ESTIMATION OF GROUNDWATER RECHARGE FOR SELECTED URBAN AREAS OF BANGLADESH USING WATER TABLE FLUCTUATION METHOD

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ABSTRACT

Water supply in the densely populated urban areas of Bangladesh for domestic and industrial purposes is mainly dependent upon groundwater extraction.The abstraction of groundwater beyond the recharge rate may lead to unsustainability and eventually depletion of groundwater aquifers. This study aims at determining the annual groundwater recharge in highly industrialized and densely populated areas of Dhaka, Narayanganj, Munshiganj, Manikganj and Gazipur districts of Bangladesh for the time period 2002-2010 using water table fluctuation method. Ten GW observation wells with water table readings at weekly intervals were selected to observe the annual time series of groundwater table fluctuation. This method is based on the presumption that groundwater table fluctuates when recharge water from the unsaturated zone enters the underlying unconfined aquifer. It is the simplest method of GW recharge estimation with minimum data requirements, which involves only the specific yield values of aquifer materials and time series data of groundwater table elevation. The specific yield values for the aquifer materials for the study area were approximated based on the lithologic data obtained from Borelog Data Book, Dhaka Division, (DPHE), and the GW table data were obtained from observation wells of Bangladesh Water Development Board (BWDB). From analysis, it was found that mean annual groundwater recharge was highest in Dhaka District (about 3000 mm/year) and lowest in Narayanganj District (about 1500 mm/year). The results of this study would provide useful information on the allowable limit of annual groundwater extraction, and emphasize on the need for conjunctive use for sustainable water management.

Keywords: *Groundwater recharge, Urban area, Water table fluctuation method, Borelog data, Specific yield.*

1. INTRODUCTION

Groundwater is a vital source of domestic, industrial and agricultural water supply in Bangladesh because of high yielding characteristics of aquifers, presence of GW table at shallow depths, ease of drilling into the unconsolidated sediments and minimum treatment requirements (Shahid, et al., 2015). Municipal water supply relies on deep groundwater aquifers, whereas, the irrigation water requirement during the dry period is fulfilled mostly by the shallow aquifers (Nowreen, 2017). Being the most densely populated city of the world, with over 47,400 people living per square kilometer, Dhaka is facing tremendous burden upon its resources including groundwater (Amin, 2018). The prevailing dependency on groundwater resources (about 87 percent of the supplied water) causes depletion at the rate of 2.81 m/year which may result in up to 120m lowering of groundwater table by 2050 (Uddin & Baten, 2011).

Since gaining independence in 1971, Dhaka was the focus of industrial development until very recently. Currently industries are being shifted to the neighboring areas of the capital such as Narayanganj, Munshiganj, Gazipur, Savar, Dhamrai, etc. due to government policy of industrial re-locating, excessive population, pollution, and traffic congestion of Dhaka city (Hassan, Alenezi, & Good, 2019). As a result, the neighboring areas of Dhaka, which were previously agrarian, are currently being transformed into industrialized and urbanized districts. The increased water demand for industrial, domestic and agricultural purposes, and reduction of GW recharge zones may result in gradual depletion of the GW aquifers as a consequence.

The GWT fluctuation method of recharge estimation has been applied and discussed in numerous literatures in a wide range of aquifer formations and climatic conditions. The simplicity and minimum data requirements of this method facilitated its application dating back to the 1920's (Meinzer & Stearns, 1929), where weekly records of 22 observation wells of GWT for the period 1913 to 1916 were used to quantify the changes of water storage in the saturation zone in the Pomperaug Basin of Connecticut.

Healy & Cook (2002) discussed the underlying theory, methodology as well as the applicability and limitations of this method. To achieve greater accuracy, they recommended this method to be applied for short time intervals, ranging from hours to a few days. However, it was suggested that to estimate gross change in groundwater storage, this method can be applied for time periods extending over a season or a year. The major advantages of this procedure enlisted by them were, it is independent of the mechanism by which water flows through the unsaturated region, and the GWT data is representative of an area expanding over several square meters, making it an integrated approach rather than a point measurement. However, one of the main limitations of this technique derive from the uncertainty in approximation of the specific yield values for different aquifer formations. Also, due to large spatial extent of the wetting front of deeper aquifers, they may not readily show fluctuations in response to groundwater recharge, and as a result, may not yield satisfactory results.

Application of GWT fluctuation method has been carried out in context of Bangladesh by Adhikary, et. al., (2013) and Shahid, et al., (2015). The study conducted in Kushtia District of the Gorai River Basin by Adhikary, et. al., (2013) showed spikes in groundwater table in coherence of the rainfall periods occurring during the same time interval. This study concluded that over the time period of 16 years between 1992 to 2007, the annual average recharge was 1413 mm, constituting 74% of the average annual precipitation (1898 mm). Shahid, et al., (2015) addressed the issue of GW over-exploitation in the Northwestern districts of Bangladesh by juxtaposing the water abstraction for irrigation and domestic purposes with the GW recharge rate.

The objectives of the current study are:

- Determine the specific yield values of the aquifer materials of the study area based on lithologic data
- Record the highest fluctuation of the GWT in response to recharge from GW data observation wells

- Determine the annual GW recharge at selected sites for the years 2002-2010, and compare the GW recharge values among various years and various sites.

1.1 Study Area

The study area consists of Dhaka and its surrounding four districts of Gazipur, Munshiganj, Narayanganj and Manikganj. Their corresponding areas are enlisted in Figure 1 below:

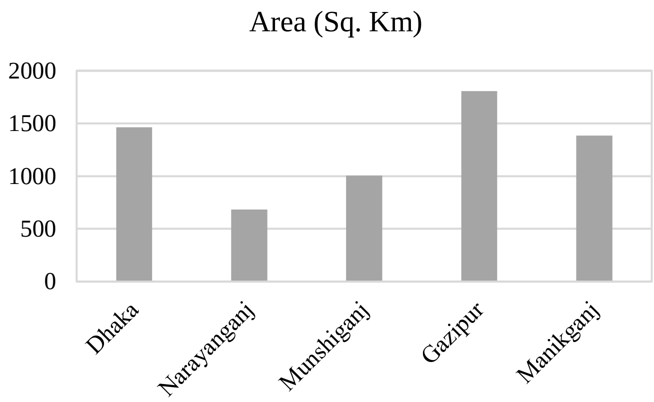

Figure 1: Areas of Selected Districts (Source: BBS 2013)

The selected areas are the focal points of various industrial, residential, commercial as well as agricultural activities. The major garments, textile, leather, jute, cement, steel and metal industries of the country are centered within these districts. Besides, remarkable portion of these districts are utilized as agricultural lands. The population densities vary from about 8229 persons per square kilometers in Dhaka to about 1007 persons per square kilometers in Manikganj.

Figure 2: Study Area Map Including Borelog and GW Data Stations

The study area falls within the tropical humid climate region, with average annual rainfall values varying from 1800 to 2200 mm. year^{-1}, and the bulk of the rainfall (about 80%) occurring during the tropical monsoon (May-September). Annual minimum and maximum temperature ranges between 12-34°C. In accordance with the dry and wet seasons, the troughs of the GW tables occurred in between the months of March-May and the peaks were observed in between August-November.

According to physiographic characteristics, Dhaka and Gazipur falls in the Pleistocene terraces in the Madhupur and Barind Tracts. The other districts of the study area fall within recent Holocene floodplains. Among them, Munshiganj and Narayanganj falls in the Old Brahmaputra Flood Plain, and Manikganj falls in the Brahmaputra-Jamuna Flood Plain. The Plio-Pleistocene aquifers of the Dupi Tila Formation account for 83% of the water supplied in Dhaka and Narayanganj cities by Dhaka WASA. (Zahid & Ahmed, Groundwater Resources Development in Bangladesh: Contribution to Irrigation for Food Security and Constraints to Sustainability, 2005) (Rahman, Wiegand, Badruzzaman, & Ptak, 2013). This aquifer formation is shown in Figure 3 below.

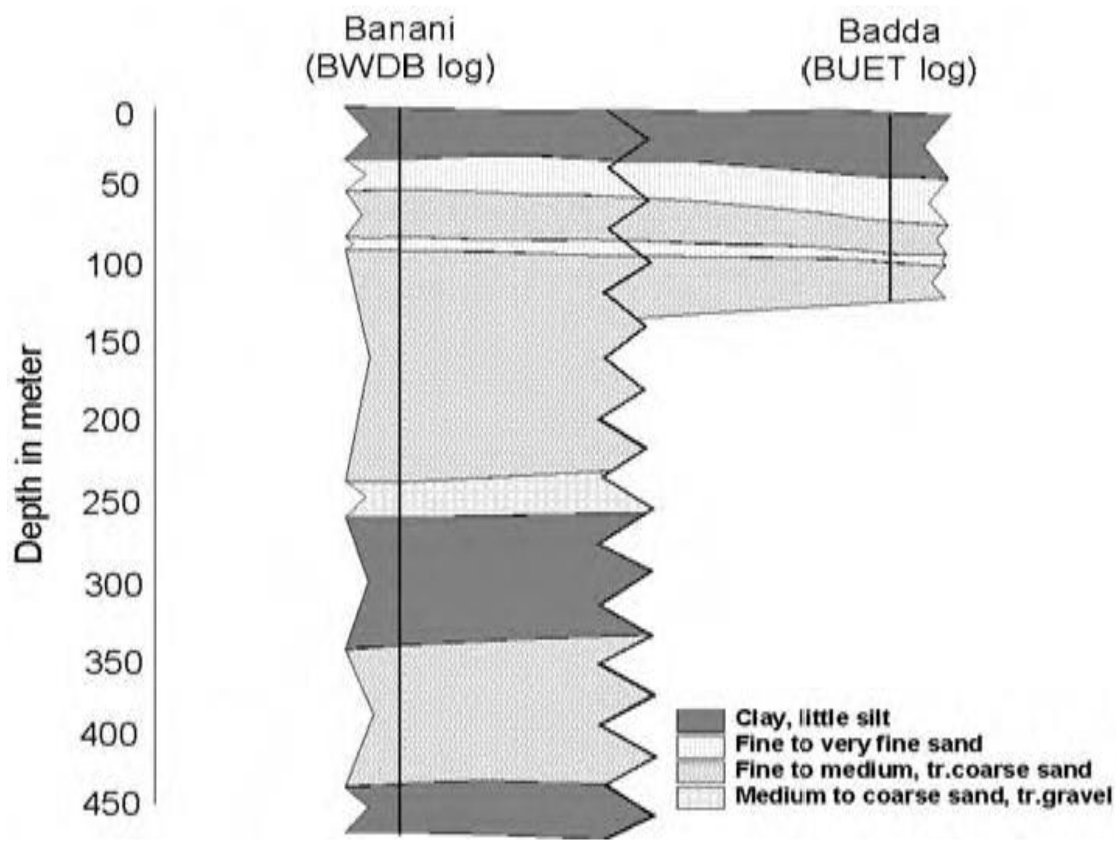

Figure 3: Peistocene Dupi Tila Aquifer of Dhaka City (Zahid, Hossain, Uddin, & Deeba, 2004)

In Manikganj District, the borelogs reveal that the upper aquifer materials consist predominately of fine to medium sand, up to depths of 50 meters. Coarse sand and silty clay could be found at depths exceeding 50m and 80m respectively. In Gazipur District, an upper aquitard layer consisting of clay was found up to 40 meters of depth, followed by silty clay (40-70m) and medium to coarse sand (70-160m). In Munshiganj, the upper aquifer consists of find sand up to depths of 40-60m, followed by medium to very coarse sands at larger depths. (Local Government Division, Ministry of LGRD & Co-operatives, Government of the People's Republic of Bangladesh, 2010).

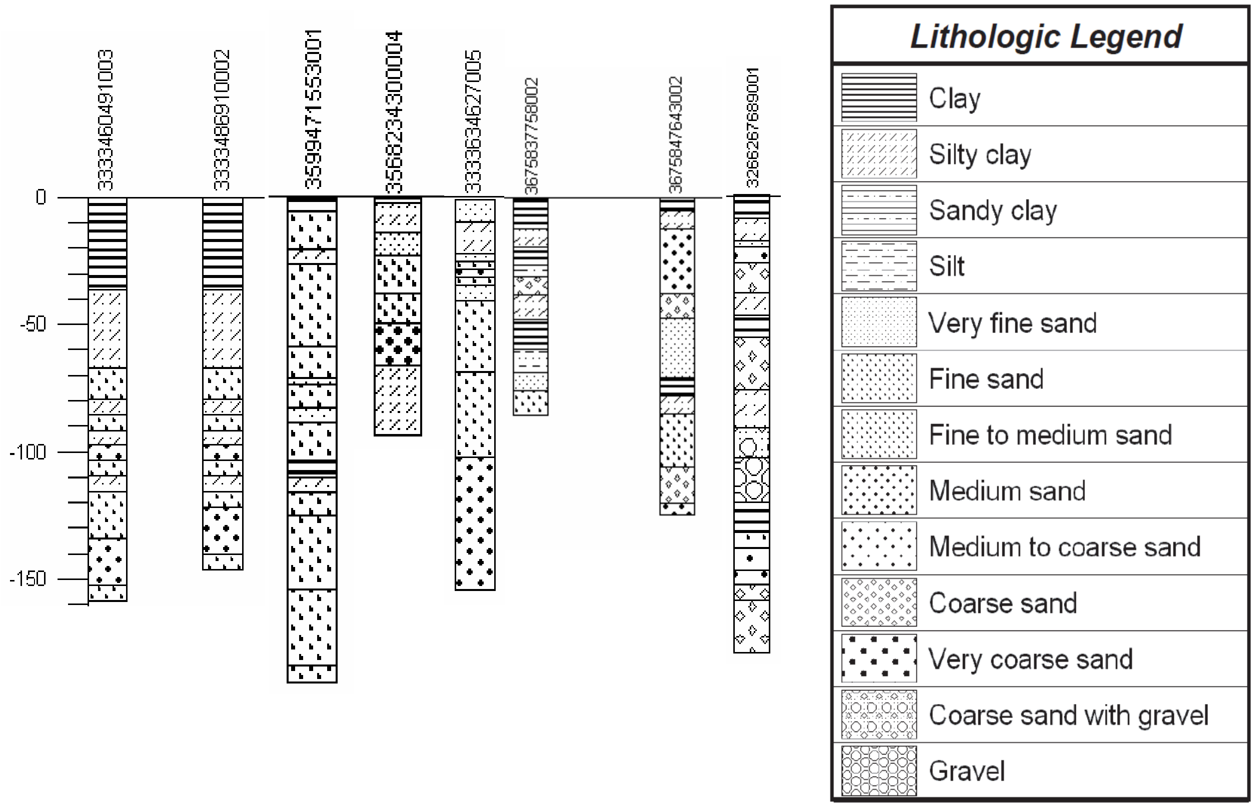

Figure 4: Lithology Data of the Selected Boreholes

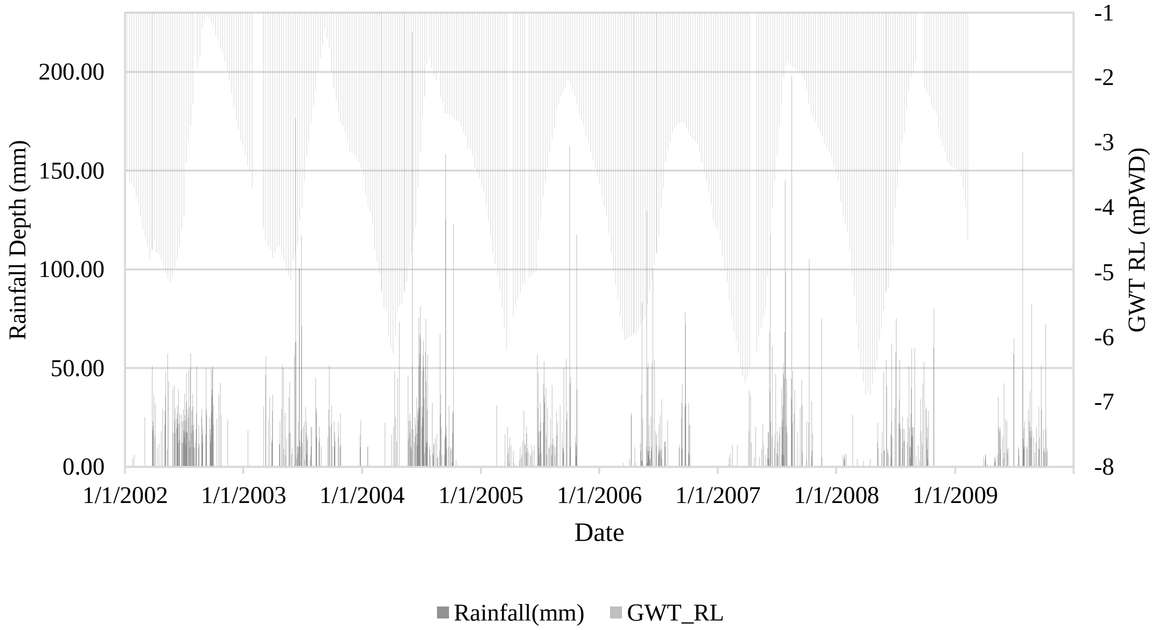

Figure 5: Fluctuation of GWT in response to rainfall at Kapasia Upazilla of Gazipur (Well ID GT3336012 and BWDB Rainfall Station ID CL37)

In the study area, 10 GWT observation wells of Bangladesh Water Development Board were selected. The lithologic data was obtained from the Bore log Data Book of Dhaka Division published by Department of Public Health Engineering (DPHE). The location of the GW observation wells and corresponding bore logs are given in Table 1 below:

Table 1: Location of Selected GWT Observation Wells and Borelogs

Sl. No.	District	Upazila	WellID	Latitude	Longitude	Borelog ID
1	Narayanganj	Narayanganj Sadar	GT6758005	23.65	90.51	5837758002
2	Narayanganj	Narayanganj Sadar	GT6758006	23.59	90.52	5847643002
3	Munshiganj	Tongibari	GT5994009	23.44	90.47	9471553001
4	Manikganj	Singair	GT5682015	23.77	90.14	8234300004
5	Gazipur	Kaliganj	GT3334009	23.96	90.54	3486910002
6	Gazipur	Kaliganj	GT3334010	24	90.58	3460491003
7	Gazipur	Kapasia	GT3336012	24.16	90.67	3634627005
8	Dhaka	Dhamrai	GT2614002	23.87	90.22	1453123000
9	Dhaka	Dhamrai	GT2614004	23.97	90.19	1477211001
10	Dhaka	Nawabganj	GT2662016	23.68	90.13	6267689001

2. METHODOLOGY

This method is based on the presumption that groundwater table fluctuates when recharge water from the unsaturated zone enters the underlying unconfined aquifer. The recharge (R) is determined using the following equation:

$$R = S_y \frac{dh}{dt} = S_y \frac{\Delta h}{\Delta t} \tag{1}$$

Where,
R = groundwater recharge (m/year)
S_y = specific yield (%)
dh = groundwater height between lowest and peak values (m)
dt = time (days)

In Equation 1, the specific yield value, S_y of a well was estimated by weighing the S_y values of each stratum against its corresponding depth, as given in Equation 2.

$$S_y = \frac{S_{y_1} \times thickness_1 + S_{y_2} \times thickness_2 + \cdots}{total\ thickness\ of\ the\ aquifer} \tag{2}$$

The specific yield values for various aquifer materials are enlisted in Table *2* below:

Table 2: Specific Yield Values of Various Aquifer Materials (Source: Johnson, 1967)

Material	Specific Yield (%)
Clay	2
Silt	8
Sandy clay	7
Fine sand	21
Medium sand	26
Coarse sand	27
Gravelly sand	25
Fine gravel	25
Medium gravel	23
Coarse gravel	22

The quantity Δh in Equation 1 reflects the difference in height between one trough and its succeeding crest, and Δt represents the corresponding time interval. These values were calculated from the GWT hydrographs. One sample calculation is shown below for GT2614004.

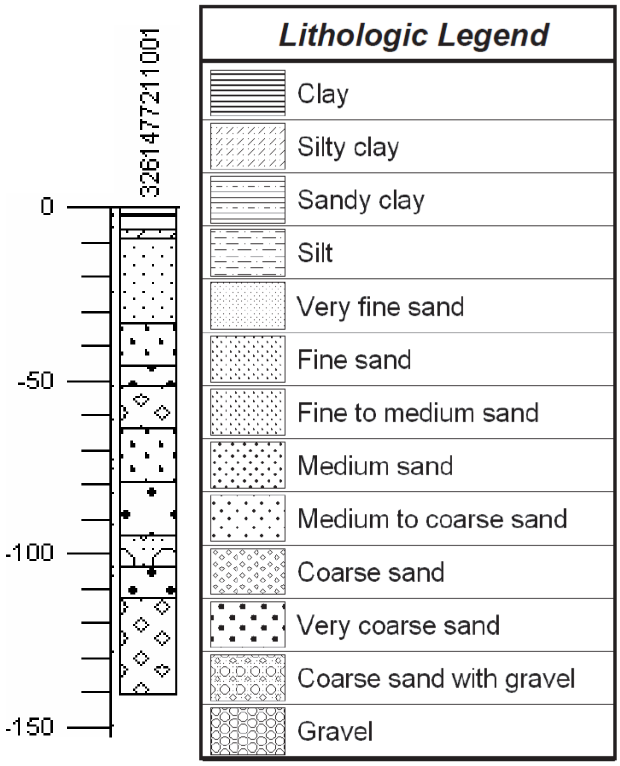

Figure 6: Lithology Data of Borehole of GT2614004

Table 3: Sample Specific Yield Calculation from Lithology Data

Depth(m)		Thickness(m)	Soil Type	Sy Value	Thickness*Sy
From	To				
0	6.5	6.5	Clay	0.02	0.13
6.5	9.03	2.53	Silty Clay	0.05	0.1265
9.03	33.34	24.34	Fine Sand	0.21	5.1114
33.34	45.52	12.15	Fine to Medium Sand	0.25	3.0375
45.52	51.27	5.75	Medium Sand	0.26	1.495
51.27	63.494	12.224	Coarse Sand	0.27	3.30048
63.494	78.864	15.37	Fine to Medium Sand	0.25	3.8425
78.864	94.214	15.35	Medium to Coarse Sand	0.265	4.06775
94.214	103.184	8.97	Coarse Sand with Gravel	0.25	2.2425
103.184	112.154	8.97	Medium Sand	0.26	2.3322
112.154	139.724	27.57	Coarse Sand	0.27	7.4439
Total		139.724			33.13

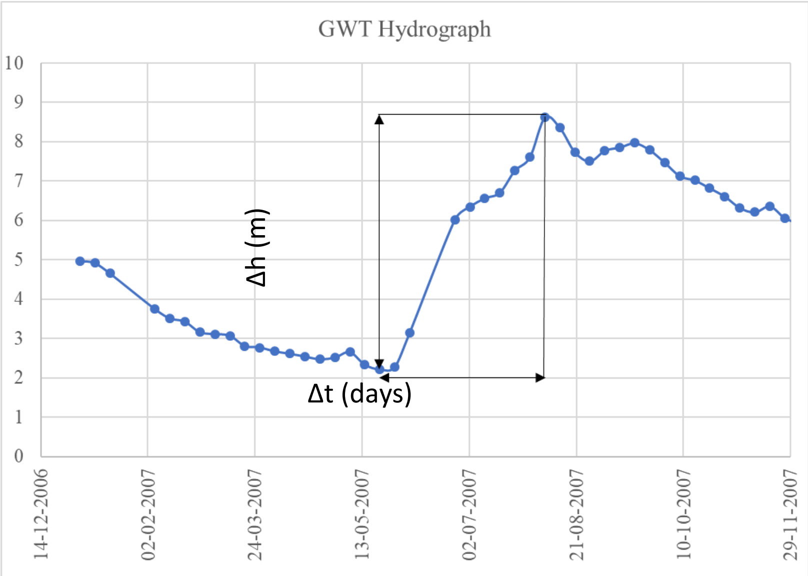

Figure 7: GWT Hydrograph for GT2614004 for the year 2007

S_y=33.13/139.724=0.237
From Figure 4,
Δh=8.62-2.21=6.41m;
Δt= (06-08-07) -(21-05-07) =77 days

Therefore, R=0.237x (6.41/77) =0.01973 m/day = 7201.26 mm/year

3. RESULTS AND DISCUSSIONS

1. From the 9 years' (2002-2010) 7-day hydrographs for different wells in the study area, it was observed that troughs of the hydrographs occurred in between April and May and peaks of the hydrographs occurred in between August and November, which is in accordance with the dry and wet periods of respectively.
2. From Figure 8, the maximum ground water recharge found for Gazipur district was 3500mm/year in the year 2004 in Kapasia Upazilla and the minimum yearly recharge was around 1500mm/year in the year 2005 in Kaliganj Upazilla. The average was found to be around 2200 mm/year.
3. In Dhaka District, GW recharge was observed to be maximum of about 7200 mm/year in the year 2007 in Dhamrai Upazilla and minimum of just below 1500 mm/year in Nawabganj upazilla. The mean annual GW recharge was about 3000 mm/year.
4. The overall annual groundwater recharge was found to be least in Narayanganj district. In 2010, the GW recharge fell as low as 110 mm/year in Narayanganj Sadar Upazilla whereas it reached its maximum in the year 2009 in Narayanganj Sadar Upazilla (GT6758006), with annual average recharge of about 1500 mm/year.
5. In Munshiganj, the groundwater recharge peaked in the year 2003 with about 3500 mm/year. It was minimum in the years 2002 and 2006, with a value of about 1900 mm/year. The mean annual recharge was about 2700 mm/year.
6. In Manikganj District, GW recharge was maximum in 2005 of about 1850 mm/year. The maximum value of 2550 mm/year was observed in the year 2002 and the mean value was observed to be around 2450 mm/year.
7. The annual GW recharge values did not follow any detectable trend.
8. The lowest annual GW recharge of Narayanganj Sadar Upazilla in GT6758005 can be attributed to its least conducive aquifer formation consisting mostly of clay and silty clay, with specific yield value of only 9.73%.

9. The large GWT fluctuation of 6.41m within a short time interval of 77 days gave rise to the highest groundwater recharge observed in Dhamrai, Dhaka in 2007. Although larger fluctuations of 7.10m was observed in Singair, Manikganj, within an interval of 119 days in 2007, the less conducive aquifer material (15% specific yield) resulted in much less groundwater recharge.
10. In the study area, the aquifers of Dhaka district were found to have higher specific yield values indicating their higher water yielding potential.
11. Although being located in close proximity, the recharge values at two GWT observation wells of Narayanganj District GT6758005 & GT6758006 showed large differences in annual GW recharge values due to sharp discontinuity in underlying hydrogeological formation, as evidenced from the borelog data.

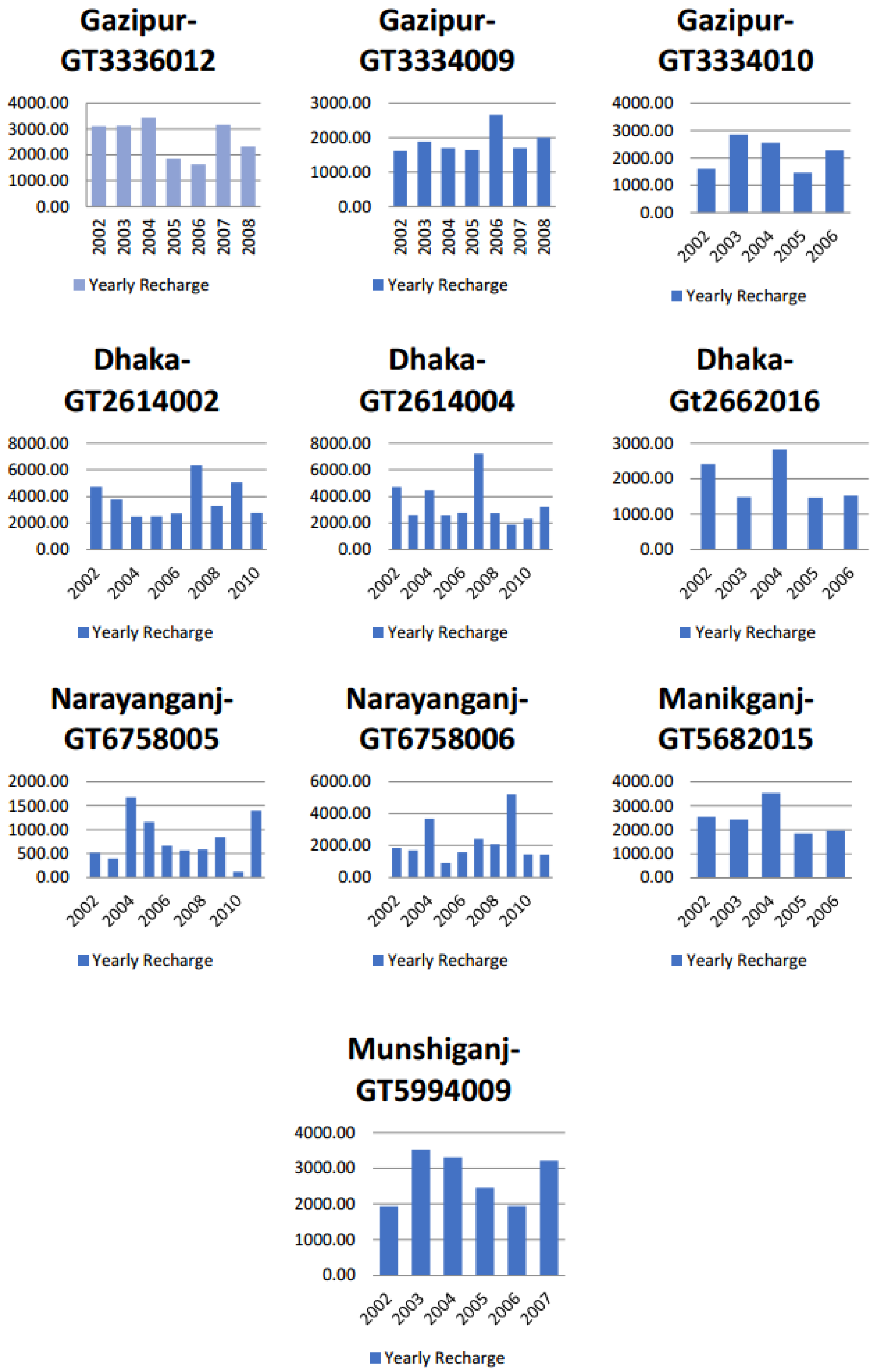

Figure 8: Annual GW Recharge Estimates at Various Locations of Study Area

4. CONCLUSIONS

1. From observation of the GW recharge patterns, it is evident that almost all the recharge occurs in the monsoon during the heavy rainfall period. The time of the rainfall recharge water to reach the GWT varied between 7 to 15 days. The rainfall occurring in the summer or winter periods are mostly converted to soil moisture or evaporation, and do not contribute to the GW recharge.
2. The annual GW recharge of the aquifers in Narayanganj were found to be significantly lower than the other districts, due to clayey lithology. As such, the aquifer in this area cannot be recommended for extraction of groundwater.
3. The aquifers of Dhamrai were seen to be recharged significantly, with annual GW recharge values exceeding 3000 mm/year. This can be a potential site for GW extraction for water supply in Dhaka city or the neighbouring semi-urban areas.
4. Based on the average annual GW recharge values, a safe yield value can be recommended for each of the aquifers of the selected districts. This safe yield value should be lower than the average annual GW recharge for sustainable groundwater exploitation.
5. At the time of conducting the study, time series data of GW level was available only up to 2010, with missing data values for periods greater than 3 months for some years, hence making the data of certain years unusable. Using recent data and longer time periods, the impact of land use change on GW recharge can be estimated. As all selected sub-districts of the study area are undergoing significant urbanization, the average annual GW recharge can be expected to decline in the recent and upcoming years.

5. RECOMMENDATIONS

1. A major drawback of the WTF method is the inaccuracy in estimation of the specific yield values. Similar geologic formations in different locations were seen to yield different specific yield values in previous studies. So, groundwater pumping test is required for accurate estimation of specific yield values, which was out of scope of the current study due to constraint of resources.
2. Besides GW recharge, GWT may fluctuate due to other causes such as air entrapment, GW pumping, changes in atmospheric pressure, etc. Also, a steady rate of recharge will not be reflected in the GWT hydrograph. In such cases, the WTF fluctuation method will not yield accurate results.

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