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TREND ANALYSIS OF GROUNDWATER LEVEL IN RAJSHAHI, BANGLADESH

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Abstract

In Bangladesh, people mostly depend on groundwater to satisfy the demand for domestic and agricultural water supplies. Insufficient surface storage and successively falling groundwater levels have created a dreadful situation in the Northwestern region. The study aims to analyze and predict the groundwater level in the Rajshahi district. Mean monthly rainfall data from 2009 to 2020 and groundwater level data from 1995 to 2020 were collected from Barind Multipurpose Development Authority for this study. “MAKESENS” software was used to analyze the trend of rainfall, depth to the groundwater table, and prediction of the groundwater table. Trend analysis showed the water table depth had increased drastically in all the observation wells (except Gopalpur 1) and increased 2.46 times higher in Haripur within 26 years. Rainfall variation in the study area was very irregular, having the highest rainfall in 2020 and the trend line showing the slightest increment in annual rainfall. Most of the wells showed an increasing trend in the depth to water table with the decrease in rainfall. On the contrary, in 2015, the well of Godagari Upazila showed that the depth to water table increased although there was maximum rainfall. The prediction for the year 2040 has implied that if the trend continues , the depth of the groundwater table will be 2-4 times higher, maximum increment in Haripur (18.056 m). The result of this study will be a scope to safeguard the groundwater to ensure the sustainability of water resources in the Rajshahi district.

Keywords: Prediction, MAKESENS, Rajshahi District.

Introduction

Groundwater is the main source of water supply worldwide. 30% of all the freshwater in the world is groundwater. It is critically important and supplies a large proportion of the water for drinking, sanitation, food production, and industrial processes (School, 2019) also contributesignificantly to irrigation, hence to food security in arid and semi-arid regions (Margat, 2020). Excessive withdrawal of groundwater and, at the same time, insufficient recharge are causing rapid depletion of groundwater levels in many places (Dhar, 2014).In the Northwest part of Bangladesh, about 95 % of irrigation water comes from groundwater using shallow tube wells, and the proportion of groundwater has increased in recent years. Twelve drought events occurred from 1971 to 2011, but the Barind tract faced the most extremes ones (Rahman, 2016).Groundwater level depletes during the dry seasons because of pumping and natural discharge to nearby rivers. Besides, the high variability in rainfall (Shahid, 2008) and high temperature left the surface reservoir extremely dry. Groundwater supplies approximately 70% of the irrigation water used in the Barind area (Jahan et al., 2010; Wang et al., 2014). Surface water resources in the area are diminishing because the Farakka barrage diverts water from upstream. The presence of a thick clay layer, recent alluvium, and the upper part of the DupiTila sand of the Pliocene-Pleistocene age form shallow aquifers which are generally located within a depth of 100m below the surface(Ahmedet al., 2004) makes aquifer recharge uncertain. As a result, groundwater use in the Barind area has exceeded recharge and GWTs have been successively falling over the years, with the increasing withdrawal of groundwater for irrigation (CSIRO et al., 2014; Rahman, 2012). Rajshahi, Pabna, Bogura, Dinajpur, and Rangpur were identified as the severely depleted areas, with depletion of GWTs between 2.3 m and 11.5 m (Dey et al., 2013).

In this study, trends and predictions of the groundwater table are found out by applying the nonparametric Mann-Kendall test for the trend and the nonparametric Sen’s method to a groundwater level database from 8 monitoring wells over the period of 1985–2005 in the Northern part of Northwest region of Bangladesh.

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Materials and Methods

Study area

The study was conducted in the Northwest part of Bangladesh. A brief description of the study area is given in the following section.

Location and extent

Geographically, this region is lying between 88°20' to 89°30' E and 24°20’ to 25°35 N. Average temperature of the Rajshahi region during 1961-2010 is 24.87°C (Baten, 2011). The Barind area is floored by Madhupur clay. This study is based on the data collected from Rajshahi district, one of the most arid regions in the Barind tract. It consists of an area of $2407.01 km^2$ and is situated in between 24°07' and 24°43' north latitudes and in between 88°17' and 88°58' east longitudes. A map of the study area is shown in Fig. 1.

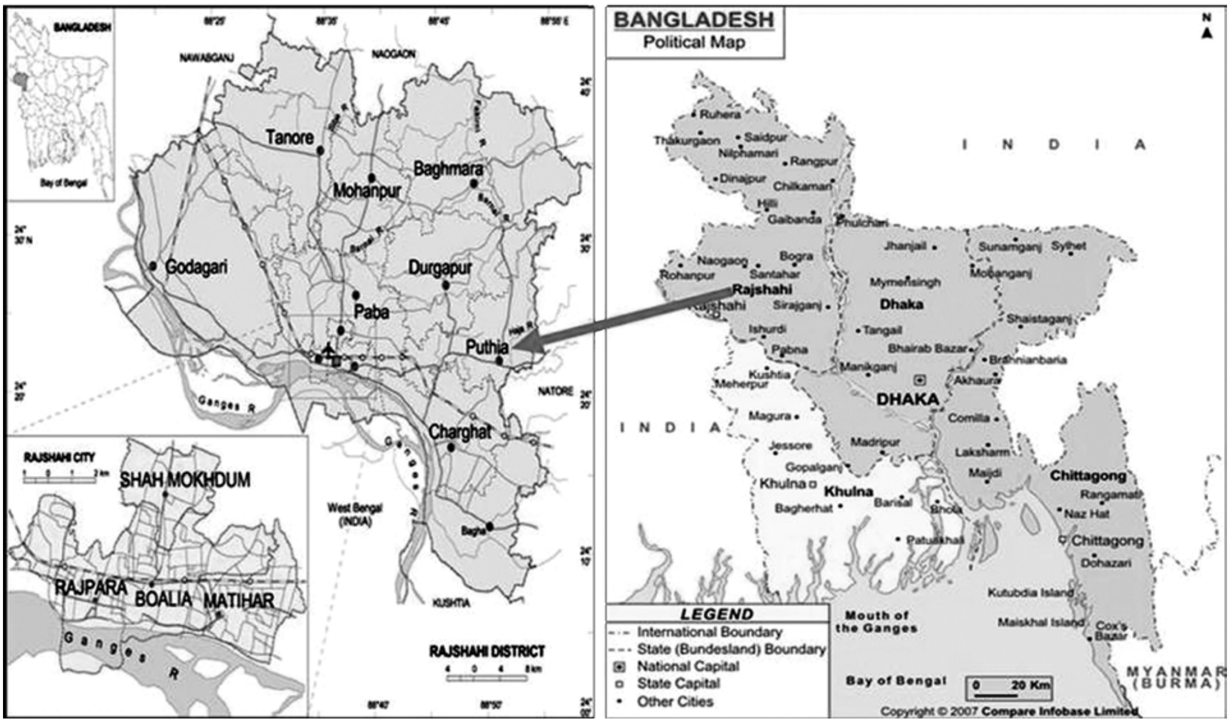

Figure 1. Map of Bangladesh in the right side and Map of Rajshahi district showing the four Upazila’s in the left side

Lithology

The elevated Barind area is characterized by less infiltration due to clayey and semi- to impermeable Barind clay with excessive surface runoff. Morpho-stratigraphically, the Barind area is subdivided into three geological units: (1) Barind clay residuum overlies and developed on Pleistocene alluvium; (2) Holocene Ganges flood-plain alluvium; and (3) active channel deposits of the Ganges and major Tributaries (modern alluvium) (Hasanuzzaman, 2017). Hydrogeologically, the area is comprised of semi-impervious recent-Pleistocene clayey silt aquitard (thickness 3.0–47.5 m), which overlays a single- to multiple-layered (2–4) aquifer system of Plio-Pleistocene age (thickness 5.0–42.5 m) (Jahan, 2005).

Topography

The Barind area is characterized by two distinct landforms: the Barind Tract- dissected and undulating, and the floodplains (Jahan, 2010). The land is classified as follows: High land: Land above average flood level, Medium high land: Land flooded up to a depth of 7.62 cm during monsoon season but the water level in the fields in normally 15.24

m or less by the end of August. Medium Land: Land flooded from 0.92 m - 1.83 m depth during the monsoon season. Low land: Land flooded above 1.83 m depth during the monsoon season (Ahmeduzzaman, 2012).

Climatic behavior

According to Koppen's classification, Rajshahi district is under the Tropical savanna climate. The area enjoys a subtropical monsoon climate characterized mainly by three seasons: i) winter (November to February)-cool and dry with almost no rainfall; ii) pre-monsoon (March to May) - hot and dry; and iii) monsoon (June to October) – rainy. The average annual rainfall for the period 2009-2021 is 1205mm. Average monthly humidity varies from 62% (in March) to 87% (in July), with a mean annual of 78%. Monthly average temperature ranges from 10°C (in January) to 33°C (in May). Sunshine hours vary from 7- 8 hr/day (October- May) to 4-5 hr/day (June-September), and wind speed is high (>3 Nm) (April-June) to low (1-3 Nm) (July-March) (Jahan, 2010).

Data and method of analysis

From four upazilas, 08 (eight) observation wells were selected for this study (Table 1). Monthly meteorological data (rainfall) for the last 11 years (2009-2020) and depth to groundwater table for the previous 26 years (1995-2020) were collected from Barind Multipurpose Development Authority (BMDA). The trend rainfall was analyzed in MS Excel spreadsheet. Trends of depth to groundwater table of the observation wells were constructed using MAKESENS software.

Table 1. Wells under different Upazilla's with J.L. No.

SL No.	Upazila (sub-district)	Mouza	J.L. No.	Plot No.
1	Godagari	Poromanondopur	188	482
2	Godagari	Amtoli-1	193	95
3	Mohanpur	Boraeel	20	1151
4	Mohanpur	Matikata-1	87	985
5	Paba	Gopalpur-1	41	1548
6	Paba	Sontoshpur	108	175
7	Tanore	Haripur	235	211
8	Tanore	Talondo	224	1138

An Excel template MAKESENS– is developed for detecting and estimating trends in the time series of annual values. The procedure is based on the nonparametric Mann-Kendall test for the trend and the nonparametric Sen's method for the magnitude of the trend. First, the presence of a monotonic increasing or decreasing trend is tested with the nonparametric Mann-Kendall test and secondly, the slope of a linear trend is estimated with the nonparametric Sen's method (Gilbert et. al., 1987). The Sen's method uses a linear model to estimate the slope of the trend and the variance of the residuals should be constant in time. Missing values are allowed and the data need not conform to any particular distribution. Besides, the Sen's method is not greatly affected by single data errors or outliers (Salmi, August 2002). The model also exploits the so-called S statistics and Z statistics (the normal approximation (Gilbert, 1987).

The Mann-Kendall test is applicable in cases when the data values x_i of a time series can be assumed to obey the model in equation 1

$$\boldsymbol{x_i} = \boldsymbol{f}(\boldsymbol{x_i}) + \boldsymbol{\varepsilon_i} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(\mathbf{1})$$

Where, f(t_i) is a continuous monotonic increasing or decreasing function of time and the residuals $\varepsilon_i$can be assumed to be from the same distribution with zero mean. In case of data values <10, the number of annual values in the studied data series is denoted by n, and the Mann–Kendall test statistic (S) is calculated as equation 2.

$$\boldsymbol{S} = \sum_{\boldsymbol{k-1}}^{\boldsymbol{n-1}} \sum_{\boldsymbol{j-1}}^{\boldsymbol{n}} \boldsymbol{sgn}(\boldsymbol{x_j} - \boldsymbol{x_k}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(\mathbf{2})$$

Where, x_j and x_k are the annual values in years j and k, j > k, respectively, and

$$sgn = \begin{cases} 1 & if, x_j - x_k > 0 \\ 0 & if, x_j - x_k = 0 \\ -1 & if, x_j - x_k < 0 \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(3)$$

A positive value of S indicates an upward trend and a negative value of S indicates downward trend.

As n (time series) is greater than 10, the normal approximation test is used. First the variance of S is computed by the equation 4 which takes into account that ties may be present:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(4)$$

Here, q is the number of tied groups and t_p is the number of data values in the p^{th} group. The values of S and VAR(S) are used to compute the test statistic Z as equation 5.

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if, S > 0 \\ 0 & if, S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if, S < 0 \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(5)$$

The presence of a statistically significant trend is evaluated using the Z value (TimoSalmi, August 2002). A positive value of Z indicates an upward trend and a negative value of Z indicates downward trend. In MAKESENS the two-tailed monotonic trend test is used for four different significance levels α: 0.1, 0.05, 0.01 and 0.001.

The WT depths were projected as (Ali et al., 2011) -

WT depth (m) = B + Q × (Simulation year − Base year)

Where, B = Intercept of linear regression equation;

Q = Slope of linear regression equation

Results

Trend of depth to GWT

Mean depth to groundwater table was analyzed, and the distribution of simulated water table depth values for 95% and 99% confidence levels, along with the residual distributions, are given in Fig.2.

The MAKESENS model analysis shows a spatio-temporal variation of groundwater table depth. The time series consists of annual averages with monotonously increasing trends in almost all the observation wells. The observation wells in Gopalpur-1 show a monotonously decreasing trend which proves the Mann- Kendall test is suitable. The residuals came from a random distribution that indicates the application of a linear model. A high level of significance with narrow angles between the confidence lines is obtained from the statistical calculations. The most increment of depth to water table is occurred in Poromanondopur within the limit from 12 m to 24 m. The accretion in depth is insignificant in Sontoshpur which is about 5 meters. However, an abnormal case is visible in Gopalpur-1. Instead of increasing, the depth of the water table has declined by about 5 meters in this area. The rest of the areas show a remarkable increment in depth which is almost 10 meters in each observation well. The data values show the most uniform increment in Haripur and Talondo. In Gopalpur-1, residual line shows a great fluctuation in the depth of the water table. Other wells show slighter fluctuations in residual lines. The residual line seems to be straightened and almost zero in Haripur and Talondo.

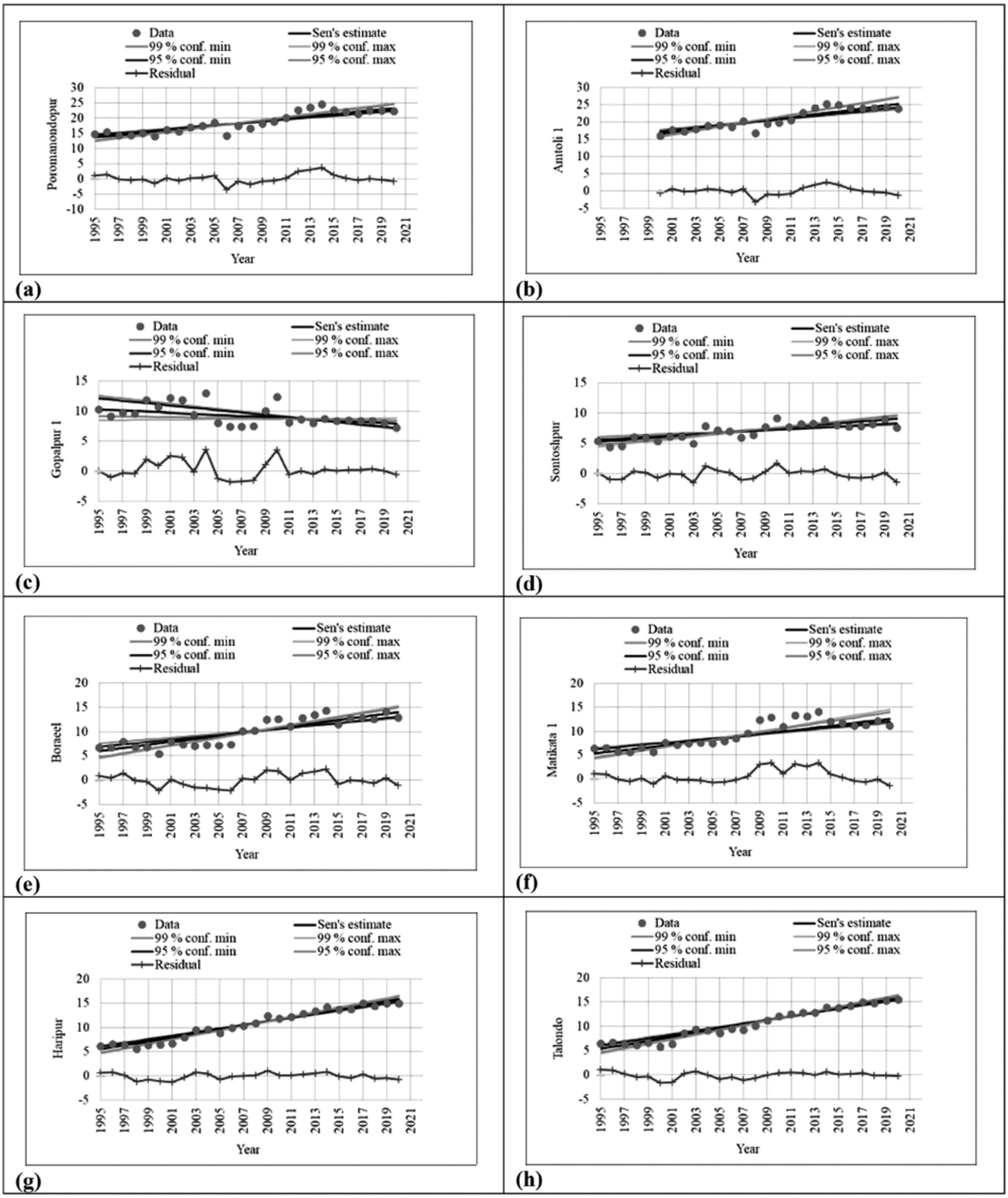

Figure 2. Trend of GWT depth at different wells- (a) Poromanondopur, (b) Amtoli-1, (c) Gopalpur-1, (d) Sontoshpur, (e) Boraeel, (f) Matikata-1, (g) Haripur, (h) Talondo.

Maximum and minimum GWT variation

The maximum and minimum depth to water table at different wells throughout the year 1995-2020 are graphically represented in Fig.3. Minimum and maximum values indicate the depth to the water table at monsoon and dry seasons. In Fig. 3, the depth to WT is rising every year. In Poromanondopur, depth to the water table increases gradually in the beginning and suddenly falls down in 2006, and at the end, it starts rising again. While in Amtoli-1 the maximum fluctuation of the depth to water table shows almost a similar trend in the beginning of the study period, and in 2006 it falls a little, then from 2011, it starts increasing. The maximum depth to water table in Poromanondopur and Amtoli-1 is found to be the same value 26 meters in the year 2014. At the beginning, the depth to water table is nearly zero in Boraeel, and it then increase steadily and reaches to 8 meters in 2020. In Gopalpur-1 and Sontoshpur, the fluctuation of minimum and maximum depth to groundwater table is very irregular. Though Gopalpur shows a slightly decreasing trend line. The maximum peak point was found about 22 meters in 2010. Haripur and Talondo show the steepest slope. However, the trend line of the minimum depth to groundwater table in Talondo shows a similar trend at the beginning and gradually increases at the end. The trend lines for minimum and maximum yearly values of the wells in Poromanondopur, Amtoli-1 and Haripur were very close. These indicate that both in dry and rainy seasons the depth to water table was increasing in each well in the same manner.

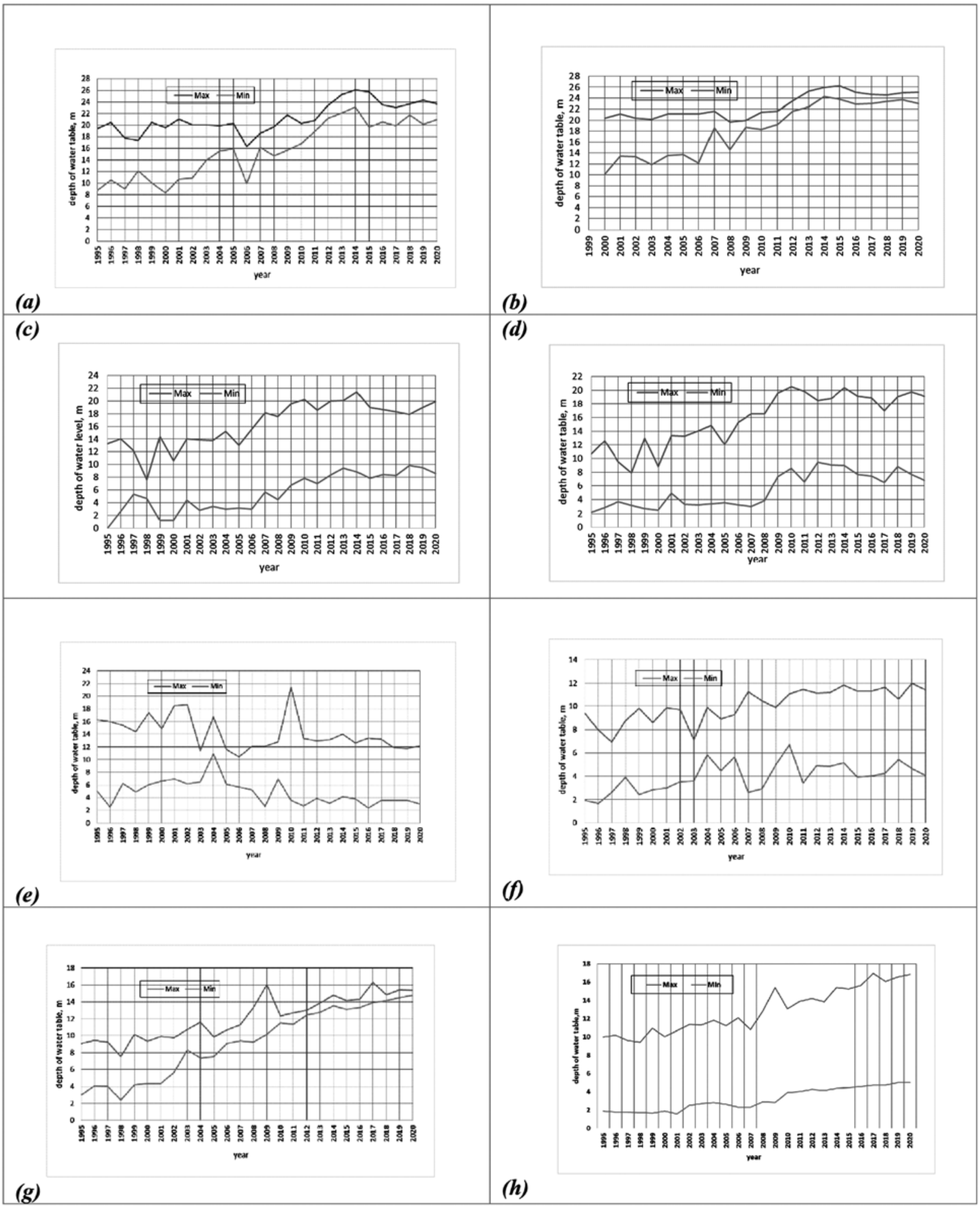

Figure 3. Minimum and maximum variation of water table depth throughout the year 1995- 2020 at (a) Poromanondopur, (b) Amtoli- 1, (c) Boraeel, (d) Matikata- 1, (e) Gopalpur- 1, (f) Sontoshpur, (g) Haripur, (h) Talondo.

Rainfall variation

The annual rainfall of the study area throughout the year 2009-2020 was analyzed. In Fig.4 the yearly rainfall was very low in Rajshahi district compared to the other part of the country. In Godagari Upazila, the maximum rainfall occurred in 2015 which was 1700 mm. The minimum rainfall occurred in 2010, which was 700 mm. The rainfall variation was irregular within eleven years; however, the trend line shows the slightest increment in rainfall. The minimum rainfall in Mohanpur was about 800 mm which was held in 2014. After this, annual rainfall persisted for the next five years and suddenly increased to nearly 1800 mm in 2020. It was the maximum recorded annual rainfall in the four upazilas. Similarly, the maximum rainfall occurred in Tanore in 2020, which was 1600 mm. But the minimum rainfall was about 850 mm. In Paba, the maximum rainfall was 1700 mm in 2011, and the minimum rainfall was nearly 850 mm in 2010.

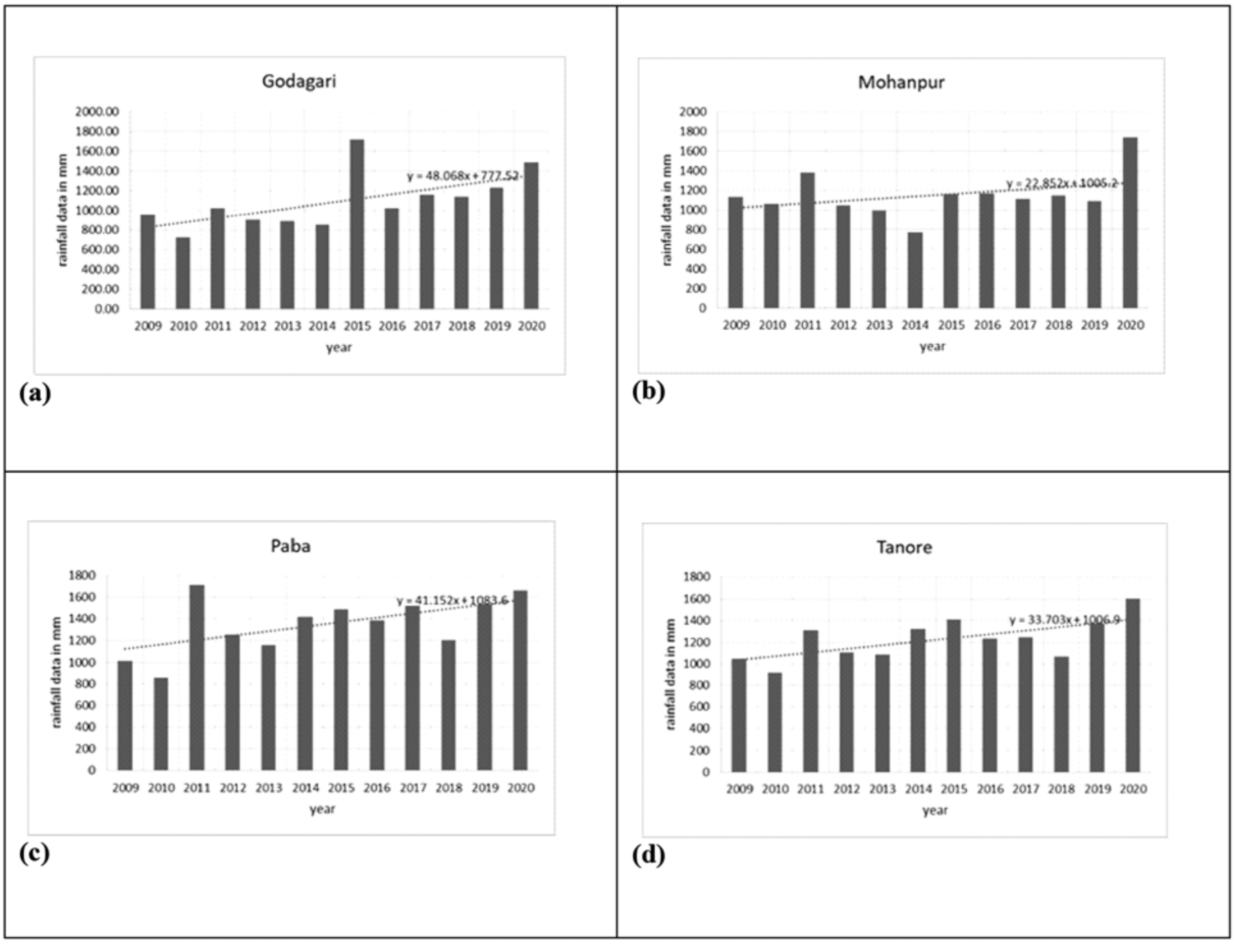

Figure 4. Rainfall variation at (a) Godagari, (b) Mohanpur, (c) Paba and (d)Tanore throughout the year 2009-2020.

Relation between groundwater table and rainfall

Groundwater table fluctuation with the variation of rainfall is given in Fig. 5. From the annual rainfall and average water table depth relationship graphit is seen that when the appreciable amount of rainfall occurs, the depth of the water table reduces (water level increases). In case of Godagari Upazila, the maximum recorded rainfall occurred in 2015. In the trend line, the depth of the water table declined in 2015. Therefore, greater rainfall does not always indicate greater recharge in groundwater storage as the change in the groundwater table depends on various factors. For example, the gradual increment of rainfall did not really affect groundwater replenishment in Tanore Upazila, and the water table depth continued to increase with time. The rainfall variation was negligible in Paba Upazila, resulting in less groundwater table fluctuation throughout 1995-2020. In Mohanpur, the fluctuation of ground water table was comparatively higher than in the other areas. The highest recorded water table depth was found in 2014, when the lowest rainfall occurred. Nevertheless, it is clear from the Fig. 5 that rainfall plays a crucial role in groundwater replenishment.

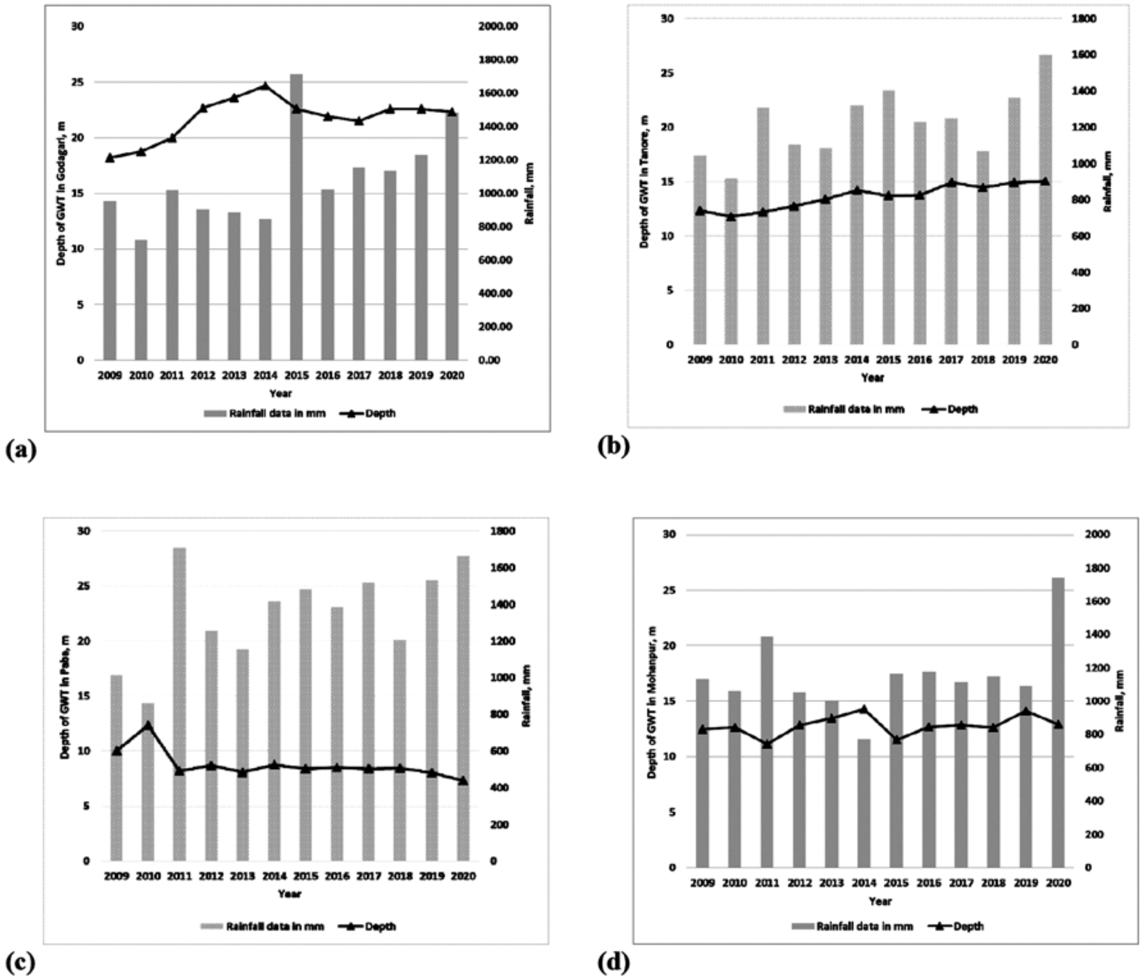

Figure 5. Fluctuation of depth of water table with the rainfall variation at (a) Gopalpur, (b) Tanore, (c) Paba, (d) Mohanpur.

Prediction of depth of groundwater table

After the analysis of 26 years of water table data, trend statistic was obtained from MAKESENS software. Only one well in Gopalpur 1 showed a negative value (-2.51) of test Z, which means more replenishment of the groundwater. Other wells showed positive value in test Z, which indicates that the water table depths are increasing. The lowest significance level (indicated by *) indicates that the null hypothesis of no trend should be rejected. The value of the slope of linear regression Q was found to be negative only for Gopalpur 1, other observation wells showed positive value. The 95% and 99% confidence levels were also obtained by the simulation. From the trend statistical values of Table 2, a prediction was made for the year 2040. Then a comparison was made between the year 2040 and 1995 and between 2040 and 2020. This comparison showed a huge change in water table depth. With the values of the intercept of linear regression, B and slope of linear regression equation Q, the prediction was made for the year 2040 shown in Table 3. Comparison of the depth of WT between 2020 and 2040 are shown in Table 4.Within 26 years, the depth of water table has already been increased at a higher rate. In Talondo, the maximum increment was about 9.091 m from the year 1995 to 2020. It is expected from the future prediction that the maximum depth will be at Haripur, about 18.056 m in 2040. Exceptionally, the depth will be lower at about 4.275 m at Gopalpur-1 in 2040.

Table 2. Trend Statistics

				Mann- Kendall Trend		Sen's slope **estimation**	
Observation well	**First year**	**Last year**	**n**	**Test Z**	**Level of Significance**	**Q**	**B**
Poromanondopur	1995	2020	26	4.76	***	0.385	13.62
Amtoli 1	2000	2020	21	4.56	***	0.430	14.46
Boraeel	1995	2020	26	5.20	***	0.324	5.92
Matikata 1	1995	2020	26	4.58	*	0.295	5.24
Gopalpur 1	1995	2020	26	-2.51	***	-0.095	10.30
Sontoshpur	1995	2020	26	4.36	***	0.152	5.26
Haripur	1995	2020	26	6.52	***	0.415	5.47
Talondo	1995	2020	26	6.17	***	0.418	5.35

Notes: 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.

Table 3. Prediction of Depth of GWT for year 2040

Observation well	**B**	**Q**	**Simulation year**	**Base year**	**Predicted depth of flow(meter) in 2040**
Poromanondopur	13.62	0.385	2040	1995	30.954
Amtoli 1	14.46	0.430	2040	2000	31.66
Borael	5.92	0.324	2040	1995	20.5
Matikata 1	5.24	0.295	2040	1995	18.515
Gopalpur 1	10.30	-0.095	2040	1995	6.025
Sontoshpur	5.26	0.152	2040	1995	12.1
Haripur	5.47	0.415	2040	1995	24.145
Talondo	5.35	0.418	2040	1995	24.16

Discussion

The ratio of groundwater to surface water use is much higher in the Barind region compared to other parts of the country (Rahman S., 2016). So, the Barind area has become a matter of concern currently. In this study long term rainfall data from 2009 to 2020 and tube wells data from 1995 to 2020 have been analyzed. In this analysis, emphasis is given on the trend of depth to groundwater table and the relation between rainfall and depth to groundwater table. On the basis of long-term analysis (1995-2020), the maximum depth was found in Poromanondopur (22.330 m) in 2020 which is expected to be around 30.95 m in 2040 from the future projection perspective. Exceptionally the well of Gopalpur 1 showed a decreasing trend of depth to water table (10.300 m in 1995 to 6.025 m in 2040). In Godagari Upazila, the maximum recorded rainfall was found in 2015. However, the depth of water table still increased at that time. It proves that in many areas, the depth of the water table continues to increase with the slightest response to excess rainfall. Relation between rainfall and groundwater table in other wells showed a good dependency of GW replenishment on rainfall. The long-term prediction for 2020-50 is that the declining trend will be 1.07 to 1.82 times higher or maximum and minimum depth to ground water table respectively in comparison to the present (Rahman, 2016). From a long-term future projection perspective, the predicted values for the year 2040 is 1.24 times higher than that of present trends (Hasanuzzaman M., 2017). In this study, long term prediction for 2040 showed that the average groundwater table depth will be 2-4 times higher than that of 1995.

The results from this study suggest that the decline of average groundwater storage due to decreasing rainfall and less recharge from surface water. It is recommended to use less water-demanding crops and other water-saving technology as the water level declines and it falls below a critical threshold of about 8 m, particularly at the end of the dry season in March, April, and May (Hodgson, 2014). Therefore, the study suggests the government and related authorities to take steps to do more research on groundwater conditions, risks to STW and DTW users, and developmental implications in order to guide future policy on agricultural expansion driven by DTWs in the Barind region. A comprehensive assessment of groundwater and surface water resources, including zoning, is also required for future planning, management, and eventually sustainable use.

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