International Journal of Research in Environmental Science (IJRES)
Volume 7, Issue 3, 2021, PP 22-32
ISSN No. (Online) 2454-9444
DOI: http://dx.doi.org/10.20431/2454-9444.0703003
www.arcjournals.org

Trends in Groundwater Tables and Present Status of Irrigation Water in North West and South West Regions of Bangladesh

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Abstract: *The long-term (1997–2020) maximum and minimum GWTs (ground water table) depth data of 114 observation wells under different districts of North West (NW) and South West (SW) hydrological regions of Bangladesh are analyzed using MAKESENSE model software to find out the trend of GWTs that helps to take policy sustainable agriculture and judicial use of GW (ground water). The rate of annual maximum GWTs depth falling was observed (0.55 to 6.42) myr-1 at NW and (0.82 to 6.45) myr-1 at SW region. Besides, the rate of annual minimum GWTs depth falling was founded (0.01 to 4.19) myr-1 at NW and (0.004 to 0.164) myr-1 at SW region. The results revealed about 94.73% of observation wells, both annual maximum and minimum GWTs depth was significantly ($p \leq 0.05$) declining. The results also discovered about 85% of observation wells beyond their GWTs below the critical depth (6m) in the dry season and maintained an annual cycle of their depth. The results also revealed that there were no wells having groundwater level always above critical depth. Both annual maximum and minimum GWTs depth were always below the critical depth at Rajshahi. If the present trend of annual minimum GWTs depth was continued only 32.45% of wells beyond their water table above the critical depth in 2040. If the present trend in the dry season is continued, suction-mode pumps may not operate at all due to the exceeding the suction limit (up to 6 m).*
Keywords: *Water table, fluctuation, sustainability, suction lift*

1. Introduction

Scarcity of surface water, Groundwater is the most essential input for increasing crop production. Recently, sustainable agricultural development is fully depended on groundwater. In most region of the world, over 70% of fresh water is used for agriculture; by 2050, feeding a planet of 9 billion people will require an estimated 50% increase in agricultural production and a 15% increase in water withdrawals [16]. Besides, large amount of drinking water comes from groundwater. Groundwater provides almost half of all drinking water worldwide [2]. Increasing population, food insecurity, growing economies and poor water management are putting unprecedented pressure on the world's freshwater resources [14]. Groundwater is the world's most extracted raw material with withdrawal rates currently in the estimated range of 982km^3/year [13]. In Bangladesh groundwater is one of the main sources for agricultural water and essential input for dramatic development in agriculture. Groundwater irrigation has contributed to a manifold increase in crop productivity in Bangladesh agriculture [12]. About 90 percent of irrigation water in Bangladesh is provided from groundwater and 75% of cultivated land is irrigated by groundwater [7]. Bangladesh, though, is blessed with abundant groundwater resources, but not unlimited. A large quantity of groundwater is being pumped each year, mainly for irrigation, and domestic and industrial uses, through different water lifting devices. Over the past few decades most of the rivers and canals of the region have dried up during the dry season and the people switched their water supply from surface to groundwater. In the North-West (NW) region of the country, about 95% of irrigation water comes from groundwater, which is extracted, mainly, by shallow tubewells (STW) and deep tubewells (DTW), in addition to some small-capacity pumping technologies, such as hand pumps, popularly known as hand tubewells (HTWs), rower pumps, and treadle pumps. There are now 1.77 million irrigation pumps in the country, of which 1.56 million are STWs [10,15]. GWTs in the NW region of Bangladesh have been successively falling over the years [3]. Consequently, groundwater research needs to be focused both in its thematic and critical areas, due to the appearance of unexpected or unanticipated problems [4]. The trend of GWTs reveals the condition of groundwater resources in terms of sustainability. So

GWTs investigation is essential by used to latest data sets. These types of study helps to take adjust groundwater development and management policy. The aim of the research is to know the trend of the yearly maximum and minimum depths of GWTs in NW and SW region of Bangladesh over the past 24 years (1997–2020). The specific objectives of this study were i) to detection quantity, magnitude and calculated the predicted value of GWTs. ii) to identify which types of pumps are used for groundwater extraction in different location of the study area based on critical depth of GWTs.

2. MATERIALS AND METHODS

Study Area

The study area, located in the North West (NW) and South West (SW) hydrological regions of Bangladesh. Bangladesh has eight Hydrological Regions, based on surface water flow processes and major rivers as boundaries (Fig. 1). This area covered the Barind tract, Ganges flood plain, Atrai flood plain and active Ganges. The elevation of the major part of the flood plain ranges 3 to 5 meter the mean sea-level. The Barind tract is the product of vertical movements of Pleistocene period and reaches maximum height of 20 m above recent flood plains. This area is a very important region in agriculture. There are eight districts like Rajshahi, Natore, Pabna in NW region and Kustia, Jhenaidah, Magura, Jashore, Faridpur in SW region are selected for this study. Sub-surface lithology of the NW hydrological region is mixed. The upper-most layer of Rajshahi area (Figure 1) covered about 2.5 to 35 m thick clay to silty clay layer. But in Pabna, the upper-most layer is clay to silty, clay layer varies from 1 to 20 m. The aquifers in these areas are generally unconfined. In the NW region annual average rainfall is 1927 mm, and potential evapotranspiration is 1309 mm. The water table varies from 4.7 to 11.54 meters below ground level.

Data collection

The historically long-term (24 years, from 1997 to 2020) secondary data of ground water table (GWTs) depth and rainfall were considered for this study. Weekly GWTs depth and daily rainfall data were collected from the Bangladesh Water Development Board (BWDB). Total 114 observation wells data were used at this study. These observation wells have been used for groundwater level monitoring. Considered, 52 observation wells data in NW region and 62 in SW region for this study. The location of observation Wells is shown in **(Table S1)**. Daily rainfall data of 24 rain gauge stations of the study area were also considered for analyzed.

Data preparation

Firstly, GWTs data were plotting against the time in scatter plots. Good quality GWTs data of observation wells were selected for trend analysis and critical GWTs depth identification. The annual maximum and minimum depths of GWTs were identified from the weekly GWTs depth data for each observation well. This annual maximum and minimum depths of GWTs were recorded separately in a MS Excel spread sheet. Yearly total rainfall was calculated from the daily rainfall data for each rain gauge station and recorder separately by MS Excel. Zilla wise average yearly total rainfall was also calculated and recorded separately in a MS Excel spread sheet.

Trend Analysis

Trend of GWTs depth and average total rainfall were analyzed by using MAKESENS trend model. MAKESENS model was introduced by [8]. MAKESENS performed two types of statistical analyses called S-statistics and Z-statistics to estimated trend. First, the presence of monotonic increasing and decreasing trend was tested with the nonparametric Mann-Kendall test and secondly, the slope of linear trend was estimated with the nonparametric Sen's method [9]. These methods are used in their basic forms; the Mann-Kendall test is suitable for cases where the trend may be assumed to be monotonic and thus no seasonal or other cycle is present in the data. The Sen's method used a linear model to estimate the slope of the trend and the variance of the residuals should be constant in time. These methods offer many advantages that have made them useful in analyzing atmospheric chemistry data. Missing values are allowed and the data need not to be conformed to any particular distribution. Besides, the Sen's method is not greatly affected by single data errors or outliers.

For time series with less than 10 data points, S-statistics is used, If $x_1, x_2, x_3, \ldots\ldots\ldots\ldots, x_j$ represent n data points, where x_j is the data point at time j, Mann-Kendall statistics "S" is expressed by

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(xj - xk)$$

In this equation,

$sgn(xj - xk)$= 1 for $(xj - xk)$ > 0,

$sgn(xj - xk)$= 0 for $(xj - xk)$ = 0,

$sgn(xj - xk)$= -1 for $(xj - xk)$ < 0

For time series with ≥10 data points, Z-statistics is used. "Z" is expressed by

$$Z = \frac{S-1}{[VAR(S)]1/2} \qquad if\ S > 0$$

$$Z = \frac{S+1}{[VAR(S)]1/2} \qquad if\ S < 0$$

$$Z = 0 \qquad if\ S = 0$$

The MAKESENS model provides trends of the annual maximum and minimum depths of GWTs and zilla wise average rainfall in terms of Z-statistics, slope, and intercept of the trend line. It also provides statistical significance level of the trends. In MAKESENS test, the significant levels alphas (α) were 0.001, 0.01, 0.05 and 0.10.

For the four tested significance levels the following symbols were used in the template:

*** if trend at α = 0.001 level of significance,

** if trend at α = 0.01 level of significance,

* if trend at α = 0.05 level of significance,

+ if trend at α = 0.1 level of significance.

If the cell is blank, the significance level is greater than 0.1.

Changes were calculated by used MS Excels based on trend analysis results: Change = (last data year – first data year) × rate of change per year. Actual values were calculated by the equation: Actual value = (change + Intercept) and Prediction was calculated based on trend analysis results as equation of the lines: f (year) = change per year × (last data year-first data year) + Intercept.

Identification of GWTs critical depth

The suction-mode pumps like STW and HTW to lift water utilize atmospheric pressure. The standard atmospheric pressure is 1.034 kg/cm^2 equivalent to 10.34 m of water column. So, maximum theoretical lift for suction-mode pump is 10.34 m which reduces to 8 m due to frictional head losses in the piping system. Besides, dynamic drawdown also occurs during the pumping period that leads to head loss. In this study, average 2 m dynamic drawdown was considering for calculating the critical depth (maximum suction lift). The critical depth is 6 m for pumping groundwater by the suction-mode pumps.

3. RESULTS

Trend detection of Annual Maximum GWTs Depth

The trend and trend magnitude of annual maximum depth of GWTs show in **(Table 1)**. The trend of annual maximum GWTs depth observed increasing and decreasing magnitude over the time period from the 1997 to 2020. The annual maximum depth of GWTs had shown increasing trend in 109 wells and decreasing in 05 wells, among the 114 observation wells. The increasing trend indicated fallings the GWTs from ground surface and decreasing indicated rising the GWTs to ground surface. Among the 114 wells, 108 wells showed significant ($p \leq 0.05$) falling rate and 1 wells showed insignificant ($p \leq 0.05$) falling rate. Besides, water table was observed rising in 1 well significantly ($p \leq 0.05$) and 4 wells insignificantly.

From the results GWTs were falling in 100% of observation wells at Rajshahi, Pabna, Kustia, Magura and Jashore area**.** On the other hands, rising to the GWTs in 05 wells, located 2 in Natore (Boraigram and Lalpure), 1 in Harinakunda Upazila at Jhenaidah , 2 in Faridpur (Sadar and Nagarkanda). The annual maximum depth of GWTs declining rate was observed (3.57 to 6.42) myr^{-1} at Rajshahi, (0.55 to 5.95) myr^{-1} at Natore, (1.96 to 6.20) myr^{-1} at Pabna, (2.48 to 5.95) myr^{-1} at Kustia, (3.10 to 6.45) myr^{-1} at Jhenaidah, (2.85 to 6.37) myr^{-1} at Magura, (2.41 to 6.00) myr^{-1} at Jashore and (0.82 to 4.96) myr^{-1} at Faridpur, respectively.

Trend detection of Annual Minimum GWTs Depth

The trend of annual minimum depth of GWTs displays changed with increasing and decreasing magnitude over the time during 1997 to 2020 **(Table 1).** Among the 114 observation wells, significantly ($p \leq 0.05$) increasing trend or GWTs falling was found in 109 wells and in 1 well insignificant. Besides, the results also revealed, insignificant decreasing trend or GWTs rising was found in 4 wells. The annual minimum depth of GWTs declining rate was found (0.065 to 0.304) myr^{-1} at Rajshahi, (0.01 to 0.135) myr^{-1} at Natore, (0.053 to 4.190) myr^{-1} at Pabna, (0.034 to 0.132) myr^{-1} at Kustia, (0.004 to 0.0151) myr^{-1} at Jhenaidah, (0.046 to 0.125) myr^{-1} at Magura, (0.042 to 0.164) myr^{-1} at Jashore and (0.018 to 0.135) myr^{-1} at Faridpur, respectively.

Observation wells categorized based on their critical GWTs depth

Different groups of observation wells based on their critical GWTs depths at the period of 1997 to 2020 shows in **(Table S2).** The observation wells were categorized into three groups: (i) wells with GWTs below critical depth (6 m) during the whole year, (ii) wells with GWTs below critical depth for certain months of the year, and (iii) wells with GWTs above critical depth during whole year. From the results; large number of observation wells (97 out of 114) beyond their GWTs below the critical depth (6m) in the dry season and maintained an annual cycle of their GWTs. In dry season, STWs was not working due to suction lift limitation but it can easily to lift water at 3 to 6 months of year.

Entirely the observation wells (17) at Rajshahi had their GWTs always below the critical depth. At this area practically impossible to withdraw water by suction mode pump. Water scarcity occurs causes the failure of STWs because of the suction-lift limitation. This location of the study areas are required force mode pump instead of suction mode pump. The results also revealed that there were no wells having groundwater level always above suction limit in this study period at entire study area. This classification of observation wells was exposed the conditions of groundwater availability. These results also indicated which location is more suitable for which types of pump like suction mode or force mode. Noted here, HTWs were not created considerable drawdown of the GWTs during pumping and they can operate up to 8.0 m suction lift.

Table1. *MAKESENS trend analysis results for annual maximum and minimum groundwater levels.*

Well ID	GWTs depth Change rate (myr^{-1})		Well ID	GWTs depth Change rate (myr^{-1})		Well ID	GWTs depth Change rate (myr^{-1})	
	Annual Maximum	Annual Minimum		Annual Maximum	Annual Minimum		Annual Maximum	Annual Minimum
GT8112001	0.185	0.105	GT7605502	0.132	2.285	GT4419003	0.078	0.088
GT8112002	0.222	0.186	GT7605503	0.132	1.537	GT4419004	0.085	0.110
GT8112003	0.081	0.113	GT622504	0.272	2.424	GT4419005	0.108	0.057
GT8122005	0.175	0.154	GT7622013	0.257	1.970	GT4419006	0.034	0.077
GT8125006	0.043	0.162	GT7622014	0.407	4.190	GT4433006	0.074	0.091
GT8125008	0.102	0.130	GT7622015	0.250	1.395	GT4433007	0.071	0.068

GT8131015	0.391	0.065	GT7639017	0.081	1.480	GT4433008	0.069	0.083
GT8134016	0.196	0.155	GT7639018	0.042	1.994	GT4433501	0.083	0.151
GT8134017	0.089	0.179	GT7639019	0.048	0.053	GT4442502	0.090	0.098
GT8153030	0.244	0.197	GT7639020	0.039	2.710	GT4442009	0.055	0.072
GT8153031	0.464	0.086	GT7639021	0.069	2.920	GT4471011	0.048	0.088
GT8172032	0.344	0.304	GT7655022	0.110	3.311	GT4471012	0.091	0.083
GT8172033	0.352	0.097	GT7655023	0.083	2.847	GT4471503	0.454	0.055
GT8182041	0.123	0.093	GT7655024	0.134	1.806	GT5557001	0.060	0.123
GT8182042	0.204	0.113	GT7655025	0.072	4.014	GT5557002	0.052	0.061
GT8194044	0.152	0.105	GT7655026	0.066	2.015	GT5557003	0.175	0.046
GT8194046	0.143	0.235	GT7655027	0.071	2.347	GT5557004	0.052	0.071
GT6963011	0.129	0.064	GT7655028	0.075	2.526	GT5557005	0.045	0.089
GT6963012	0.056	0.021	GT7655900	0.092	2.221	GT5557501	0.292	0.125
GT6963504	0.043	0.135	GT5015004	0.077	0.132	GT5585008	0.336	0.048
GT6909501	0.112	0.106	GT5015005	0.043	0.089	GT5595009	0.097	0.098
GT6915002	0.065	0.060	GT5015006	0.083	0.034	GT5595010	0.083	0.107
GT6915003	0.100	-0.010	GT5015007	0.079	0.060	GT5595011	0.092	0.063
GT6915004	0.165	0.042	GT5015008	0.067	0.063	GT5595012	0.074	0.075
GT6915503	-0.024	0.119	GT5015501	0.031	0.125	GT5595013	0.065	0.112
GT6944006	0.006	0.114	GT5015900	0.068	-0.001	GT5595014	0.044	0.121
GT6944007	-0.012	0.057	GT5079024	0.025	0.044	GT5595015	0.073	0.106
GT6944009	0.036	0.012	GT5079025	0.066	0.103	GT4109002	0.060	0.042
GT6944010	0.038	0.079	GT5079026	0.161	0.067	GT4109003	0.062	0.155
GT6944502	0.076	0.135	GT5079504	0.166	0.116	GT4147003	0.113	0.115
GT6944505	0.245	0.064	GT5079505	0.073	0.077	GT4147004	0.153	0.164
GT7605500	0.050	2.139	GT4414001	0.236	0.004	GT4147005	0.094	0.087
GT7605501	0.115	2.113	GT4414002	-0.015	0.090	GT4147900	0.042	0.079

(Negative Sign indicate rising of GWTs, Significant level ($p \leq 0.05$))

Well ID	**GWTs depth Change rate (myr^{-1})**		**Well ID**	**GWTs depth Change rate (myr^{-1})**		**Well ID**	**GWTs depth Change rate (myr^{-1})**	
	Annual Maximum	**Annual Minimum**		**Annual Maximum**	**Annual Minimum**		**Annual Maximum**	**Annual Minimum**
GT4123006	0.252	0.046	GT2947505	0.141	0.135	GT2962010	0.029	0.035
GT4123007	0.238	0.126	GT2947506	0.040	0.018	GT2962011	0.050	-0.033
GT4123008	0.066	0.108	GT2947900	0.018	0.045	GT2962012	0.028	0.077
GT2947007	-0.022	0.034	GT2956009	0.072	0.280	GT2962013	-0.028	-0.054
GT2947008	0.027	0.038	GT2956010	0.076	0.050	GT2962014	0.007	0.034

(Negative Sign indicate rising of GWTs, Significant level ($p \leq 0.05$))

Table 2. Rate of change of average total rainfall of the study area (24 stations)

Name of Zilla	Number of rain gauge Station	Change rate (mmy^{-1})	Test Z	Actual annual average Total Rainfall at 2020 (mm)	Prediction of Rainfall (mm)	
					2030	2040
Rajshahi	4	-16.876**	-2.85	1542	1373	1204
Natore	4	-16.127**	-2.85	1562	1401	1239
Pabna	4	-17.411**	-2.85	1527	1353	1179

Kustia	2	-16.127**	-2.85	1562	1401	1239
Jhenaidah	2	-19.552**	-2.95	1470	1275	1079
Magura	2	-17.839**	-2.85	1516	1338	1159
Jashore	3	-12.701**	-2.85	1653	1526	1399
Faridpur	3	-26.402**	-3.05	1287	1023	759

(Negative Sign indicates decreasing of rainfall; "**" indicates significant level)

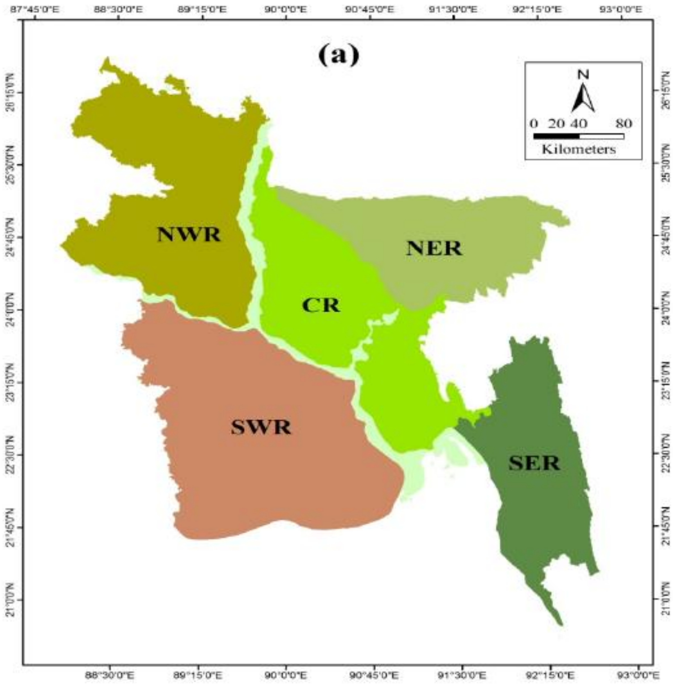
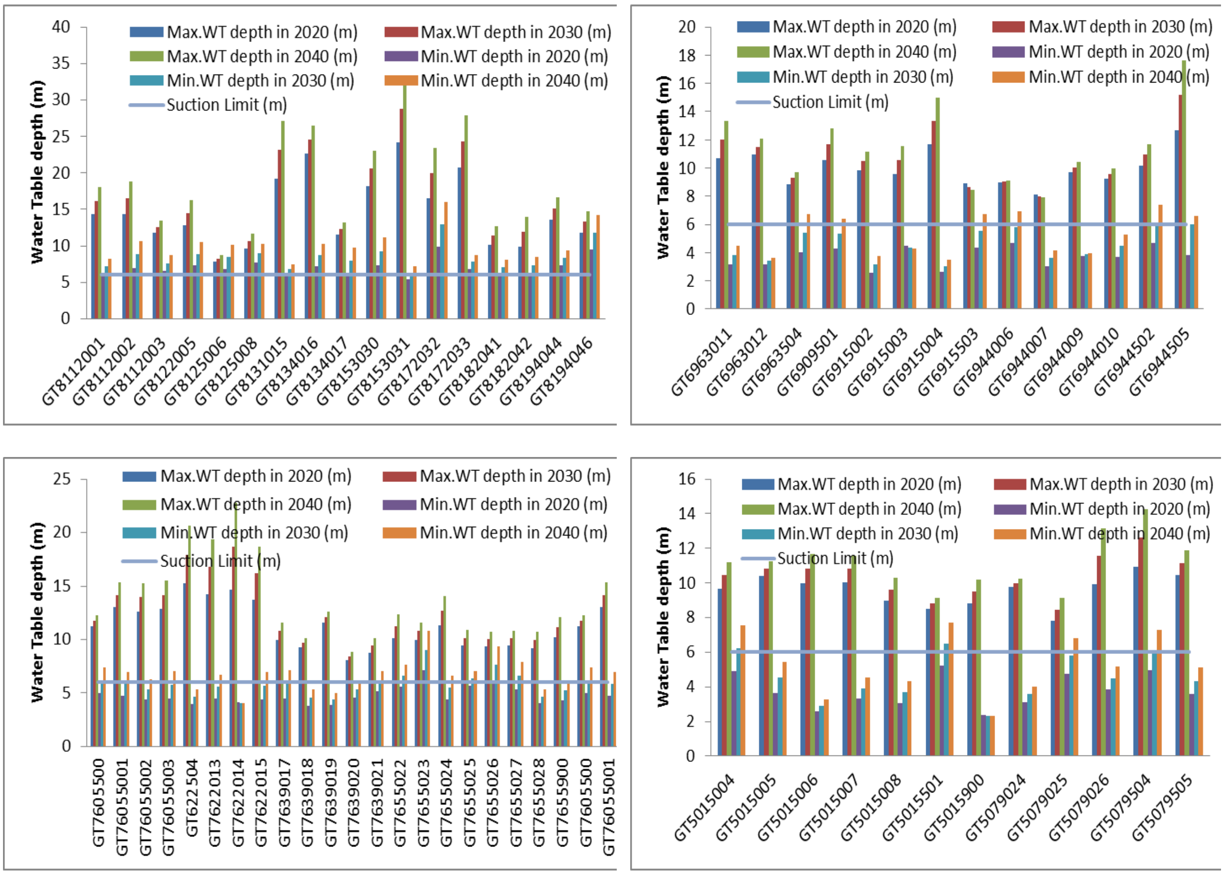


Fig1. *Hydrological Regions of Bangladesh*



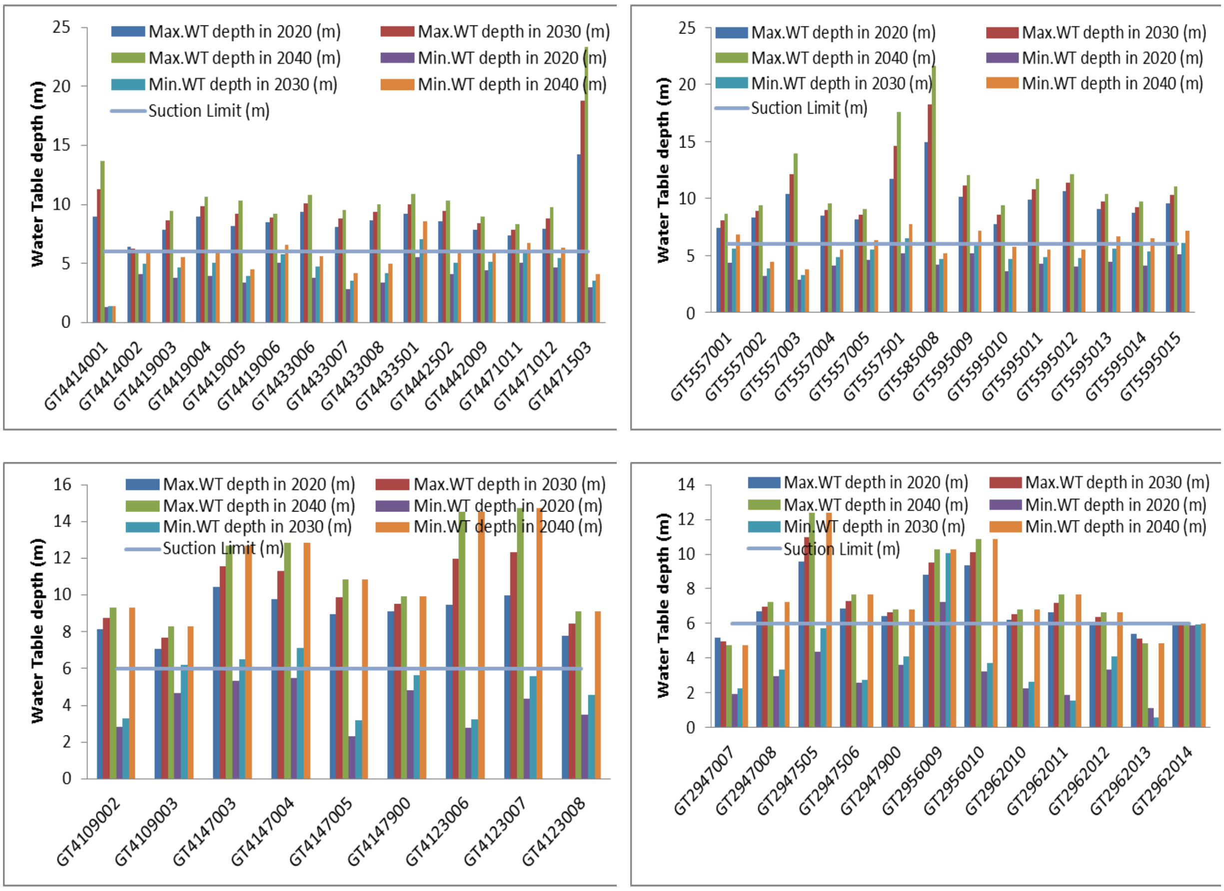


Fig2. *Present status and prediction of annual maximum and minimum GWTs depth*

Supplementary Materials

Table1. *Location of observation wells at the study area.*

Well ID	Name of the Zilla	Name of the Upazila	Well ID	Name of the Zilla	Name of the Upazila
GT8112001	Rajshahi	Bagmara	GT7639021	Pabna	Sadar
GT8112002	Rajshahi	Bagmara	GT7655022	Pabna	Sadar
GT8112003	Rajshahi	Bagmara	GT7655023	Pabna	Sadar
GT8122005	Rajshahi	Boila	GT7655024	Pabna	Sadar
GT8125006	Rajshahi	Charghat	GT7655025	Pabna	Sadar
GT8125008	Rajshahi	Charghat	GT7655026	Pabna	Sadar
GT8131015	Rajshahi	durgapur	GT7655027	Pabna	Sadar
GT8134016	Rajshahi	Godagari	GT7655028	Pabna	Sadar
GT8134017	Rajshahi	Godagari	GT7655900	Pabna	Sadar
GT8153030	Rajshahi	Mohanpur	GT5015004	Kustia	Bheramara
GT8153031	Rajshahi	Mohanpur	GT5015005	Kustia	Bheramara
GT8172032	Rajshahi	Paba	GT5015006	Kustia	Bheramara
GT8172033	Rajshahi	Paba	GT5015007	Kustia	Bheramara
GT8182041	Rajshahi	Puthia	GT5015008	Kustia	Bheramara
GT8182042	Rajshahi	Puthia	GT5015501	Kustia	Bheramara
GT8194044	Rajshahi	Tanore	GT5015900	Kustia	Bheramara
GT8194046	Rajshahi	Tanore	GT5079024	Kustia	Sadar
GT6963011	Natore	Sadar	GT5079025	Kustia	Sadar
GT6963012	Natore	Sadar	GT5079026	Kustia	Sadar
GT6963504	Natore	Sadar	GT5079504	Kustia	Sadar
GT6909501	Natore	Boraigram	GT5079505	Kustia	Sadar
GT6915002	Natore	Boraigram	GT4414001	Jhenaidah	Harinakunda
GT6915003	Natore	Boraigram	GT4414002	Jhenaidah	Harinakunda

GT6915004	Natore	Boraigram	GT4419003	Jhenaidah	Sadar
GT6915503	Natore	Boraigram	GT4419004	Jhenaidah	Sadar
GT6944006	Natore	Lalpure	GT4419005	Jhenaidah	Sadar
GT6944007	Natore	Lalpure	GT4419006	Jhenaidah	Sadar
GT6944009	Natore	Lalpure	GT4433006	Jhenaidah	Kaligonj
GT6944010	Natore	Lalpure	GT4433007	Jhenaidah	Kaligonj
GT6944502	Natore	Lalpure	GT4433008	Jhenaidah	Kaligonj
GT6944505	Natore	Lalpure	GT4433501	Jhenaidah	Kaligonj
GT7605500	Pabna	Atghoria	GT4442502	Jhenaidah	Kotchandpur
GT76055001	Pabna	Atghoria	GT4442009	Jhenaidah	Kotchandpur
GT76055002	Pabna	Atghoria	GT4471011	Jhenaidah	Mohespur
GT76055003	Pabna	Atghoria	GT4471012	Jhenaidah	Mohespur
GT622504	Pabna	Atghoria	GT4471503	Jhenaidah	Mohespur
GT7622013	Pabna	Chatmohor	GT5557001	Magura	Sadar
GT7622014	Pabna	Chatmohor	GT5557002	Magura	Sadar
GT7622015	Pabna	Chatmohor	GT5557003	Magura	Sadar
GT7639017	Pabna	Ishurdi	GT5557004	Magura	Sadar
GT7639018	Pabna	Ishurdi	GT5557005	Magura	Sadar
GT7639019	Pabna	Ishurdi	GT5557501	Magura	Sadar
GT7639020	Pabna	Ishurdi	GT5585008	Magura	Shalikha
			GT5595009	Magura	Shreepur

Table S1). *Location of observation wells at the study area (continued).*

Well ID	Name of the Zilla	Name of the Upazila	Well ID	Name of the Zilla	Name of the Upazila
GT5595010	Magura	Shreepur	GT4123008	Jashore	Monirampur
GT5595011	Magura	Shreepur	GT2947007	Faridpur	Sadar
GT5595012	Magura	Shreepur	GT2947008	Faridpur	Sadar
GT5595013	Magura	Shreepur	GT2947505	Faridpur	Sadar
GT5595014	Magura	Shreepur	GT2947506	Faridpur	Sadar
GT5595015	Magura	Shreepur	GT2947900	Faridpur	Sadar
GT4109002	Jashore	Bagharpara	GT2956009	Faridpur	Madhukhali
GT4109003	Jashore	Chaugachha	GT2956010	Faridpur	Madhukhali
GT4147003	Jashore	Sadar	GT2962010	Faridpur	Nagarkanda
GT4147004	Jashore	Sadar	GT2962011	Faridpur	Nagarkanda
GT4147005	Jashore	Sadar	GT2962012	Faridpur	Nagarkanda
GT4147900	Jashore	Sadar	GT2962013	Faridpur	Nagarkanda
GT4123006	Jashore	Jhikargacha	GT2962014	Faridpur	Nagarkanda
GT4123007	Jashore	Jhikargacha			

TableS2. *Observations Wells Categorized*

Wells having groundwater level below suction limit maintaining an annual cycle.				
GT6963011	GT7622013	GT5015007	GT4471503	GT4109003
GT6963012	GT7622014	GT5015008	GT4442502	GT4147003
GT6963504	GT7622015	GT5015501	GT4442009	GT4147004
GT6909501	GT7639017	GT5015900	GT4471011	GT4147005
GT6915002	GT7639018	GT5079024	GT4471012	GT4147900
GT6915003	GT7639019	GT5079025	GT5557001	GT4123006
GT6915004	GT7639020	GT5079026	GT5557002	GT4123007
GT6915503	GT7639021	GT5079504	GT5557003	GT4123008
GT6944006	GT7655022	GT5079505	GT5557004	GT2947007
GT6944007	GT7655023	GT4414001	GT5557005	GT2947008
GT6944009	GT7655024	GT4414002	GT5557501	GT2947505
GT6944010	GT7655025	GT4419003	GT5585008	GT2947506
GT6944502	GT7655026	GT4419004	GT5595009	GT2947900
GT6944505	GT7655027	GT4419005	GT5595010	GT2956009

GT7605500	GT7655028	GT4419006	GT5595011	GT2956010
GT76055001	GT7655900	GT4433006	GT5595012	GT2962010
GT76055002	GT5015004	GT4433007	GT5595013	GT2962011
GT76055003	GT5015005	GT4433008	GT5595014	GT2962012
GT622504	GT5015006	GT4433501	GT5595015	GT2962013
			GT4109002	GT2962014
Wells having groundwater level always below suction limit.				
GT8112001	GT8125006	GT8134017	GT8172033	GT8194046
GT8112002	GT8125008	GT8153030	GT8182041	
GT8112003	GT8131015	GT8153031	GT8182042	
GT8122005	GT8134016	GT8172032	GT8194044	

Present status and prediction of annual maximum and minimum GWTs depth

Present status and prediction of annual maximum and minimum GWTs depth shows in **(Fig. 2**). From the results, the present status of annual maximum GWTs depth was detected below the critical depth (6m) in all wells except 3 wells (GT2947007, GT2962013 and GT2962014). Both annual maximum and minimum GWTs depth was always below the critical depth at Rajshahi. The results also exposed 97 wells beyond their annual minimum GWTs depth above the critical depth in 2020, shrieked to 77 wells in 2030 and 37 wells in 2040. The results also revealed, the annual maximum GWTs depth (7.81 to 24.15 m in 2020) will fall more and more, touched (8.25 to 28.79) m in 2030 and (8.68 to 33.43) m in 2040 at NW region . At SW region, annual maximum GWTs depth (6.1 to 14.9 m in 2020) fall to (6.38 to 18.82) m in 2030 and about (6.66 to 23.36) m in 2040.

Rainfall trend

The trend of changes of average total rainfall shows in **(Table 2).** The rainfall was significantly decreased about 16 to 17 $mmyr^{-1}$ in NW region and 13 to 26 $mmyr^{-1}$ in SW region during 1997 to 2020. Total reduction of average total rainfall was calculated about 388 mm, 371mm, 400mm, 371 mm, 450mm, 410mm, 292mm and 607 mm at Rajshahi, Natore, Pabna, Kustia, Jhenaidah, Magura, Jashore and Faridpur respectively. The average annual total rainfall of entire study area was calculated about 1515 mm in 2020 by used MAKESENS software. Besides, predicted value of average annual total rainfall was also calculated 1336 mm in 2030 and 1157mm in 2040 at constant decreasing rate.

4. DISCUSSIONS

Annual maximum depth of GWTs was significantly ($p \leq 0.05$) falling in 108 wells where GWTs had been declining in the dry season over the years from 1997 to 2020. This is occurs mainly over exploitation of groundwater than recharging aquifer. These results agree with [11] where reported the falling trend of annual maximum depths of GWTs, thus, indicates an over-increasing extraction of groundwater in most parts in the NW hydrological region. The trend of annual fluctuation of groundwater table was declining in NW region; Rajshahi, Pabna were identified as the severely depleted areas, with depletion of GWTs between 2.3 m to11.5 m [12]. The annual abstraction of groundwater was increased for various usages those areas. The declining trend of the annual maximum depths of GWTs in the dry season over the successive years for most of the monitoring wells was largely due to increased abstraction of groundwater for increased cultivation of irrigated crops [5].

The falling trend of the annual minimum depths of GWTs indicated the depleted aquifers were not fully replenished due to a deficit in the amount of recharge during the main recharging period. The similar result was found that the actual recharge in some areas of the NW region was still less than potential recharging [6]. Resulting this incomplete replenished of aquifer leading to the effective mining of aquifer. On the other hands, rising the annual minimum GWTs depth exposed the aquifer was completely replenishment during monsoon after depletion in the dry season.

Low rainfall is one of the major obstacles to completely replenishment of aquifer. In Bangladesh rainwater is one of the major principle sources of ground water recharge that infiltrate and percolate through the unsaturated zone and lie above the water table also percolate to ground water. Most parts of the study area are flood-free zones and the main source of groundwater recharge is rainfall, which is also the lowest in this region. The annual total rainfall was decreased about -2.55mm/year at Faridpur, about -5.43 mm/year at Ishurdi, about -7.24 mm/year at Rajshahi; annual total rainfall and monsoon rainfall both are decreased in NW region of Bangladesh during 1948-2007[1].

STWs were adopted as a widespread irrigation technology in most parts of the study area, especially to support year-round rice production. However, this technology no longer remains technically feasible in most parts of study area due to declining groundwater levels. The non-functioning of STWs has created a number of negative impacts. GWTs remain below the suction lift limit throughout the whole year at Rajshahi district. For this reasons, many farmers as well as households depends entirely on DTWs at Rajshahi district. In most parts of the study area, GWTs remained below suction lift limit throughout the dry sessions (January to May) and maintained cycle with in suction lift limit at monsoon period. Consequently, STW users can no longer provide supplementary irrigation for aman rice in case of inadequate rainfall. The non-functioning of STWs for a few weeks or months in most parts of the study area reduces yields of the rabi crops by hindering adequate irrigation. When declining water tables approach the suction lift limit, this can cause a reduction in the discharge of many STWs, requiring more time to irrigate the same land area, leading to higher production cost. Many farmers as well as households depend entirely on DTWs located close by their localities; many of the DTWs also struggle to supply water during peak water demand in the rabi season. In some area, increasing STW failure is significantly curtailing the crop production and income of the farmers. Water crises affect both men and women in different ways. Millions of women carry a double burden of disadvantage from the water crisis. In rural Bangladesh, men are mainly engaged in irrigation, and women are primarily responsible for the collection of water for domestic use. DTWs and STWs are exclusively used for irrigation, whereas some STWs and all HTWs are used for domestic water supply. In the dry season, when STWs and HTWs become non-functional due to declining GWTs, women have to walk a significant distance to DTWs to collect water for domestic usage. The increased workload for women often causes delays or failure to perform their household obligatory activities, such as cooking, due to additional expense of both time and energy to collect water. Such situations often bring risks of normative marital male violence against women as a punishment for not performing their obligatory activities in a timely manner.

From the study results, it is clear maximum and minimum water table depth both are declining and depleted aquifers were not completely replenished. This study suggested must be applying groundwater recharge techniques for increasing groundwater recharge. Groundwater sustainability fully depended on limited amount of groundwater abstractions and maximum amount of groundwater recharge.

Rainwater harvesting in the existing ponds and canal can contribute to groundwater recharge. Adopting low water-demanding crops and cropping patterns, replacing rice with less water-demanding crops, water-saving techniques, mulching, conservation agriculture, direct seeding especially zero and strip tillage, direct-seeded rice or aerobic rice cultivation, raised-bed planting technology which can reduce groundwater abstraction from the aquifers or increase recharge to the aquifers. Besides, different water-conserving management practices like buried pipe for water distribution, alternate wetting and drying (AWD) irrigation method for rice, micro-irrigation, sprinkler irrigation, drip irrigation, deficit irrigation, alternate furrow irrigation can reduce cost of irrigation and increase irrigation command area. Otherwise, water-saving measures, such as high-velocity low-flow showerheads, dual-flush toilets, and sensor-activated faucets, can also be practiced at the household level. The advantages of above technologies also reduce groundwater abstraction and increase GWTs recharge at the study area.

5. CONCLUSION

Water table of an area is an important available identity to study aquifer and groundwater changes in the formation. The economy of an area depends mainly on the available water resources. Recently, it has been found from the study, the fluctuations of GWTs depth were varied spatially. Annual maximum and minimum GWTs depth both were exhibited a declining trend and depleted aquifers were not fully replenished. If the present trend of both groundwater tables is continued, suction-mode pumps may not operate at all due to the exceeding the suction limit. DTW is essential instead to STW for water extraction which leads to increasing wells installation and water extraction cost as well as agricultural production cost. To remedy these problems, we should be taken to groundwater development and use policy.

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Citation: *Roknuzzaman., "Trends in Groundwater Tables and Present Status of Irrigation Water in North West and South West Regions of Bangladesh .", International Journal of Research in Environmental Science (IJRES), vol. 7, no. 3, pp. 22-32, 2021. Available: DOI: http://dx.doi.org/ 10.20431/2454-9444.0703003*