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Behaviour of Groundwater Table with Rainfall in North-West Region of Bangladesh

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ABSTRACT

Groundwater is the major source of water to meet up the vast domestic and agricultural demand in Bangladesh. Additionally, reduction in reliable surface water resources resulting the increased reliance on groundwater day by day. Therefore, monitoring the groundwater fluctuation over time is crucial to ensure the sustainable use of groundwater resources in future. The present study analyzed historical groundwater data to know the behaviour of groundwater at four locations of two districts Pabna and Rangpur in the North-Eastern part of the country. Historical groundwater level data and monthly rainfall data from 1989 to 2017 were collected from Bangladesh Water Development Board and Bangladesh Meteorological Department, respectively. The annual maximum groundwater table depth (MaxGWT) and minimum groundwater table depth (MinGWT) and its trend was analyzed, and positive and negative recharge years were identified from these values. We found the maximum declining rate at 6.6 cm annually and the maximum 205 cm total depletion in the study area. The number of years of negative recharge is more than that of positive recharge for 32 years. As a result, a declining trend in groundwater table was found at three locations of the study area. The maximum groundwater table remains below suction limit at Ishwardi, causes no shallow tubewell (STW) works during that period. A declining trend in annual rainfall is observed in Pabna district. A linear relationship between rainfall and recharge was found at two locations of the study area.

Key words: Groundwater recharge, deficit recharge, recharge depth, rainfall pattern

INTRODUCTION

Groundwater supplies eighty percent of agricultural water demand in Bangladesh, specially to cultivate the dry season crops (Boro rice and others). Surface water is very scarce during dry season in most of the agro-ecological zones, except in the Southern parts of the country. A huge withdrawal of groundwater during dry season causes decline of groundwater table. These decline of groundwater (strong declining trends, 0.5 – 1.0 m/year in the central part of the country; moderately declining trend, 0.1 – 0.5 m/year in Western, North-Western, and North-Eastern areas during dry season) is a threat to water resources if it is not replenished from annual seasonal rainfall. Groundwater depletion can be defined as long-term water level lowering caused by sustained groundwater withdrawing (USGS, 2003). Groundwater depletion can occur when groundwater withdraw exceeds groundwater recharge for a long time in aquifer (Gleeson *et al.*, 2010). According to the Bangladesh Water Development Board (BWDB), the groundwater existed beneath 2 to 14 meters of sediment during the pre-monsoon period. While in the dry season, it was found between 4 and 12 meters in the North-Eastern part of Bangladesh (Kutub, 2015). The larger values mostly represent the depletion in urban areas. In the South-Eastern part, groundwater level remained between 2 to 8 meters during the dry period, whereas this level was ranged in between 6 and 12 in urbanized areas. Previous study on groundwater resource using Visual MODFLOW modeling showed that groundwater recharge occurs due to percolation of rainfall and this recharge rate is lower in urban areas compared to village areas. Historical (1985–2016) trends of North-West hydrological region of Bangladesh revealed that the aquifers were not completely

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replenished in the wet season and mining of groundwater tables were taking place (Mojid *et al.*, 2019). Water level fluctuates seasonally due to unequal recharge and discharge. In addition to rainfall, hydraulic connection between river and aquifer aids in groundwater recharge through influent flow. Nevertheless, groundwater shortage (1000 million liter/year) especially in the vicinity of the Padma River during dry season indicates the excessive use of groundwater. The total groundwater withdrawal in 2004 (15000 million liters) is less than the total input to aquifer, reveals a sufficient potentiality for groundwater declination with increasing demand (Haque *et al.,* 2012). However, no comprehensive studies so far have been conducted on the physical status of groundwater level fluctuation during wet and dry period over the NW region of Bangladesh. Therefore, the objectives of the present study were set to: (i) determine groundwater declination trend; (ii) investigate withdrawal and recharge pattern; and (iii) explore the relationship between rainfall and recharge.

METHODOLOGY

Study location

Four locations were selected to conduct this study in two districts (Figure 1): Ishwardi (24.13° N, 89.06° E) and Santhia (24.06° N, 89.55° E) upazila in Pabna district as well as Mithapukur (25.54° N, 89.27° E) and Pirganj upazila (25.50° N, 89.22° E) in Rangpur district. In Rangpur region, the mean annual temperature is 24.9 ºC. Rangpur region has the warmer period from April to May and colder period from December to January. Average annual rainfall of Rangpur is 2,200 mm and 80% of which occurs during the monsoon (June to October) period. In Pabna region, the average high and low temperatures are 31.2 °C and 20.8 °C, respectively, having average annual rainfall 1,603 mm (Hossain *et al.,* 2021b). The topography in both the locations is medium highland to highland. Soils of top layers is dominated by silt loam texture, the soils are moderately acidic (pH of 4.6–6.5), and organic carbon content is generally 0.94% (Hossain *et al.,* 2021a).

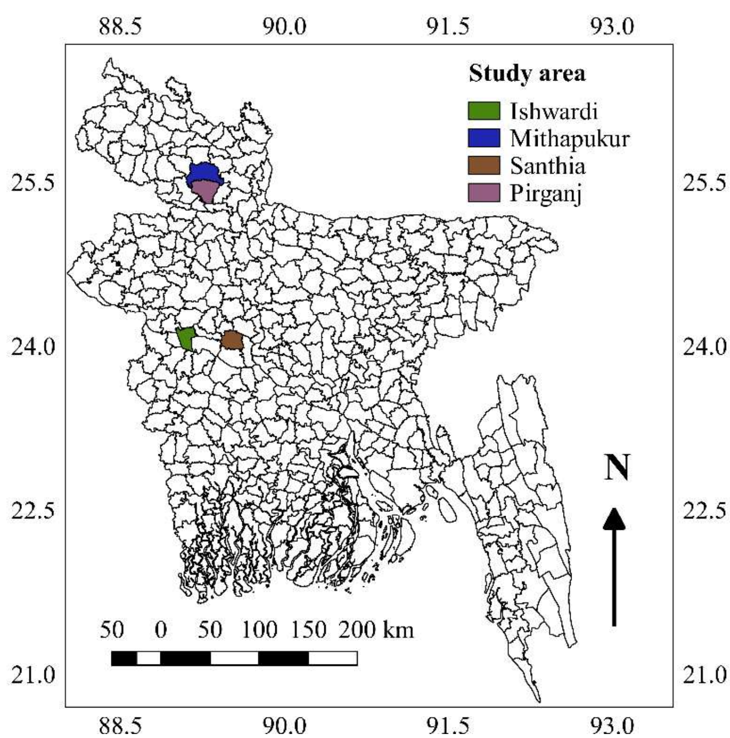


Fig. 1. Study locations.

The fertility of these regions soils ranges between low to medium and soils have good water holding capacity. Rice (Boro, T. Aman, and Aus) is the major crop in these regions. However, farmers also grow other crops like potato, wheat, vegetables etc. covering huge cultivable lands (Zaman *et al.*, 2017).

Data collection

Historical daily data of groundwater table (GWT) from 1987 to 2017 of four observation wells of four upazilas were collected from Bangladesh Water Development Board (BWDB). The observation wells are GT8576013 in Pirganj and GT8558008 for Mithapukur of Rangpur district, GT7639017 for Ishwardi and GT7672029 for Santhia of Pabna district. Besides, historical rainfall data of Ishwardi and Rangpur weather stations were collected from Bangladesh Meteorological Department (BMD).

Groundwater table analysis

The annual maximum (MaxGWT) and annual minimum (MinGWT) groundwater table of each year were determined from the daily data. The annual linear trend of MaxGWT and MinGWT were determined from the data. The groundwater table were compared to the reference value of shallow tubewell suction limit (8.0 m below ground surface). The average groundwater withdrawal and recharge was calculated from the maximum and minimum groundwater table data. Groundwater withdrawal is the difference between MinGWT of the (n-1) year and MaxGWT of the (n) year. Similarly, groundwater recharge was the difference of MaxGWT and MinGWT of the (n) year. A relationship exists between groundwater withdrawal and annual recharge with the annual rainfall. If the amount of withdrawal of groundwater is greater than the amount of recharge, deficit in groundwater storage (aquifer) occurs and it is called the year of negative recharge. 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 for more years through extended period, a declining trend both in MXGWT and MNGWT is shown after couple of years. Similarly, if the withdrawal amount is less than the recharge volume then the year is called positive recharge. It is mentionable that MXGWT and MNGWT occurs in April-May and September-October period, respectively, in Bangladesh. Groundwater depletion of the study locations were calculated from MinGWT of the base year 1989 to 2017. The difference between MinGWT for the “n” years is termed as groundwater depletion and the annual depletion rate was calculated from dividing the total depletion by “n.”

Groundwater recharge with rainfall

A relationship was derived from the annual rainfall to MinGWT and recharge depth. A linear trend line of recharge depth and rainfall was developed from the historical data of each station.

RESULTS AND DISCUSSION

Trend of ground water table

Figure 2 presents minimum and maximum groundwater table trend which was analyzed. The figure shows that minimum groundwater table had the declining trend in all the study locations. The maximum declining rate of MinGWT was found 0.073 m year^{-1} at Ishwardi, Pabna whereas, the lowest rate was found in Pirganj, Rangpur (0.0092 m year^{-1}). Rangpur showed the lowest declining rate than Pabna since comparatively higher recharge was occurred in Rangpur areas. The higher rainfall, higher surface water bodies, less crop diversification led to less water declination in Rangpur areas. The MaxGWT trend revealed that almost every location there was a declining trend in groundwater table except Santhia, Pabna. The maximum declination of MaxGWT was found in Ishwardi and the minimum rate was in Mithapukur, Rangpur. Santhia showed the positive trend of groundwater table declination.

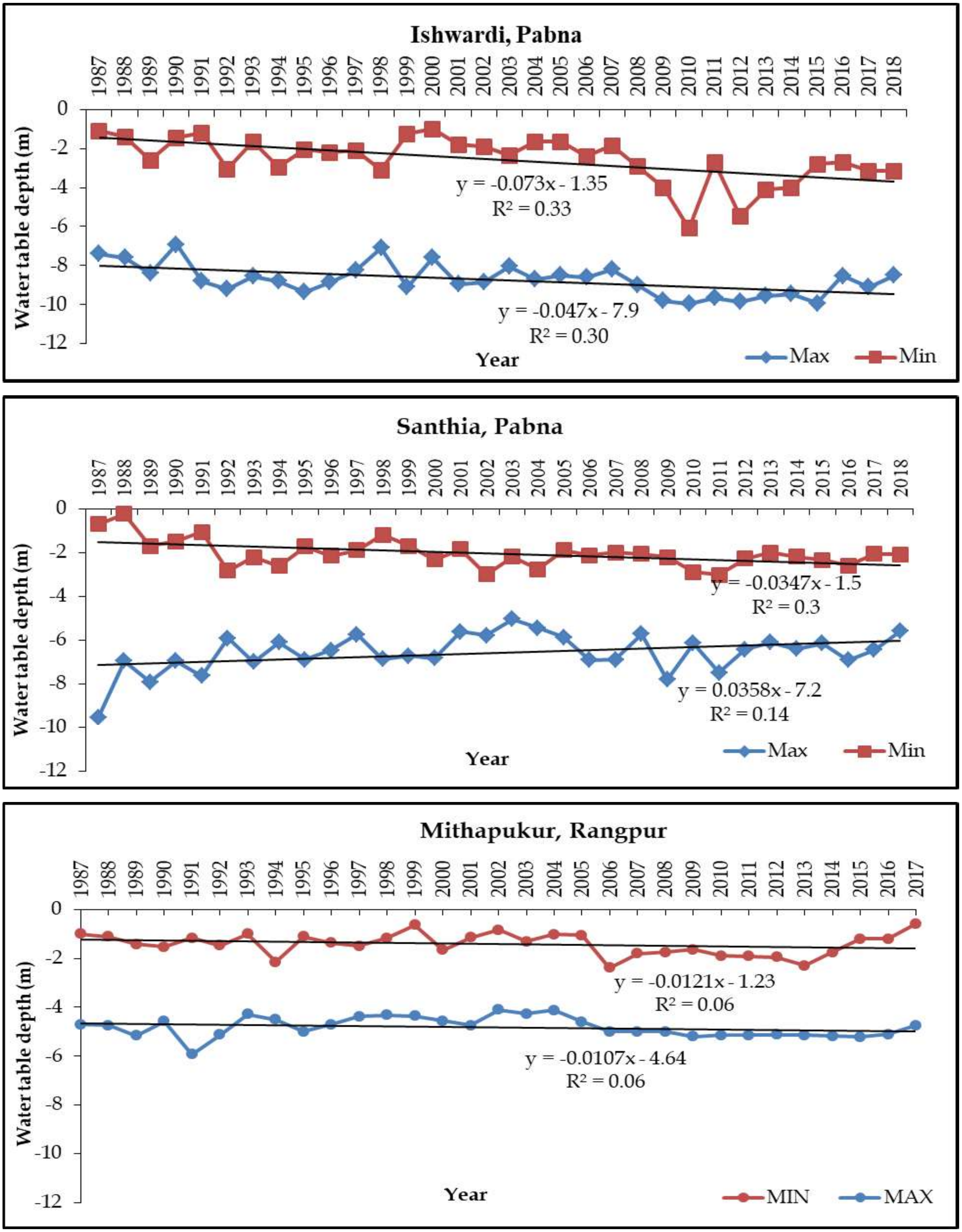


Fig. 2. Trend and fluctuation of groundwater table in various locations of the project area.

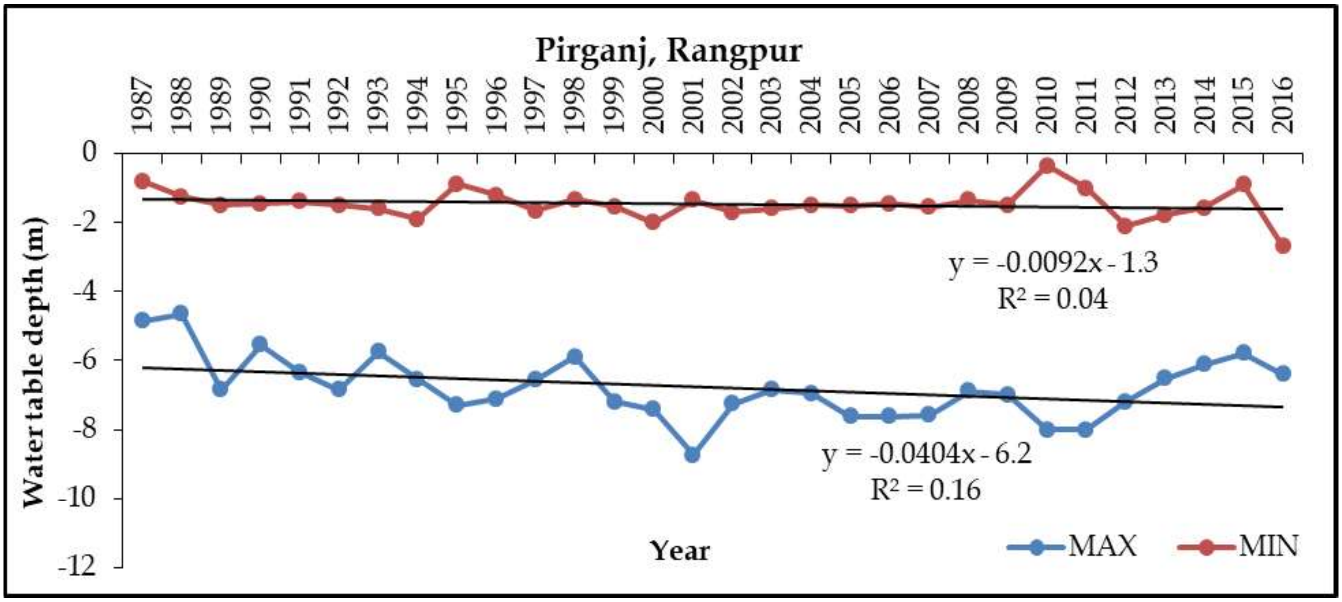


Fig. 2. Continued.

Character of groundwater table

Long term GWT data of various locations were analyzed to know why declination of groundwater occurred. Tables 1 and 2 present the outputs of withdrawal and recharge pattern of groundwater at different locations those were investigated. In Table 1, presents the ranges of maximum and minimum GWT depths from 9.95 m to 6.92 m and from 6.1 m to 1.0 m, respectively, at Ishwardi. These range values are comparatively higher than range values of other locations. It indicates that the groundwater level from the ground surface at Ishwardi always remained lower than those at Santhia, Mithapukur and Pirganj. Average withdrawal depth, i.e., difference between minimum and maximum GWT depth was also the highest (6.20 m) at Ishwardi among the locations. It means, per year withdrawal of ground water was more at Ishwardi than the other location. Mojid *et al.,* (2019) showed a significant falling trend of maximum groundwater table in about 65.71% observation wells in a study with 350 wells in North-West hydrological region of Bangladesh. They also noticed the over withdrawal of groundwater behind the GWT depletion. BRRI (2020) also found similar results of decreasing GWT in Pabna and Bogura. Number of years of negative recharge, when minimum GWT depth of any year is greater than last 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 last year means positive recharge). Beside that number of years of excess withdrawal (when maximum GWT depth of any year is greater than that of last 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 is taking place. As for example, out of 30 years in Ishwardi, 14 years had positive recharge whereas 15 years had negative recharge and, in one year, there was no positive and negative recharge. Again, excess withdrawals were higher than less withdrawals at Ishwardi, so groundwater trend is declining.

Table 1. Water table, recharge, and withdrawal pattern of groundwater in Pabna and Rangpur.

Location	Period year	MaxGWT range (m)	MinGWT range (m)	Average withdrawal (m)	Positive recharge (yr)	Negative recharge (yr)	Less withdrawal (yr)	Excess withdrawal (yr)
Ishwardi	30	9.95-6.92	6.10-1.00	6.20	14	15	15	17
Santhia	32	9.56-5.05	3.02-0.25	4.40	14	17	17	14
Mithapukur	30	5.92-4.10	2.40-0.51	3.37	15	15	14	16
Pirganj	27	8.75-4.64	2.70-0.35	5.40	14	13	11	16

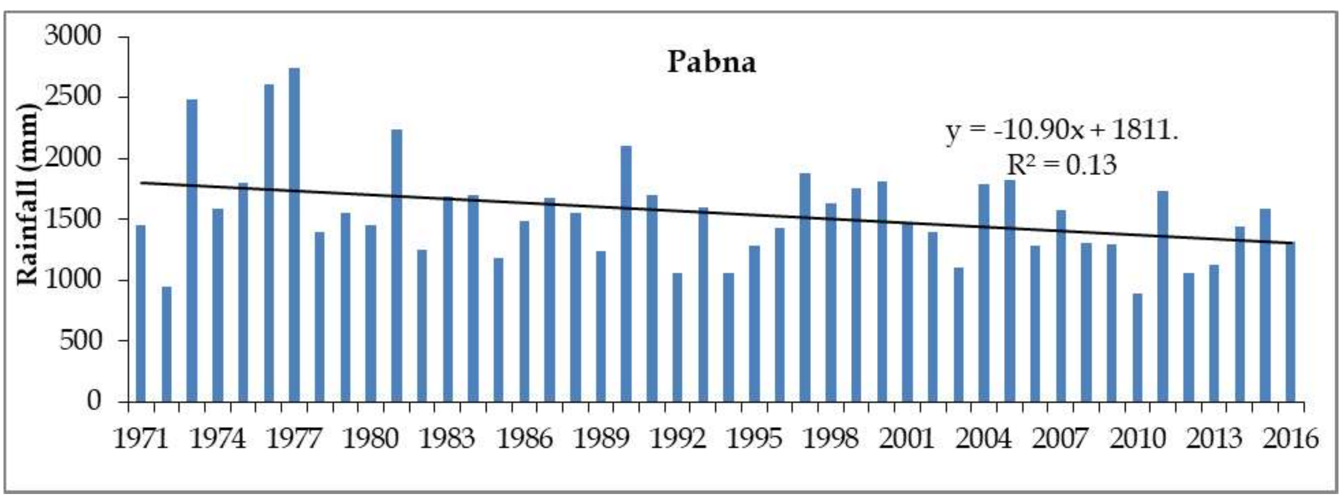
In Table 2, total depletion (difference between minimum GWT depths before 30 years and present year) has occurred in Ishwardi which was the highest (205 cm) among the locations and average per year depletion was 6.6 cm. Nevertheless, there was no depletion in groundwater in Mithapukur. In Ishwardi, maximum GWT remained beyond suction limit for 28 times out of 30 years (suction limit means a reference depth of eight meter below the ground surface). As a result, no shallow tubewell works during dry period in Ishwardi. But in Mithapukur, maximum GWT always remained above suction limit.

Annual rainfall and it's trend

Rainfall is 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 is not same in every year and variation was observed (Fig. 3). But deviation of the variation is more observed in Pabna district. As a result, there is a declining trend in annual rainfall occurred in Pabna district.

Table 2. Groundwater table depletion pattern in Panba and Rangpur district.

Location	Period (yr)	GWT beyond suction limit (yr)	Total depletion (yr)	Average per year depletion (cm)
Ishwardi	30	28	205	6.6
Santhia	32	1	140	4.38
Mithapukur	30	0	0	0
Pirganj	27	3	155	5.7



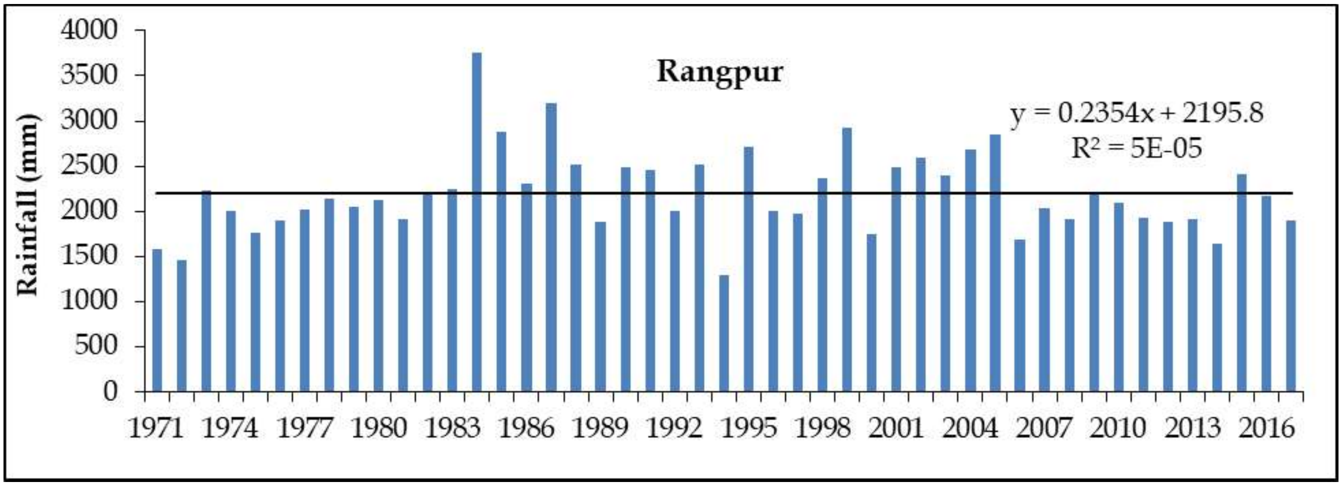


Fig. 3. Trend analysis of historical rainfall at Pabna and Rangpur district

Annual rainfall and minimum groundwater table relationship

Annual rainfall is one of the main sources for recharge and minimum GWT (MinGWT) is directly related to recharge. Figure 4 shows linear relationship observed between annual rainfall and MinGWT. It shows, MinGWT raised at a rate of 0.0025 m and 0.0008 m per each meter increasing rainfall at Ishwardi, Pabna and Mithapukur, Rangpur, respectively. It indicates the positive relation of groundwater recharge with annual rainfall. Shahid and Hazarika, (2010) found the same relationship between rainfall and groundwater recharge in North-West region of Bangladesh.

Recharge period rainfall and recharge depth relationship

Another attempt was taken to explore the relation between recharge period rainfalls (RPRF) and recharge period 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, Figure 5 shows that RD increased with the increasing of RPRF. Greater RD indicates minimum groundwater table was closer to ground surface.

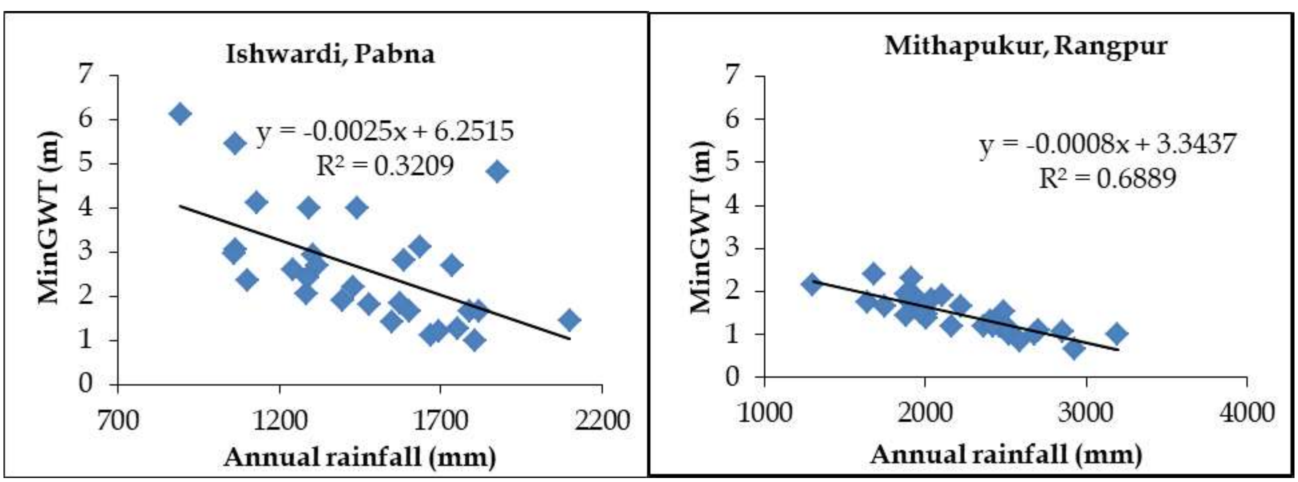
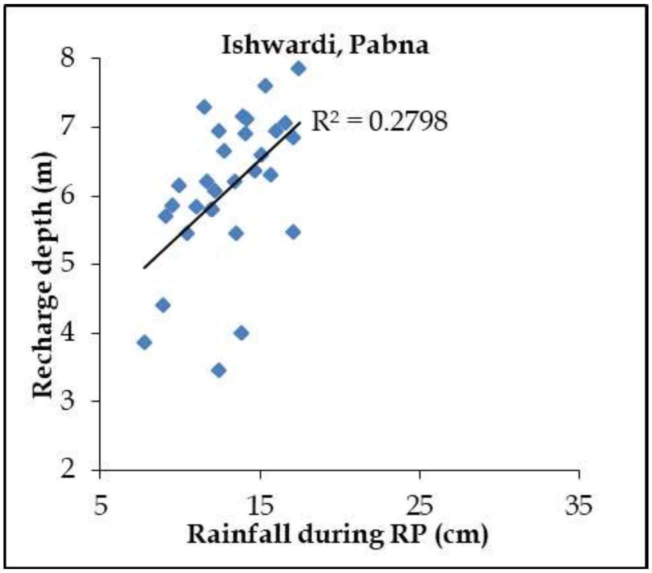


Fig. 4. Relationship between annual rainfall and minimum groundwater table at Ishwardi, Pabna and Mithapukur, Rangpur.



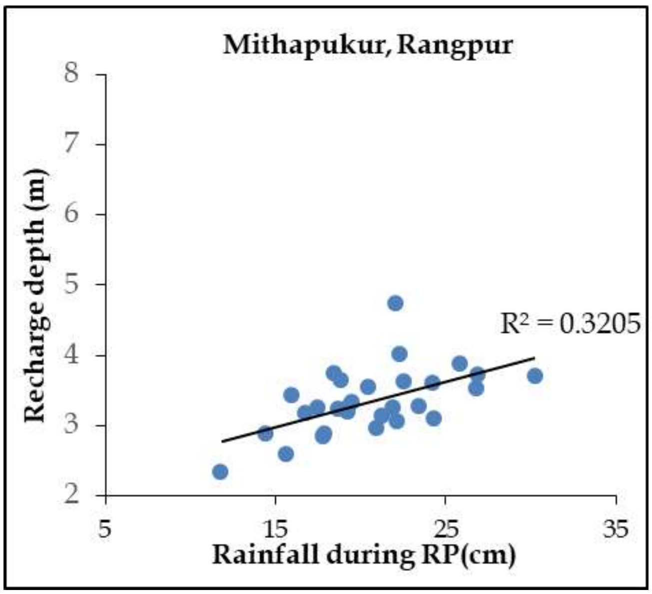


Fig. 5. Relationship between recharge depth and rainfall during recharge period at Ishwardi and Mithapukur.

CONCLUSION

A declining trend of groundwater table persists in the study area except at Pirganj, Rangpur. The maximum total depletion is 205 cm with the maximum 6.6 cm per year depletion and number of years of negative recharge is more than that of positive recharge for 32 years. The maximum groundwater table remains below suction limit at Ishwardi, causes no shallow tubewell (STW) works during that period. A declining trend in annual rainfall is observed in Pabna district. A positive linear relationship between rainfall and recharge was found at two locations of the study area.

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