by the LLPs located upstream of the proposed rubber dam. A total of 4200 ha land is irrigated by LLPs where 3245 ha of land irrigated by the LLPs located upstream of the proposed rubber dam. The remaining 955 ha of land irrigated by LLPs located downstream of the proposed rubber dam

groundwater recharge. The maximum depth to groundwater table occurs at the end of May, ranging from 5 to 29 m in the dry season, mainly due to irrigation abstraction and natural drainage. In comparison, the minimum depth to

the groundwater table ranges from 0.33 to 15 m below the ground surface in monsoon. The average fluctuation of the groundwater level varies from 5 to 10 m. The discharge in the Mohananda river varies from 4.85 m³/s during the dry season to 2480 m³/s during monsoon.

Numerical model

Three models were used in this study: rainfall–runoff, river, and groundwater models. Figure 3 shows a schematic diagram of the adopted methodology of the study. Of the three models, the rainfall–runoff model was used to generate runoff from rainfall data. The generated flow from the rainfall–runoff model was used to define the discharge boundary to the upstream of the modeled Mohananda river. The river model simulated 1D flow in the Mohananda river. In contrast, the groundwater model simulated 3D groundwater flow beneath the study area. The river model was coupled with the groundwater model to simulate both surface water and groundwater flow in an integrated way. In this study, MIKE NAM, MIKE 11, and MIKE SHE modeling tools were used for rainfall–runoff, river, and groundwater modeling, respectively (DHI 2017a, b).

The rainfall–runoff model used in this study was modified from the existing northwest regional rainfall–runoff model developed and maintained by IWM. The model was updated up to 2015 and modified to suit the study requirements. Figure 4 shows the two catchments used in the rainfall–runoff model. The upstream boundary of the Mohananda river was generated from the flow from catchment 1, which is a sub-basin of the greater Ganges river basin. The contributed area of catchment-1 upstream of the river is 10986 km². It was delineated from satellite-based topography data. Rainfall data obtained from the satellite were used to generate flow for it. In contrast, catchment-2 contributes the river along

Fig. 3 Schematic diagram of the approach and methodology applied in the study. This work uses a river–groundwater integrated model developed using MIKE 11 and MIKE SHE to analyze the impact of storage reservoir facilitated surface water irrigation on the adjacent aquifer in the model area

its length inside the model domain and covers an area of 830 km². The flow generated from catchment-2 was obtained from the measured rainfall data collected from BWDB.

Similar to the rainfall–runoff model, the river model was modified from the existing northwest regional river model developed by IWM. The upstream boundary of the Mohananda river was defined at the Bangladesh-India border, and the downstream boundary was defined near the confluence of the Mohananda and the Ganges rivers near Godagari Upazila of Rajshahi district. The upstream flow boundary was generated from the rainfall–runoff model, while the downstream water level boundary was generated from the northwest regional river model. Figure 5 shows a schematic diagram of the river model setup. The river model was calibrated against both water level and discharge data obtained from Chapai Nawabganj station (Fig. 6). The calibration period was 2008–2015.

The groundwater model domain was selected covering the present and planned irrigation areas by LLPs from the Mohananda river. The model area is 462 km² and covers

Fig. 4 Catchment delineation for rainfall–runoff model setup. The flow generated from catchment-1 (10,986 km²) is used as an upstream flow boundary condition for the modeled Mohananda river. The runoff generated from catchment-2 (830 km²) is distributed along the segment of the Mohananda river in the river model

Nawabganj Sadar, Shibganj, Godagari, and Gomastapur Upazila partially. It is bounded by Indian territory to the west and north, to the south by the Ganges river, and to the east by Tanore Upazila of Rajshahi District. Figure 7 shows the groundwater model domain in the MIKE SHE. The study area was discretized into 46,532 cells having 100 m square grids in its horizontal plane. Five computational layers vertically discretized the groundwater model. Geological layers having similar properties and small thicknesses were merged to define the computational layers. Special attention was given to the unsaturated zone, where the vertical resolution was assigned as fine as 0.05, 0.1 and 0.5 m toward the increasing depths. Besides, a 100 m Digital Elevation Model (DEM) was developed to define the topography of the study area in the model.

The temporal rainfall data from six stations were distributed in the model domain using the Thiessen polygon method. Besides, evapotranspiration time-series data of Chapai Nawabganj station was given as input to the model. The spatial distribution of cropping patterns and soil type

Fig. 5 Schematized river system of the 1D river flow model in MIKE 11. The upstream boundary located to the north of the model domain is generated from the rainfall–runoff model. The downstream boundary located to the south of the model domain is generated from the northwest regional river model developed by IWM

were also applied in the model. The existing crop database of IWM was used to define the leaf area index, root depth, and other properties of each crop used in the model.

Potential heads of the monitoring wells in and around the study area were used to generate initial heads for the groundwater model. All the five modeled layers are leaky and thus assumed as interconnected. Therefore, the initial condition was applied in all the computational layers. There are a total of seven monitoring wells located along the boundary of the model. The time-series head data at these boundary wells were interpolated along the model boundary to generate groundwater level time-series boundary for the groundwater model.

The groundwater pumping data were not available for the modeled period. Consequently, the groundwater abstraction for the study area was estimated for the 2001–2015 period

to assign in the groundwater model. In this work, the total abstractions by the DTWs and STWs for different cropping seasons (Rabi, Kharif-I and Kharif-II) were determined from the seasonal irrigation water requirement, which was estimated from the cropping pattern and crop coverage data.

The river–groundwater integrated model was calibrated for a period of three years, from 2011 to 2013. The calibration was carried out against groundwater levels. The overland leakage coefficient, hydraulic conductivity, storage coefficient, and river leakage coefficient were the primary calibration parameters for the coupled model. Two observation wells were used to evaluate the calibration processes. Figure 1 shows the locations of the monitoring wells used in the calibration process, and Fig. 8 shows the calibration plots.

Long run and scenario development

The model was simulated up to 2030 to predict groundwater condition of May 27, 2029, since the historical groundwater data showed that groundwater reaches the lowest level approximately at the end of May each year. The climate change factor was applied to rainfall data to introduce its effect in the model during the long run. International Centre for Integrated Mountain Development (ICIMOD) has developed a manual to predict temperature and precipitation data for 2021–2050 based on observed data from 1960 to 1990 (Lutz and Immerzeel 2013). The manual uses four climatic combinations, such as dry-cold, dry-warm, wet-cold, and wet-warm for the two representative concentration pathways (RCP)-RCP4.5 and RCP 8.5. RCP is a greenhouse gas concentration trajectory adopted by the Intergovernmental Panel on Climate Change (IPCC). RCP8.5 is considered the worst-case climate change scenario. In this study, the dry-warm combination was selected with the RCP8.5 climate change scenario to predict future groundwater levels in the study area, assuming that decreasing recharge would stress the aquifer to the extreme. Table 2 provides delta factor dp and dt to project changes in precipitation and temperature data, respectively, for each combination. The precipitation data of the design year were multiplied by the delta factor to generate precipitation data for 2014. Then, the obtained precipitation data for 2014 were multiplied by the dp factor to obtain data for 2015. In this way, rainfall time-series data were predicted up to 2030.

Irrigation projects are generally planned for a design year of average hydrological conditions representing a dry year with a 2-year return period (IWM 2006). This work added more safety factor while predicting the design year. Therefore, it concentrated on the rainfall event having a 5-year return period to define the design year. FAP25 (1992) study recommends to fit the rainfall data to a 3-parameter log-normal distribution to find the design

Fig. 6 The river model is calibrated against both water level and discharge data obtained from Chapai Nawabganj station. The figure is showing **a** the water level calibration and **b** discharge calibration plots

year. This work used statistical software HYMOS 4.0 for the analysis. The statistical analysis took observed annual rainfall at six stations in and around the study area for 35 years (1980–2015) as input. Table 3 presents the results of the analysis. According to the result, the stations failed to provide a unique design year attributed to the randomness of the rainfall events. Besides, the result shows that year 2001 appeared twice. However, 2001 is outside of the model simulation period. The table shows that two years appeared inside the simulation period: 2011 and 2013. Since Shibganj Upazila is located near the surface water irrigation zone than Rohanpur Upazila, this study considered 2013 as the design year instead of 2011. As such, remaining time-series data were replicated from the design year 2013.

In this work, three scenarios, as listed in Table 4, were formulated to simulate the groundwater model—scenario-0: base condition, scenario-1: rainfall data were modified according to RCP8.5 climate change scenario keeping the existing river water irrigation coverage by LLP schemes, and scenario-2: in addition to climate change effect, the proposed

rubber dam was introduced in the model to store the river water, and the projected area was irrigated upstream of the dam by that stored water.

Application of the mathematical model

The river–groundwater integrated model was simulated from 2010 to 2014 for scenario-0. This model generated the groundwater condition for the base year 2013. The base condition was used to evaluate the effect of scenario-1 and scenario-2. In contrast, the coupled models for scenario-1 and scenario-2 were simulated from 2013 to 2030 to produce groundwater levels for 2029. Here, the scenario-1 simulation did not include the proposed rubber dam and kept the existing surface irrigation coverage. However, the effect of lowering rainfall due to climate change was assigned. Then, the model was simulated for scenario-2 to predict groundwater conditions in the study area due to the proposed rubber dam. Scenario-2 increased the river water irrigation coverage and maintained a higher stage in the Mohananda river than the existing condition. The results obtained for scenario-0,

Fig. 7 a The groundwater model domain in MIKE SHE with 100 m grid, b vertical discretization of the model domain along cross section 1–1', and c vertical discretization of the model domain along cross section 2–2'

scenario-1, and scenario-2 were compared to evaluate the future groundwater condition, impact of surface water irrigation on groundwater, and the river–aquifer interaction.

Results and discussion

Groundwater condition in the base year

The calibrated groundwater model was used to generate groundwater spatial distribution for 2013. The groundwater condition of 2013 was used as the base condition for the study. Figure 9 shows a contour map of groundwater levels for the base condition. The groundwater levels remained within -2 to 16 mPWD in the study area on May 27, 2013. The highest groundwater level is observed to the west of the study area where Shibganj Upazila is located. In contrast, the lowest groundwater level is observed in the

north of the study area where Gomastapur and Nachole Upazilas are located. The groundwater level in the lower central and south regions of the study area where Nawabganj Sadar Upazila is located is found between 6 and 12 mPWD.

Predicted groundwater condition for scenario-1

The groundwater model was simulated until 2030, incorporating the climate change effect on rainfall data for scenario-1. Cropping pattern in the surface water irrigation area was also modified, assuming that cultivation would switch to Boro in the future. Besides, the water production for the Chapai Nawabganj municipality was modified as well based on the projected population growth. Figure 10 shows the groundwater level contour maps for May 27, 2029, which

Fig. 8 The river–groundwater integrated model was calibrated against observed groundwater level data obtained for monitoring wells **a** GT7066013 and **b** GT7066016. The model was calibrated for 2011–2013 period

Table 2 Delta factor to project precipitation and temperature from 1961–1990 to 2021–2050 (adopted from Immerzeel and Lutz 2012)

Description	RCP	dP (%)	dT (K)	Selected model
DRY, COLD	RCP4.5	−1.8	1.4	GISS-E2-R-r4i1p1_rcp45
DRY, WARM	RCP4.5	−1.8	2.3	IPSL-CM5A-LR-r4i1p1_rcp45
WET, COLD	RCP4.5	8.9	1.4	CCSM4-r5i1p1_rcp45
WET, WARM	RCP4.5	8.9	2.3	CanESM2-r4i1p1_rcp45
DRY, COLD	RCP8.5	−1.1	1.7	GFDL-ESM2G-r1i1p1_rcp85
DRY, WARM	RCP8.5	−1.1	2.7	IPSL-CM5A-LR-r4i1p1_rcp85
WET, COLD	RCP8.5	12.1	1.7	CSIRO-Mk3-6-0-r3i1p1_rcp85
WET, WARM	RCP8.5	12.1	2.7	CanESM2-r4i1p1_rcp85

suggest a fall of groundwater about two meters from 2013 across the study area.

Table 3 Result of the statistical analysis to determine the design year

Station	5-year return period rainfall (mm)	Matching year
Bholahat	1680.42	2004
Godagari	1400.16	2005
Nachole	1526.76	2001
Nawabganj	1469.71	2001
Rohanpur	1446.49	2011
Shibganj	1719.26	2013

Predicted groundwater condition for scenario-2

The groundwater model was also simulated up to 2030 to predict the groundwater condition for scenario-2. The scenario used both climate change effect on rainfall and the rubber dam on the Mohananda river. The stored water was pumped from the river and used for irrigation at the specified area in the groundwater model. Figure 11 shows the groundwater level contour map for scenario-2. The lowest groundwater level reaches −4 mPWD to the north of the study area, and the highest groundwater level reaches

Table 4 Groundwater model simulation scenario

Scenario	Description of option
Scenario-0	No rubber dam, no climate change effect, and design year is 2013
Scenario-1	Without rubber dam, with climate change effect of RCP8.5 (dry-warm), design year is 2013
Scenario-2	With rubber dam and climate change effect of RCP 8.5 (dry-warm), abstraction from the river for irrigation, design year is 2013

Fig. 9 GWL contour map of May 27, 2013, for scenario-0 showing the lowest GWL (-2 mPWD) to the north of the model area where Nachole and Gomastapur Upazilas are located. The highest GWL (16 mPWD) is seen to the west of the model domain

16 mPWD in the central region on May 27, 2029. Notice that the groundwater level to the north of the study where Nachole and Gomastapur Upazilas are located remains the same for both scenario-1 and scenario-2. Therefore, despite surface water irrigation, the overall groundwater level decreases in the study area.

Fig. 10 GWL contour map of May 27, 2029, for scenario-1 showing the lowest GWL of -4 mPWD to the north of the model area where Nachole and Gomastapur Upazilas are located. The highest GWL (14 mPWD) is seen to the west of the model domain. The highest GWL is observed inside the surface water irrigation zone which is 12 mPWD

Impact of surface water irrigation on groundwater

The groundwater abstraction for irrigation inside the surface water irrigation area was reduced to zero for scenario-2. Figure 12a shows the impact of this migration in well GT7066013, which is located inside the surface water irrigation area. The lowest groundwater level reaches 15 mPWD in 2029 for scenario-2 compared to 7.8

Fig. 11 GWL contour map on May 27, 2029, for scenario-2 showing the lowest GWL of -4 mPWD to the north of the model area where Nachole and Gomastapur Upazilas are located. The highest GWL (16 mPWD) is seen at the center of the model domain, which lies inside the surface water irrigation zone

mPWD for scenario-1. The groundwater level decreases at a rate of 96 mm/year when scenario-1 is simulated, where the rate reduces to 50 mm/year for scenario-2 at the well. However, for GT706616, since the well is located outside of the surface water irrigation area, the impact is less, which is shown in Fig. 12b. The groundwater level decreases at a rate of 92 mm/year when scenario-1 is applied, where the rate slightly reduces to 87 mm/year for scenario-2 at the well. The adopted climate change scenario gradually decreases the overall recharge in the study area. As a result, the difference in groundwater level with the base year also decreases with time.

Groundwater level increases for an area of 141 km^2 for scenario-2 on May 27, 2029, relative to the base condition (Fig. 13a). In contrast, it increases for an area of 242 km^2 for scenario-2 relative to scenario-1 (Fig. 13b). Figure 13c shows the groundwater level difference between

scenario-1 and scenario-2 inside the surface water irrigation area on May 27, 2029. In 2029, the groundwater level rises at most of the area inside the surface water irrigation zone for scenario-2 compared to scenario-1. The highest rise of six meters is observed to the east of the surface water irrigation area, as shown in Fig. 13c.

River-aquifer interaction

The interaction between the Mohananda river and the adjacent aquifer was analyzed for both scenario-1 and scenario-2 for 2029, as shown in Fig. 14. The analysis covers the segment of the river from the international border to the confluence of the Ganges and the Mohananda river at Godagari. During 2029, the aquifer discharges to the river from the end of November until mid-January, where river discharges to the aquifer from mid-January to mid-November for scenario-1. Conversely, scenario-2 shows that the aquifer discharges to the river from mid-September to the end of January and the river discharges to the aquifer from February to mid-September. Results indicate that the aquifer discharges more to the river for scenario-2, where the river discharges more to the aquifer for scenario-1.

The study finds that the flow from the river to the adjacent aquifer increases with time for both scenarios since groundwater gradually decreases due to a gradual decrease in recharge by the climate change effect. The river discharges $6.75 \text{ million meter}^3$ of water to the aquifer during 2029 when scenario-1 is simulated. In contrast, the river discharges $4.36 \text{ million meter}^3$ of water to the aquifer during 2029 when scenario-2 is simulated. The comparison of flow also indicates that the loss of water by the river decreases by about 35% when scenario-2 is applied compared to scenario-1 during the final year of the model simulation. On the other hand, flow from the aquifer to the river increased by 4.7 times, where it is $0.13 \text{ million meter}^3$ for scenario-1 and $0.74 \text{ million meter}^3$ for scenario-2. Due to surface water irrigation, the groundwater level increases adjacent to the Mohananda river, especially in the surface water irrigation area. Consequently, the aquifer discharges more water to the river for scenario-2 compared to scenario-1.

Conclusion

Bangladesh is an agricultural country where irrigation is a vital factor for crop cultivation during the dry season. The high-yield varieties of paddy such as Boro require much water for its growth. It is common practice that the demand for water for dry season irrigation meets up with groundwater sources. This over-exploitation is leading to groundwater level lowering across the country. The groundwater declination phenomenon is even worse in the Barind area.

Fig. 12 Long-term simulation of well **a** GT7066013 and **b** GT7066016. The groundwater level decreasing rate is 50 mm/year for GT7066013 for scenario-2. In contrast, the groundwater level

decreasing rate is 87 mm/year for scenario-2 for GT7066016. Note that GT7066013 is located inside the surface water irrigation zone, while GT7066016 is located outside

As a result, the country's policymakers are leaning toward surface water irrigation. Since the flow in the rivers dries out in the dry season, it is required to obstruct the flow and store the available river water to be used for irrigation purposes. If the natural flow of streams is forced to restrict, we need to ensure that the outcomes yield much positivity. In this study, the construction of the proposed rubber dam on the Mohananda river and the subsequent irrigation from the ponded water was analyzed. The primary purpose of the study was to investigate the impact of surface water irrigation from the river reservoir on the overall groundwater of the area. This work used a coupled river-groundwater modeling technique, which was simulated for three scenarios: (i) scenario-0: existing condition, (ii) scenario-1: impact

of climate change and existing irrigation practice, and (iii) scenario-2: impact of climate change and augmented surface water irrigation by ponded water in the river. Scenario-0 was simulated from 2010 to 2014, while both scenario-1 and scenario-2 were simulated from 2013 to 2030. The predicted groundwater level on May 27, 2029, for scenario-2 in the study area was compared with the groundwater condition of scenario-0 on May 27, 2013, and scenario-1 on May 27, 2029.

The study finds that surface water irrigation successfully lowers the groundwater declination rate in the surface water irrigation zone. The groundwater level decreasing rate is 96 mm/year for scenario-1 inside the area, which reduces to 50 mm/year for scenario-2. In

Fig. 13 **a** The area (approx. 141 km²) where groundwater level on May 27, 2029 for scenario-2 is higher than scenario-0, **b** the area (approx. 242 km²) where the groundwater level is higher for scenario-2 than scenario-1 on May 27, 2029, and **c** the difference of

groundwater level between scenario-1 and scenario-2 in the surface water irrigation zone on May 27, 2029. The negative sign indicates that the groundwater level for scenario-2 is higher than scenario-1 and vice versa

Fig. 14 Comparison of river–aquifer interaction between scenario-1 and scenario-2 in 2029. Negative exchange volume indicates a flow from the river to the aquifer, while positive exchange volume indicates a flow from the aquifer to the river. Results indicate that aquifer discharges more to the river in scenario-2, where river discharges more to the aquifer in scenario-1

contrast, the groundwater level decreasing rate is 92 mm/year for scenario-1, where the rate reduces to 87 mm/year in scenario-2 outside of the surface water irrigation zone. Besides, the overall flow from the river to the adjacent aquifer increases with time for both scenarios. It is noticeable that the flow from the river to the aquifer in scenario-1 is higher than scenario-2. Due to surface water irrigation, the groundwater level increases adjacent to the Mohananda river, especially in the surface water irrigation area. Thus, the flow from the river to the aquifer decreases, where the flow from the aquifer to the river increases for scenario-2. Also, the groundwater level increases for an area of 141 km² in 2029 due to surface water irrigation for scenario-2 relative to base condition. In addition, the groundwater level rises for an area of 242 km² in 2029 for scenario-2 relative to scenario-1.

In the rainfall–runoff model, the upstream catchment of the Mohananda river was delineated from satellite-based topography data. Besides, the assigned rainfall data to generate flow in this upstream catchment were also collected from satellite-based precipitation data. The borelog data used to define the computational layer for the groundwater model have a depth up to 80 m only below the ground surface. In addition, the borelog data are not homogeneously distributed over the model area. Considering these limitations, higher-resolution topography data, ground-measured precipitation data, and distributed and deeper borelog data can help to represent the natural system more precisely in the model and thereby leading to a more accurate and comprehensive prediction of the groundwater condition for sustainable management of the resource.

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Compliance with ethical standards

Conflict of interest There is no potential conflict of interest reported by the authors.

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