ASSESSMENT OF GROUNDWATER DEPLETION BY LITHOLOGICAL STUDY AND MAPPING WITH GIS: IN THE CONTEXT OF MAHADEVPUR UPAZILA

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ABSTRACT

Groundwater (GW) is the main source of irrigation for increasing crop production as well as for climate change adaptation owing to sustainable agricultural intensification in the northwest region of Bangladesh. In this study, successive depletion of groundwater level (GWL) with expansion of GW irrigation in Barind Tract has been discussed in the context of Mohadevpur Upazila of Naogaon District and is conducted to evaluate the nature of hydrograph which reflects the history of the behaviors of the parameters of the shallow aquifers on the basis of lithology and other parameters concerning GWL depletion. It has been observed that GW development; sources of recharge and properties of upper finer materials influence the GWL depletion phenomenon. Hydrograph analysis, GWL mapping, GW depletion rate calculation are done from GWL observation well data of Bangladesh Water Development Board (BWDB). For scaling adjustment both groundwater table (GWT) and lithology are plotted from the ground surface throughout the study and analysed for the understanding of the geology surrounding the observation wells. From our analysis it has been found that out of seven observation wells in the study area some of them show the declining trend of GWL and excessive withdrawal of GW exceeds the potential recharge for most of the observation wells. Crop diversification, artificial recharging, increasing dependency on surface water, increasing irrigation efficiency, rainwater harvesting etc. can be option for the area.

Keywords: *Barind tract, GWL depletion, hydrograph, lithology, potential recharge*

1. INTRODUCTION

Bangladesh is an agro based country and rice is the main agricultural product. The cultivation of rice in Bangladesh varies according to seasonal changes in the water supply. Rice in Bangladesh is grown in three distinct seasons, namely Boro (January to June), Aus (April to August), and Aman (August to December) covering almost 11.0 million hectares (ha) of land in Bangladesh (Awal & Siddique, 2011). Boro rice provided 56.47% and 55.77 % of total rice in Bangladesh in the year 2009-10 and 2010-11 respectively (Bangladesh Bureau of Statistics, 2011). But, in dry season Boro rice mainly depends on supplementary irrigation. In dry season surface water (SW) source becomes limited for irrigation. So, GW provides the major irrigation water which causes severe GW depletion and may be a great threat for future GW availability and irrigation ultimately. Northern part of Bangladesh is now facing water scarcity problems in both agriculture and secured livelihood (Alice, 2010). Barind Tract was excluded during 3000 Deep Tube well (DTW) installation programme of Bangladesh Agricultural Development Corporation (BADC) in North-west Irrigation Project considering as low potential area for GW development (Rahman & Mahbub, 2012).

GW recharge in Bangladesh is mainly take place by monsoon rainfall and flooding. Due to high elevation of Mohadebpur Upazila, it is located in flood free zone. So, main source of GW recharging in this area is rainfall, but lowest amount of rainfall occur in north western part of Bangladesh and the area has become very severely drought prone area. Moreover, thick sticky clay surface of Barind Tract act as aquitard which impede GW recharge and increase surface runoff. As a result, GWL in this part is successively falling by years with increasing withdrawal of water for irrigation (Rahman & Mahbub, 2012). To have proper monitoring on GWL and keep agriculture practice smooth, there is a need of analysis work for better crop yield; it is a must to keep the GWT within suction limit (Adhikary et al., 2014). Geological condition of an area governs the occurrence and distribution of GW, so evaluation is needed to measure the geological condition in this regard.

2. METHODOLOGY

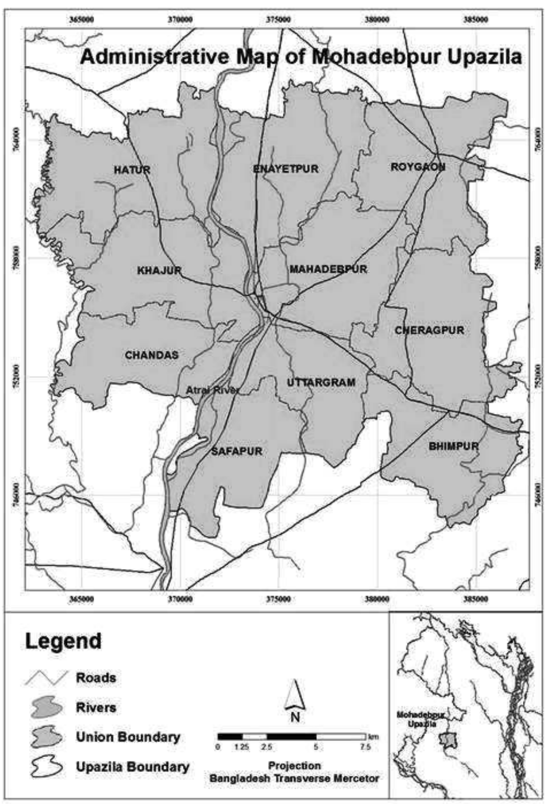
Secondary data is mainly used for this study. The study is based on GW monitoring piezometer data of BWDB from 1980 to 2012. Grided rainfall data from 1965 to 2012 which used in National Water Management Plan (NWMP) 2001 is used to carry out this study. Minor irrigation statistics are collected from BADC. Lithology of Mohadebpur Upazila is studied from borehole logs collected by Institute of Water Modelling (IWM) from Barind Multipurpose Development Authority (BMDA).

Seven piezometer data in around Mohadebpur Upazila are used for mapping of contour elevation of GWL of study area. GWL is referenced to a common datum (Public Works Datum, PWD) which was originally set to the mean sea level (msl). Groundwater depletion rate is calculated form the BWDB monitoring well. Mapping software ArcGIS 10.1 is used for mapping. Other data such as the land type data, crop coverage data etc are collected from Water Resource Planning Organisation (WARPO).

3. RESULTS AND DISCUSSIONS

3.1 Location of the Study Area

Mohadebpur Upazila is located at Naogaon District in the Division of Rajshahi. It is bounded by Patinitala on the north, Manda and Naogaon Sadar on the south, Badalgachhi and Naogaon Sadar on the east and Niamatpur and Porsha on the west. Main river of this area is Atrai river. Mohadebpur Upazila consists of ten (10) Unions. Figure 1 shows the administrative location, location of BWDB observation wells and general information of Mohadebpur Upazila.



District	Naogaon
Upazila	Mohadebpur
Geocode	56450
MPO Code	324
Region	NW
Gross Area (ha)	39101
Net Cultivable Area (ha)	28533

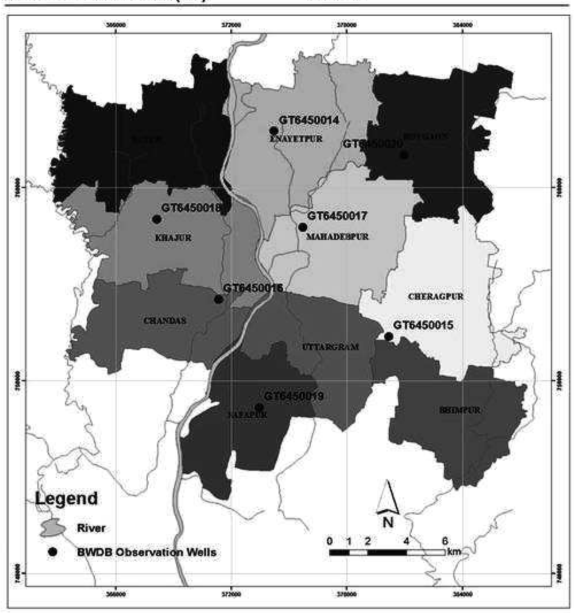


Figure 1: Administrative map and location of BWDB observation wells of Mohadebpur Upazila

3.2 Observation Wells

There are seven BWDB monitoring wells in Mohadebpur Upazila. They are surrounded uniformly all over the Upazila area. Locations of these wells are shown in figure 1. Among these wells the monitoring well bearing GT6450020 is showing the most development of GW which is located in the north-eastern part of the upazila. The monitoring wells bearing GT6450015, GT6450016, GT6450017 and GT6450018 are also showing development in the recent past. The hydrograph of these seven observation wells are shown in Figure 2 and the depletion rate is shown in table 1.

Table 1: Calculation of depletion rate (m/yr) of GW in dry period

	GT6450015	GT6450016	GT6450017	GT6450018	GT6450020
Rate of Depletion (considering 1992 to 2012)	0.06	0.08	0.13	0.13	0.33
Rate of Depletion (considering 2005 to 2012)	0.14	0.94	0.18	0.30	0.99

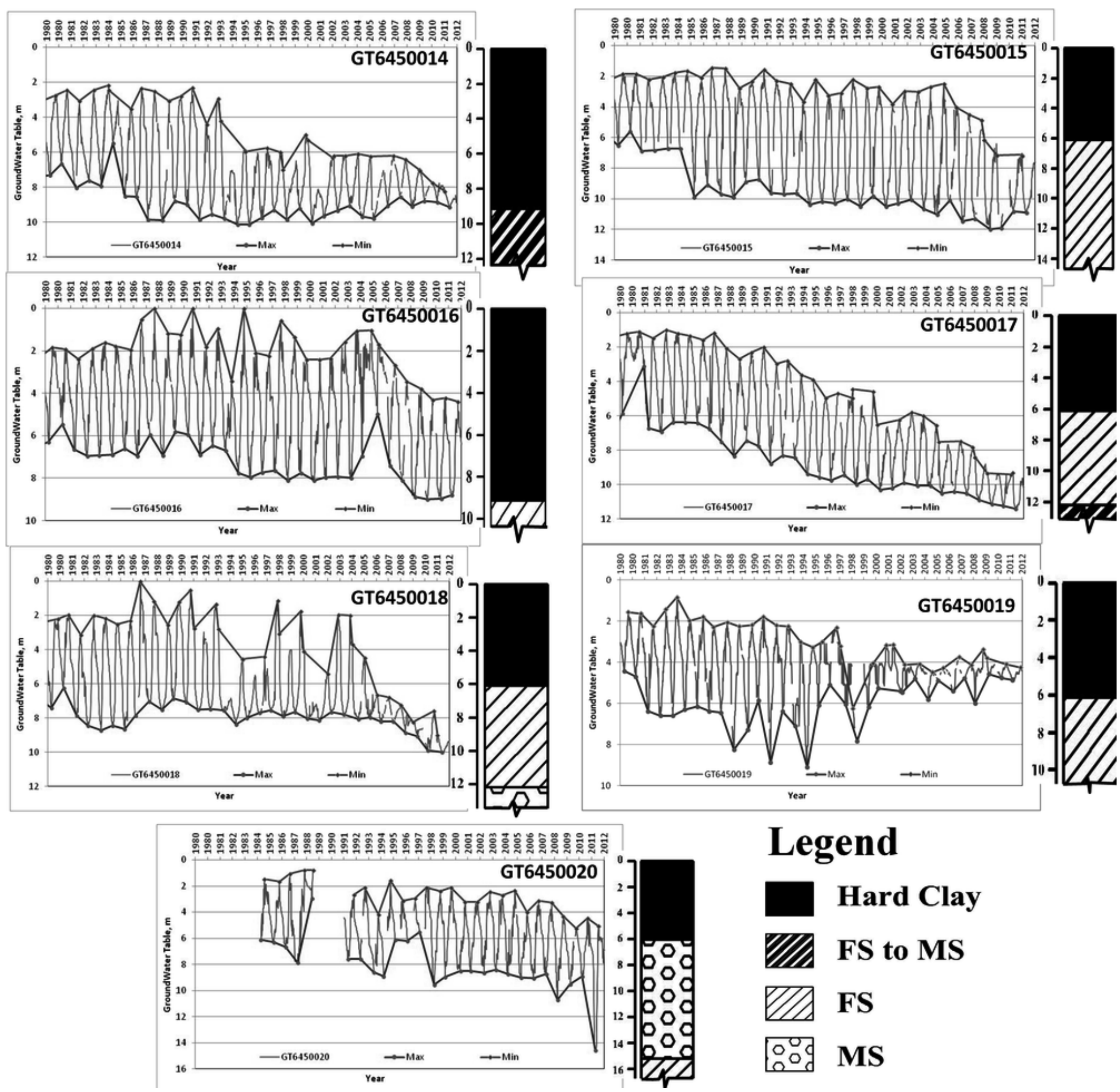


Figure 2: Hydrograph of seven BWDB observation wells

From table 1 we can illustrate that the rate of depletion of GW is increased immensely from year 2005 and for observation well GT6450020 and GT6450016 it is almost 1 m/yr.

3.3 Geology

The most significance to hydrograph analysis are the thickness and composition of the aquifer and the characteristics of the deposits that overly the aquifer (upper layer). With respect to the latter it is important to identify if extensive clay layers confine the aquifer. The Level Barind in the northwest region contains a blanket of contiguous clay with limited variability in thickness. In contrast, in the Atrai basin, considerable clay thickness can occur, but this spatially more variable and the clay is of a different composition. Figure 2 shows the nearby lithologs of the BWDB observation wells. From the lithologs we can perceive that there exists a thick clay layer in and around the observation wells and it varies around 6 to 9 m. Figure 3 shows the upper clay distribution of Mohadebpur Upazila where it gives us an idea that the eastern part of the Upazila possesses less upper clay layer than the western part. A probability lithological log is also included based on all boreholes within the upazila (Figure 3). Based on probability information it is clearly observed that the aquifer is partially connected up to the bottom of the upper finer materials. The probability log also supports the thick clay bed. A thick aquifer is also exist there below 20' (6 m) of ground surface.

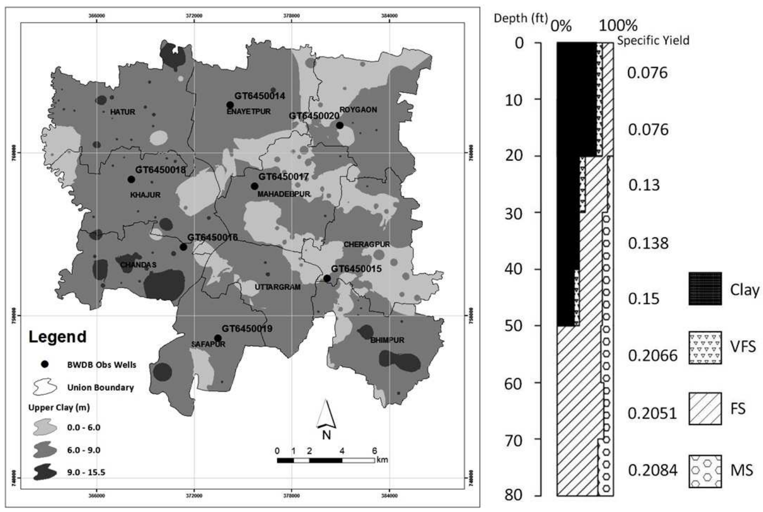


Figure 3: Clay thickness map and probability lithological log of the study area

The hydrostratigraphic section study reveals that there exists a four-layer system with an upper layer comprising hard clay underlying a layer comprising fine sand, medium sand and fine to medium sand which is followed by a thin plastic clay layer and finally the bottom layer is dominated by medium sand and coarse sand with gravels (Figure 4).

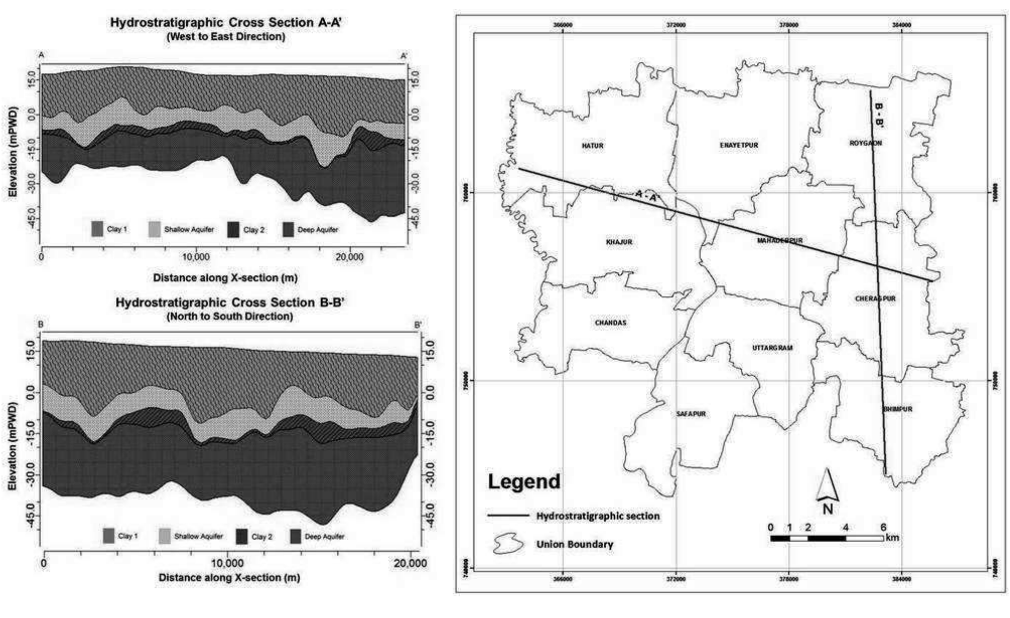


Figure 4: Hydrostratigraphic section

3.4 Physiography, Land Form and Soils

Mohadebpur Upazila exhibits three physiographic units naming Teesta Meander Floodplain at the middle surrounded by, Level Barind Tract and a few portion of Lower Atrai Basin at the south of Upazila. Teesta

Mendering Floodplain possesses ridge soils generally silty and basin soils which is mostly shallowly flooded by runoff from local rainfall and raised GWT. The characteristics of Lower Atrai Basin is quite similar to Teesta Mendered Floodplain possesses heavy clay soil. Deep flooding may occur due to heavy rainfall. Level Barind Tract exhibits seasonal flooding which is shallow and is caused by rainwater which is retained within field bunds on the relatively higher parts of the relief. Flooding becomes deeper in the south towards the margin with the Lower Atrai Basin. Figure 5 shows the physiographic map and drainage map of Mohadebpur Upazila.

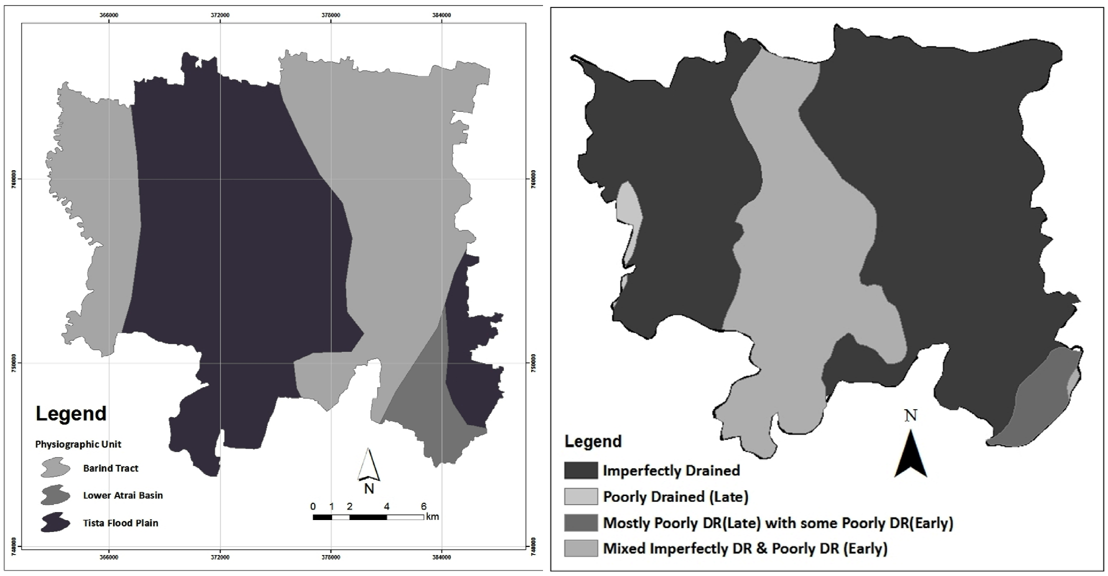


Figure 5: Physiographic map and drainage map

From figure 5 it is observed that the Teesta Flood Plain is both imperfectly drained and poorly drained where Level Barind Tract is mostly imperfectly drained. Poorly drained area is spotted in the western part of the Upazila.

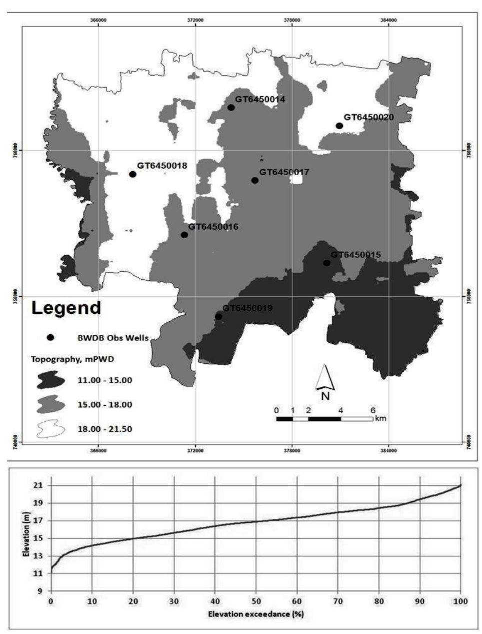


Figure 6: Digital elevation model and area-elevation curve

Figure 6 shows the digital elevation model of Mohadebpur Upazila which is sloped from north-west to south-east. The elevation of the Upazila varies from 11 mPWD to 21.5 mPWD. Figure 6 also shows the area-elevation curve of Mohadebpur from where we can calculate the relief differences for the Mohadebpur. Table 2 shows the relief differences for Mohadebpur.

Table 2: Relief differences of Mohadebpur Upazila

Land types	**Homestead (HO)**	**High land (H)**	**Medium high land (MH)**	**Medium low land (ML)**	**Low land (L)**	**Bottom land (B)**	**Open water (OW)**
Flood phase as % of gross area	8.22	76.10	8.56	4.67	2.28	0.00	0.17
Weighted average elevations (m)	20.28	17.04	14.29	13.45	12.27	11.46	11.46
Relief difference from area-elevation curve analysis (m)			2.75	3.59	4.77	5.58	5.58
Average elevation (m)				16.78			

From the Table 3 we can clearly obtain that the dominating land type for Mohadebpur Upazila is high land permeable (68.97%) and the dominating soil type is silty clay. Significant quantity of direct recharge can be retained from the rainfall as the dominating land type part is permeable.

Table 3: Percentage of land type and soil type in Mohadebpur

Land type	**Percent**	**Soil Type (%)**							
		Fine Sandy Loam	**Silt Loam**	**Loam**	**Silty Clay Loam**	**Clay Loam**	**Basin Clay**	**Silty Clay**	**Sandy Clay Loam**
High Land Permeable	68.97	7	17					76	
High Land Impermeable	7.13				4	96			
Medium High Land Permeable	5.9		29		54	17			
Medium High Land Impermeable	2.66				99		1		
Medium Low Land Permeable	0.01		100						
Medium Low Land Impermeable	4.66		56				44		
Low Land	2.28						100		
Bottom Land	0						100		
Open Water	0.17								
Homestead	8.22						100		

Piezometers are most often located on highest ground (generally village mounds). Relief differences largely control the early recession of the hydrograph after the monsoon. Rapid recession may indicate low land near the piezometer and rapid lowering of flood levels during October and November. In areas where local relief is minor and thus piezometers are located on land surrounded largely by high land, early recession is generally slow.

3.5 Rainfall

Rainfall may have a significant influence on GWL behaviour both directly (through direct recharge) or indirectly (contribution to flooding of low lying areas). Annual rainfall, as well as cumulative deviations from the long-term average for different time periods is show in Figure 7. The long term average (LTA) annual rainfall is 1524 mm with a range from 886 to 2115 mm which is way below the average rainfall of yearly rainfall in Bangladesh. There is a slight downward trend in the annual rainfall, but this is largely due to the below average rainfall that has persisted from 2005 to 2012. This is clearly indicated at the cumulative deviation of annual rainfall, which shows a significant decline over that period, indication of prolonged and significant rainfall deficit. The period from 1975 to 2004 has shown a steady increase in the cumulative deficit. Cumulative deficits are also shown for the main irrigation period (January to early May) and for the T Aman period (August to October). These also show declining trends for the period from 2005 to 2012.

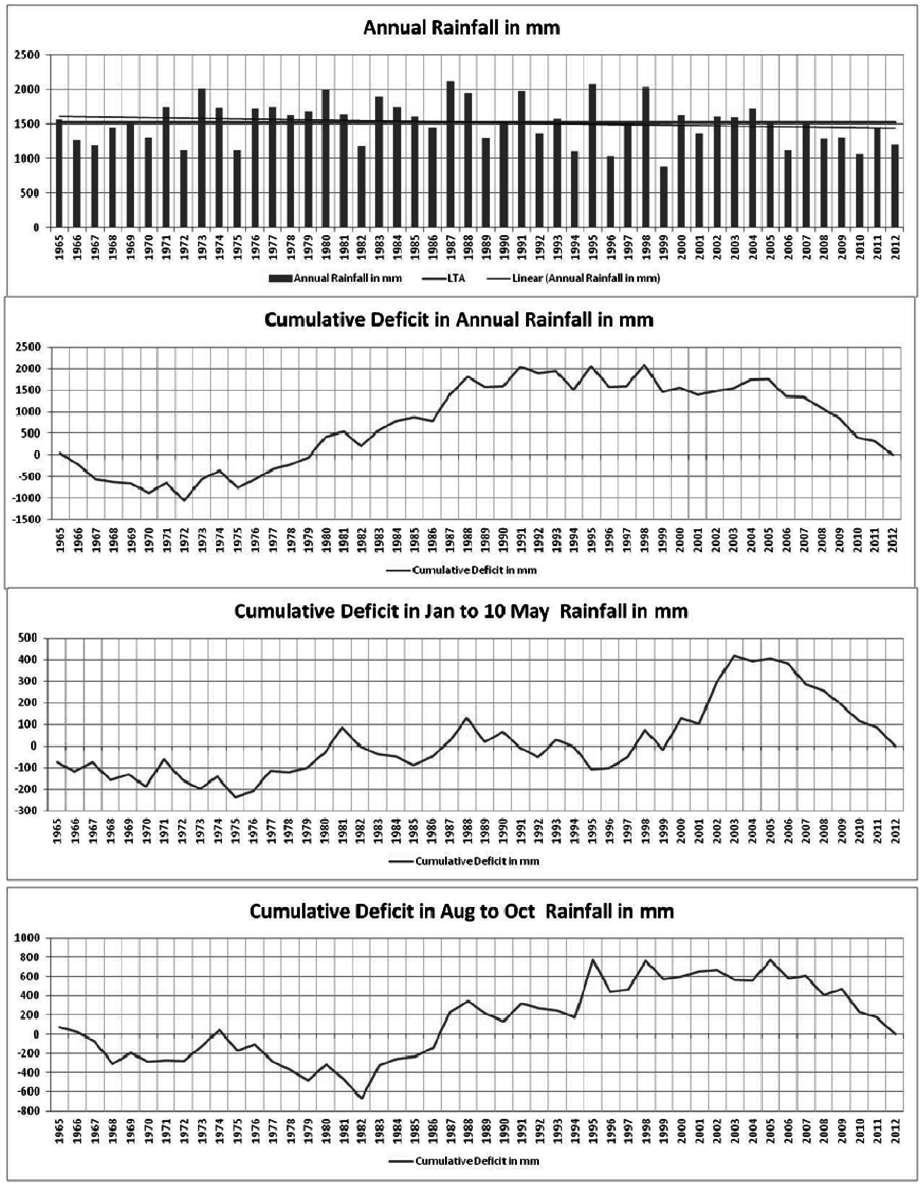


Figure 7: Rainfall trend for Mohadebpur Upazila

3.6 Flooding

It is previously found that most of the Upazila is dominated by high land and figure 8 shows us that high land (F0) is not at all flooded while medium high land (F1) is partially flooded. Table 4 shows average elevation of different land type.

Table 4: Relief differences and elevation of different land type

	Average elevation	F0	F1	F2	F3	F4	OW
Relief Differences		0	2.75	3.59	4.77	5.58	5.58
Elevation	16.78	17.44	14.69	13.85	12.67	11.86	11.86

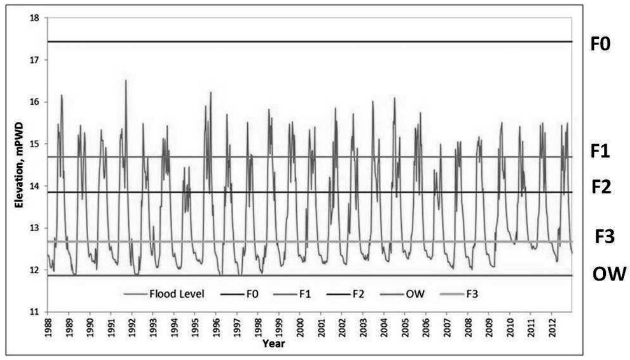


Figure 8: Flood hydrograph of Mohadebpur Upazila

3.7 Land use

Irrigation development with use of GW impacts on GWL. The historical development is shown in table 5 and figure 9. From table 5 it is observed that the use deep tubewell is increased from 2005 and it is almost double the value of 2004. Figure 9 it is shown that the percentage of gross area irrigated by GW resources and SW resources.

Table 5: Minor irrigation statistics of Mohadebpur Upazila

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012
DTW (ha)	5073	11400	10330	13546	14085	17489		18674	17600
STW (ha)	14376	14195	15750	20190	16665	15072			16035
LLP (ha)	297	205	235	230	170	310	103	138	210
Total STW (nos)	10368	10713	10971	11554	11275	11542	14603	13540	15578
Total DTW (nos)	201	512	510	525	549	568	570	571	572

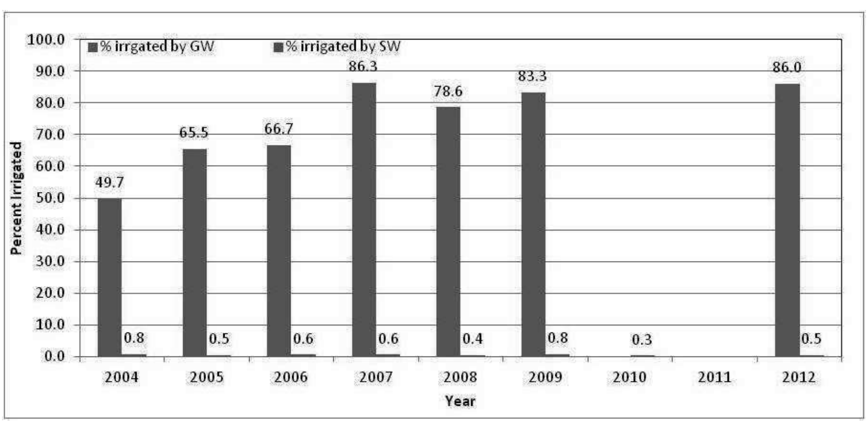


Figure 9: Percentage of area irrigated by GW and SW resources

In the study area, main crops are rice-paddy, jute, wheat, sugarcane and variety of vegetables and they grow in rain fed and irrigated condition. Different fruit trees grow all round the year. Boro, Wheat, potato, oilseeds and winter vegetables are the main Rabi (November to March) crops, while Kharif-I (April to June) crops are HYV Aus, B. Aus, Jute and summer vegetables and Kharif-II (July to October) grow HYV Aman, Local Variety Aman and rainy season vegetables. Sugarcane grows over the year. The major cropping pattern is Boro – Fallow – T. Aman prevails within the study area. It may be mentioned here that recent development of vegetable seed is also becoming a popular practice. Drought and inadequate irrigation facilities are the major limitation to intensive land use and optimum crop production. During Rabi season much of the lands remain barren. Figure 10 shows the distribution of the DTW in the study area and the homestead in and around the study area.

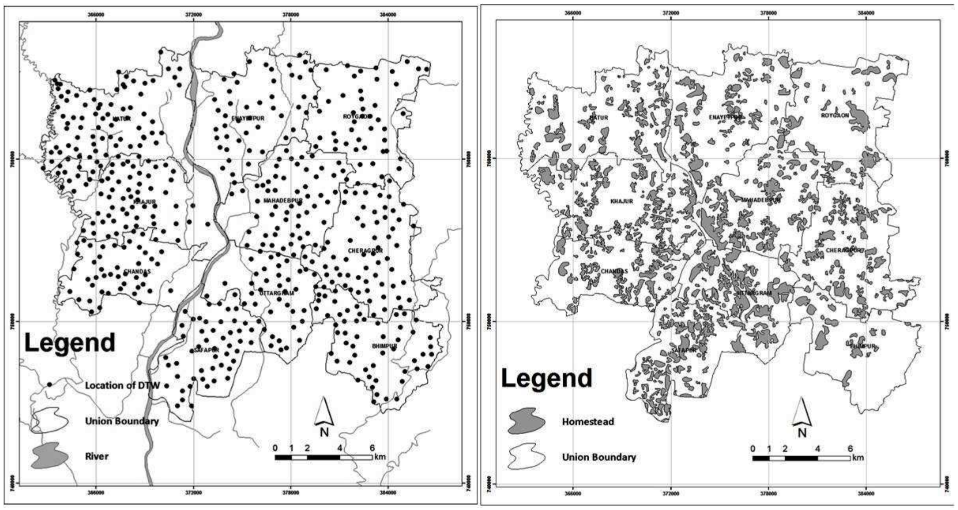


Figure 10: Distribution of DTW and homestead of the study area

3.8 Subsurface Flow Direction

GWL data of an aquifer system shows the direction of the subsurface flow in the aquifer. Figure 11 shows GWL contours for different time periods (2012) based on GWL obtained from monitoring wells. The objective to draw flow net is to determine the directions of subsurface flow in and around the study area. Two flow nets are prepared at a contour interval of 1m (Figure 11), one for maximum elevation and other for minimum elevation considering the data of 2012. When the elevation is maximum it tends to move towards the middle of the Upazila while during dry season, it tends to move toward south-west to north-east of the Upazila which indicates that there is a close SW-GW interaction in the aquifer system.

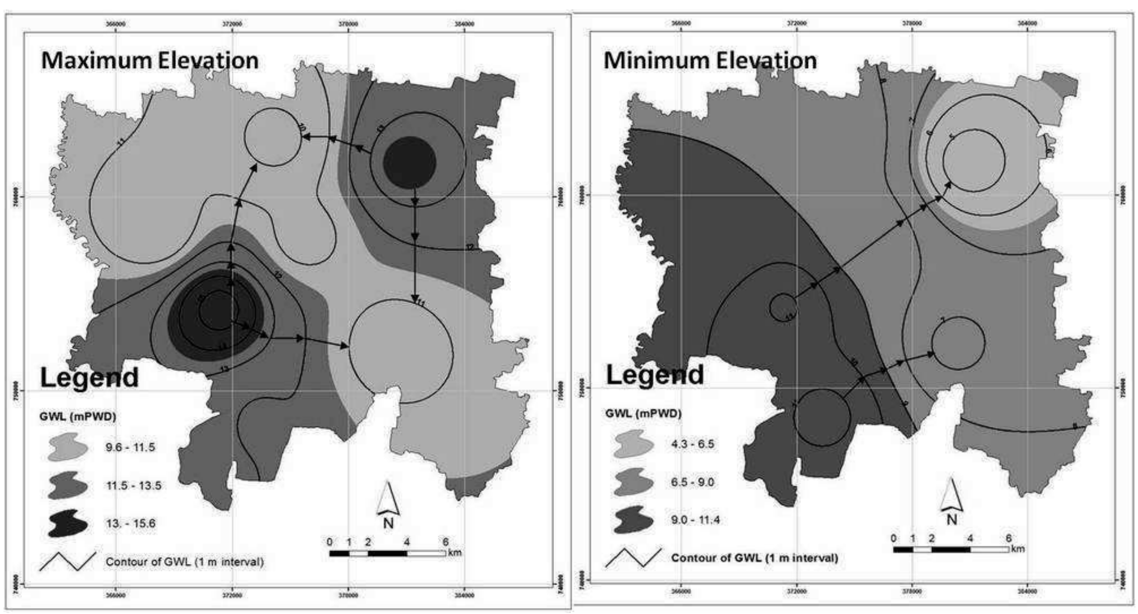


Figure 11: Sub surface flow direction of GWL in Mohadebpur Upazila in 2012

4. CONCLUSIONS

From overall assessment it is evident that both maximum and minimum GWL of the study area are depleting. The declining rate of GW in GT645000 is almost 1 (0.99) m/yr in the recent year. From the hydrostratigraphic section study it is obtained that there exists a four layer aquifer system and the upper aquifer is narrowed down in the east of the Upazila. Borelog analylsis shows that all the piezometer wells have thick upper clay layer varying from 6 m to 9 m and the thickness of the upper clay layer is increasing from north east to south west. Rainfall statistics shows us that the rainfall is comparatively very low in comparison with the average annual rainfall for the whole country which is a major reason behind the low recharge scenario. Mohadebpur Upazila is dominated by high land and significant amount of flooding does not occur in this region. The subsurface flow net study shows that there is an interaction between SW and GW. Agriculture is very important in the context of Bangladesh because to feed a huge number of population. The statistics shows that from 2005 the agricultural development is increased immensely which is the major reason for GW depletion. Crop diversification from water consuming crop (paddy) to less water consuming crops (vegetables, fruits etc.), artificial recharging, increasing dependency on SW, increasing irrigation efficiency including application of Alternate Wetting and |Drying (AWD) method, rainwater harvesting etc. can be option for the study area.

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REFERENCES

Adhikary, S. K., Sharif, A. A., Das, S. K. and Saha, G. C. (2014). Geostatistical Analysis of Groundwater Level Fluctuations in the Shallow Aquifer of Northwestern Bangladesh: *Proceedings of the 2nd International Conference on Civil Engineering for Sustainable Development 2014 Conference*, 391.

Alice, M. (2010). *Report on Water Scarcity in Northern Bangladesh: Prepared for Voluntary Service Overseas*. Retrieved from https://www.vsointernational.org/sites/vso_international/files/documents/Country%20specific%20documents/2012/Asia/Bangladesh/water-scarcity-in-bangladesh-report-2011.pdf

Awal, M. A. and Siddique, M. A. B. (2011). Rice Production in Bangladesh Employing by Arima Model. *Journal of Bangladesh Journal of Agriculture Research, 36*(1), 51-52.

Bangladesh Bureau of Statistics. (2011). *Statistical Yearbook of Bangladesh 2011*. Retrieved from http://www.bbs.gov.bd/WebTestApplication/userfiles/Image/LatestReports/YB2011.pdf

Rahman, M. M. and Mahbub, A. Q. M. (2012). Groundwater Depletion with Expansion of Irrigation in Barind Tract: A Case Study of Tanore Upazila. *Journal of Water Resource and Protecton,* 567-575