Research Journal of Environmental Sciences

ISSN 1819-3412

Academic
Journals Inc.

www.academicjournals.com

OPEN ACCESS

Research Journal of Environmental Sciences

ISSN 1819-3412
DOI: 10.3923/rjes.2018.247.255

Research Article
Groundwater Depletion and its Sustainable Management in Barind Tract of Bangladesh

[1]M.R. Hasan, [2]M.G. Mostafa, [1]Nafiur Rahman, [3]Md. Saiful Islam and [3]Md. Moynul Islam

[1]Department of Civil Engineering, Bangladesh Army University of Engineering and Technology, Qadirabad Cantonment, Natore-6431, Bangladesh
[2]Institute of Environmental Science, University of Rajshahi, Rajshahi 6205, Bangladesh
[3]Department of Chemistry, Bangladesh Army University of Engineering and Technology, Qadirabad Cantonment, Natore-6431, Bangladesh

Abstract

Background and Objective: Groundwater is one of the most important renewable resources which play a great role into livelihood, economies and agriculture sector in a nation. However, this valuable resource has been defected through various ways. This study aimed to investigate the effect of over exploitation of groundwater on Barind Tract area and its probable impact on the environment. The effect of groundwater fluctuation due to deep tubewells installed in the study area for irrigation has also been investigated. The study area was Chapai Nawabganj district in Barind Tract area which is located in North-western part of Bangladesh. **Materials and Methods:** The study area consisted of five upazilas namely Nawabganj, Shibganj, Nachole, Gomastapur and Bholahat. **Results:** The experimental data were analyzed and the result revealed that the minimum water level depletion recorded was about 6.33 m below the surface at Shibgonj Upazila in 2008 and maximum water level depletion recorded was about 109.40 m below the surface at Nachol upazila in 2014. A 10-year rainfall data of the said district showed that the maximum annual rainfall recorded was 2029 mm in 2007 and since then rainfall was gradually decreased. The highest annual rainfall received in the area was 1793 mm in 2007 and the lowest was 1025 mm in 2010 in the district. The average rainfall received in Chapai Nawabganj district was 1372 mm during 2007-2016. A good trend of water table fluctuations of Chapai Nawabganj district was found during 2007-2016. **Conclusion:** From the analysis results, a good relation between rainfall and water table fluctuations can be observed where the groundwater table was possibly recharged through the rainfall. The overall yearly water table declining trend indicates that the unsustainable withdrawal of groundwater for irrigation purposes played a vital role in groundwater table depletion in the study area. Moreover, groundwater level fluctuation depended on the extraction and recharge of the area.

Key words: Groundwater management, environment, fluctuations, depletion, recharge, rainfall

Citation: M.R. Hasan, M.G. Mostafa, Nafiur Rahman, Md. Saiful Islam and Md. Moynul Islam, 2018. Groundwater depletion and its sustainable management in barind tract of Bangladesh. Res. J. Environ. Sci., 12: 247-255.

Corresponding Author: Md. Saiful Islam, Department of Chemistry, Bangladesh Army University of Engineering and Technology, Qadirabad Cantonment, Natore-6431, Bangladesh

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Ground water depletion is the common concern around the world and its effect is more prominent in the developing countries. The water stored underground both in the aquifers and void spaces within soil is known as ground water. It is a resource which is both natural and dynamic. The quantity of this water by calculating the difference between the highest and lowest levels of the water table within the aquifer, which is recharged rainwater during the monsoon[1]. Over extraction or exploitation of ground water (i.e., excess withdrawal of groundwater) put stress on groundwater storage, which disrupts the equilibrium of aquifer recharge-withdrawal. The result of which usually is a continuous declination in the level of ground water table. This in terms may cause severe impact both on surface as well as on the subsurface environment[2].

Depletion of water table is a growing matter of concern for the global food supply[3]. Both human intervention and variation in climate affect the groundwater recharge, including excess withdrawal and abstraction of groundwater. Researches have shown that the over extraction of ground water is a threat to this resource and it is being pushed to the brink of complete exhaustion[4]. This problem is worse in the South-Asian region, where agriculture totally depends on monsoon rain-water. Irrigation aided by ground water is used for the cultivation of high-yielding rice in the dry periods of the year, where India and Bangladesh are respectively the 2nd and 4th highest rice producing nations in the world[5]. In the period of 2004-2005, the total amount of water used for irrigation was estimated to be 246 km^3 in Bangladesh, 18 km^3 of which is derived from groundwater using various methods and distribution systems[6]. The agriculture of Bangladesh was completely dependent on monsoon. However, from a more recent study it is seen that of the agricultural land, 79.1% are irrigated by groundwater[7]. Another research performed in Bangladesh and India has showed that the declination of groundwater level at 0.1-0.5 m $year^{-1}$, indicating a reduction of the storage in aquifer resulting from unsustainable withdrawal of groundwater for both irrigation and domestic use[8-10]. Because of tropical monsoon climate in summer, maximum temperature is often above 35°C and minimum temperature stays below 10°C. About 80% rainfall occurs in the rainy season, which is primarily from the month of June-October[10]. This study has considered the "Barind tract" of Bangladesh as the study area. This area is located at the north-western part of Bangladesh which includes parts of greater Dinajpur, Rangpur, Rajshahi, Naogaon, Pabna, Bogra and Joypurhat districts of Rajshahi. This drought prone area is distinguished as Barind Tract. Usually this region does not face any seasonal flood and also faces the lowest levels of rainfall in the country[11]. That's why groundwater is mainly recharged through rainwater. Conversion of small catchments into agricultural lands has also been affected the recharge of groundwater, which increases the dependence on rainwater. A previous study has shown a strong affiliation between the production of Boro rice and the depletion of groundwater[12]. The study area has also been intensely affected by severe droughts. Groundwater-fed "Barind irrigation project" is the largest irrigation project of the country, where 75% water is driven from groundwater[13]. Previous study shows that the hydrodynamics of the GBM deltaic aquifers has been substantially modified by groundwater abstraction[14-17]. Intensive abstraction for irrigation (25-75 wells per km^2 of irrigated land) occurs in many areas of northwestern Bangladesh and began during the late 1960s to early 1970s with the installation of deep (depth >80 mbgl) tubewells (DTW) by the Bangladesh Water Development Board (BWDB). This scarcity of water is mainly due to the depletion of groundwater table and the decrease of surface water leading to climate change[18]. In spite of an increase in rainfall in the southern part of Barind area, groundwater level is gradually declining mainly because of the increase of irrigation water demand. On the contrary, in the northern part of Barind area, less resource potential is major cause of depleting groundwater level[19]. It has also been investigated that the use of groundwater is not sustainable in the study area.

Water demand is increasing rapidly due to population growth and socioeconomic development in recent times. In such conditions, the scarcity of water can affect the economy as well as the lifestyle of the people. So this matter needs urgent attention in order to save the water supply sector. The groundwater over exploitation caused the water table depletion to the extent of not getting fully replenished by the rainfall recharge. There are many research have been carried out on groundwater depletion and its diverse effect on the environment, however; very less research work conducted to Barind Tract groundwater table and its depletion effect on the surrounding environment in Bangladesh. Therefore, the aim of this study is to explore the effect of over exploitation of ground water of Barind Tract and its probable effect on crops, climate and environment.

MATERIALS AND METHODS

Study area Barind area is located in the Northwestern part of Bangladesh consisted of most parts of 6 districts, namely

Chapai Nawabganj, Rajshahi, Naogaon, Joypurhat, Bogra, Dinajpur and Rangpur. The area is situated in 24-23-25-15 N and 88-02 to 88-57 E. The study area was Chapai Nawabganj district in Barind area and this district consists of five Upazilas namely Nawabganj, Shibgonj, Nachole, Gomastapur and Bholahat and it lies under the Barind tract and has an area of 1744.33 km^2. The main rivers of the district are the Ganges and Mahanadi. The Barind Integrated Area Development Project (BIADP) was initiated under the Barind multipurpose development authority (BMDA) (in 1985). For achieving sustainable growth of agriculture by irrigation and to preserve environmental balance, socio-economic development in the agro-based but drought-prone terrain of Barind area, for boosting cropping intensity and reaching self-sufficiency. As result the cropping intensity increased from 117% to about 200% (national average: 174.64%). In the agro-based Barind area, groundwater is an important source of water for irrigation, through deep tube-wells (DTWs), shallow tube-wells (STWs) and power pumps (Pps)[19]. The area has a space for groundwater extraction by 2-cusec[20]. Pre-monsoon (March to May) and post-monsoon (October and November) maps of the area indicate outflow of groundwater from its central part towards the valleys of the Padma (Ganges), Mahananda, Atrai Rivers, streams and low-lying areas in both dry and rainy seasons[19] (Fig. 1).

Data collection: The study largely considered secondary data of groundwater level fluctuation and rainfall of Nawabganj, Nachole, Shibgonj, Gomastapur and Bholahat of Barind area for the period from 2007-2016. The data was collected from the zonal office of Barind Multipurpose Development Authority (BMDA). Data of the deep tube wells used by BMDA for irrigation purpose was also collected from BMDA head office.

Data analysis: The collected data were analyzed as the following manner:

- Analysis of monthly fluctuation of ground water level of study area
- Analysis of the yearly variation of maximum and minimum ground water table of study area
- Normal graphs of maximum and minimum depth of water table from ground surface
- Analysis of monthly rainfall data of five Upazilas of chapai Nawabganj district of Barind area
- Analysis of the variation in number and status of deep tubewells of BMDA in barind tract

RESULTS AND DISCUSSION

Variation of ground water level: In this study, groundwater level of Barind area in Chapai Nawabganj district has been

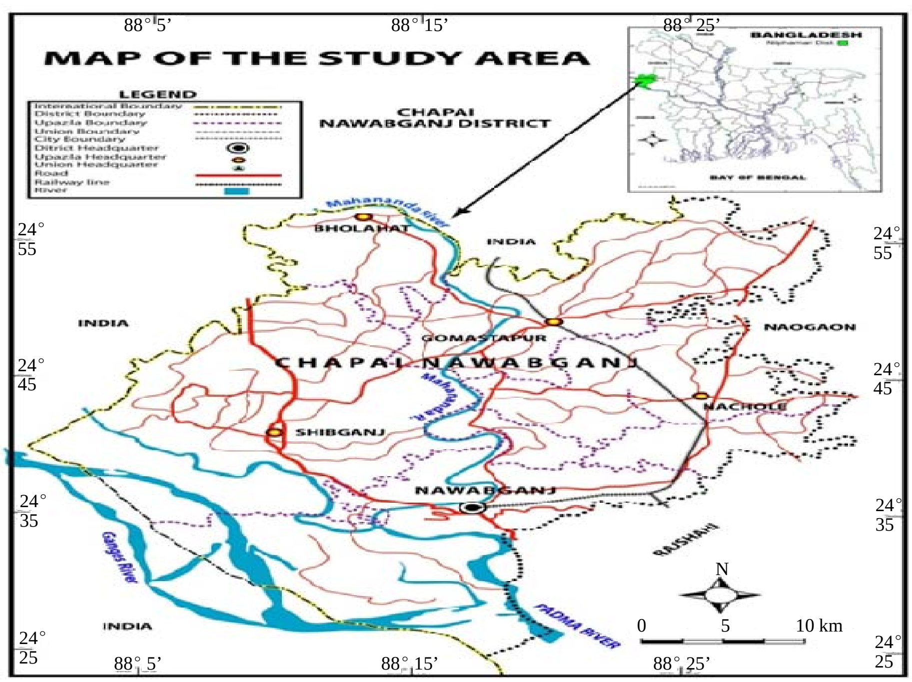

Fig. 1: Study area indicating five Upazilas

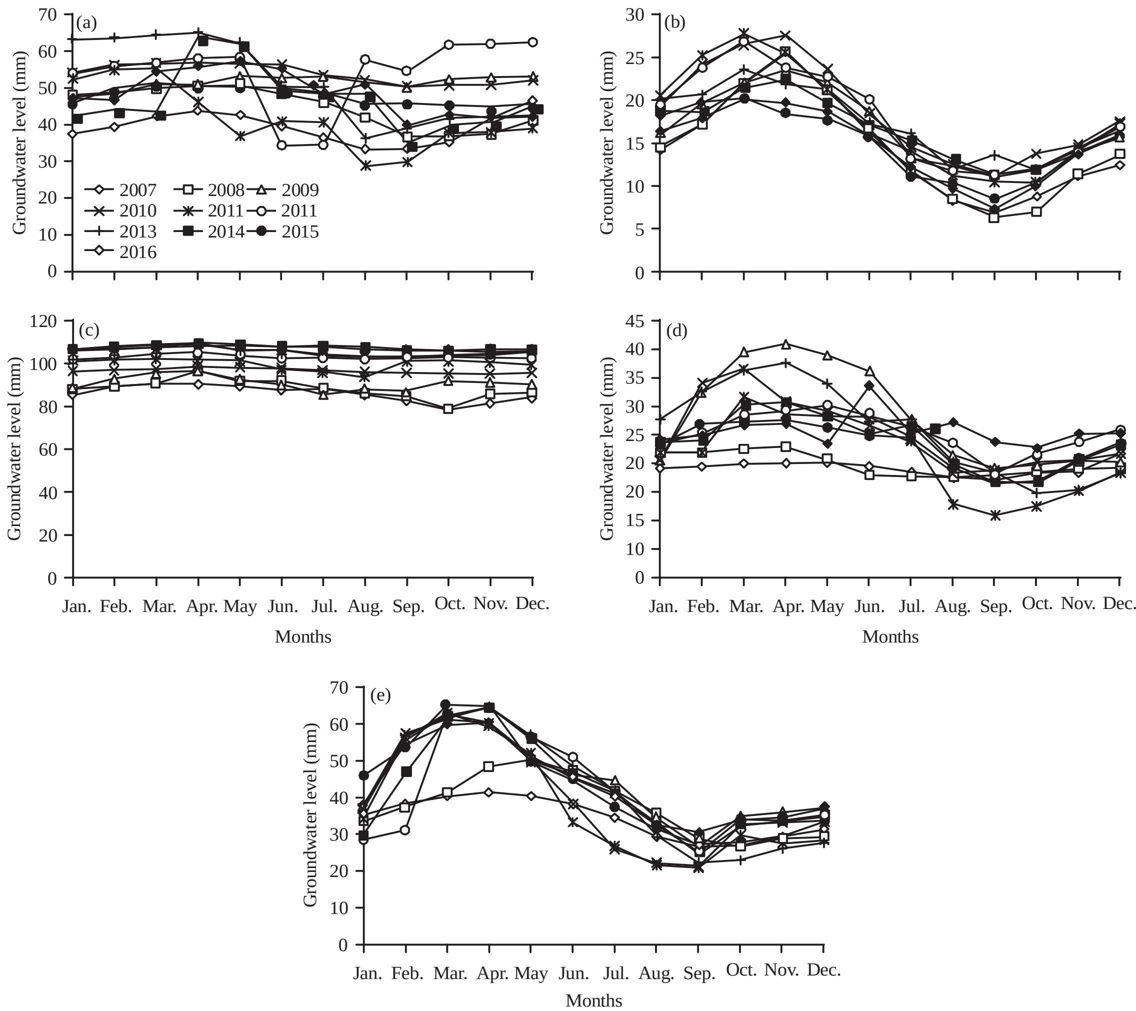

Fig. 2(a-e): Monthly variation in groundwater level of (a) Nawabganj Upazila, (b) Shibganj Upazila (c) Nachole Upazila, (d) Gomastapur Upazila and (e) Bholahat Upazila for the years 2007-2016

analyzed. All available data of Nawabganj, Nachole, Shibganj, Gomastapur and Bholahat Upazilas of Barind area in Chapai Nawabganj district have been considered for preparing hydrographs.

Monthly variations of groundwater level fluctuation of five Upazilas in Chapai Nawabganj district in the Barind area for the year from 2007-2016 are shown in Fig. 2(a-e). Fluctuation of groundwater level is different in magnitude depending on the extraction and recharge in different locations. The maximum water table depletion was found between February-May and elevated water tables were found throughout July and October as expected due to monsoon and post-monsoon groundwater level. The study results also illustrated the maximum water level depletion was about 109.40 mm at Nachole Upazila in 2014 and minimum water level depletion recorded was about 6.33 mm at Shibganj Upazila in 2008.

During the dry season, aquifer replenishment gradually stops because of low rainfall in the monsoon period and less soil moisture[19]. The main reason behind this are more groundwater being extracted than required to recharge the aquifers[21,22]. The increasing of extraction of groundwater for irrigation purposes without being increased of rainfall caused a serious drop in groundwater levels resulted in a groundwater deficit in Barind area. Of late, the FAO reported that forceful irrigation accounts for 80% of groundwater withdrawals, employing enormous pressure on groundwater resources and depletion of groundwater storage[23]. Another research showed that overuse of groundwater resources leads to adverse impacts on drinking water supply such as contamination of groundwater with arsenic, which is widely predominant in Bangladesh[24].

Yearly maximum and minimum groundwater level graphs have been prepared by taking the highest and

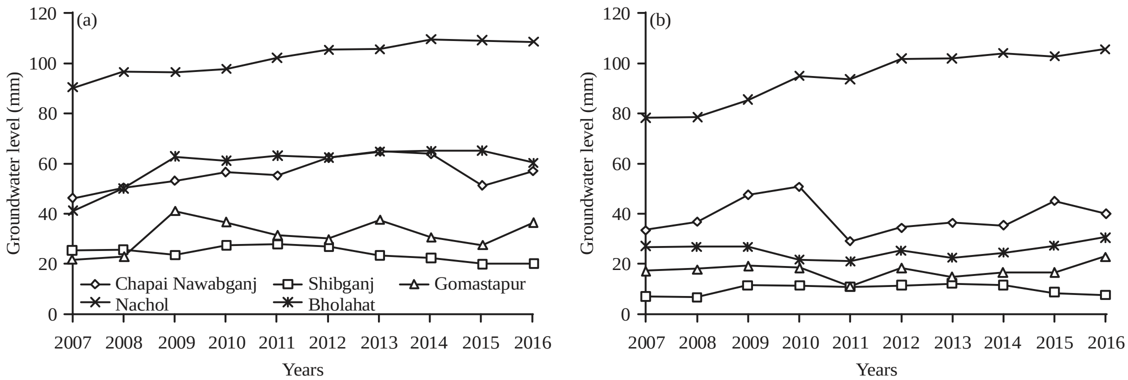

Fig. 3(a-b): (a) Maximum depletion of groundwater level and (b) Minimum depletion of groundwater level in five Upazilas of Chapai Nawabganj district from 2007-2016

lowest groundwater table and shown in Fig. 3a-b. The water level varies from 28.60-64.80 m during 2007-2016 at Nawabganj Upazila. The maximum depletion of water level was found to be 64.80 m in 2013 and minimum was 28.60 m in 2011. In Shibganj Upazila, the water level varies from 27.20-6.33 mm. The maximum depletion of groundwater level was found to be 27.7 mm in 2011 and the minimum was about 6.33 mm 2008. The groundwater level varies from 109.40-78.17 mm at Nachole Upazila for the same period was observed. The maximum water level was observed to be 109.40 mm in 2014 and the minimum was 78.17 mm in 2007. In Gomastapur Upazila, the water level fluctuated from 41.0-10.90 mm. The maximum water level was 41.00 m in 2009 and minimum was 10.90 m in 2011. The study also observed groundwater level fluctuation at Bholahat Upazila through the years 2007-2016. The groundwater level varies from 65.0-20.8 mm. The maximum water level was observed to be 65.0 m in 2015 and minimum was 20.80 mm in 2011.

Figure 3a shows the maximum groundwater level depletion observed in five Upazilas of Chapai Nawabganj district during the years 2007-2016. The results illustrated that the highest groundwater depletion was about 109.40 mm found at Nachol Upazila in 2014 and the lowest was about 20.10 mm at Shibganj in 2016.

Figure 3b shows that the minimum groundwater level depletion of five Upazilas in Chapai Nawabganj district through the years 2007-2016. Among the five Upazilas, the highest groundwater depletion was observed in 2016 at Nachol and it was about 105.70 mm below the surface and the lowest was about 6.33 mm at Shibganj in 2008.

A comparison of depth to water level during 2007-2016 reveals that there was a declining trend found in groundwater level in all Upazilas in the study area (Fig. 4). From figure, it can observed that the water level in the range of about

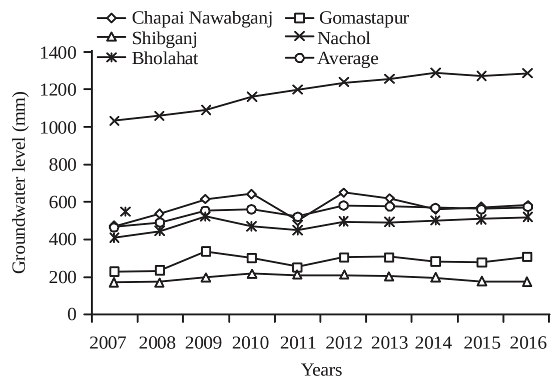

Fig. 4: Average groundwater level declined in five Upazilas of Chapai Nawabganj district through the years 2007-2016

0-2 m year^{-1}. A slight fall in water level was observed through 2007-2016 in Bholahat, Nawabganj, Shibganj and Gomastapur and rise in water level in 2011 in these areas were more prominent, which is an indication of extremely frequent and heavy rainfall. Comparatively rapid and continuous declines (about 2 m year^{-1}) in water levels were observed at Nachole Upazila during the study period.

Although, irrigation has provided farmers with an opportunity to grow more rice varieties on the same piece of land, however' this led to environmental degradation such as reduced soil fertility and the added use of harmful agrochemicals[25]. In spite of the environment being good for standing water between July and October in Barind, the presence of a thick, deep, sticky clay-rich layer in the top soil increases surface runo rather than allowing it to contribute to the groundwater[19]. Groundwater recharge potentially has investigated by Adham *et al*.[26] and found that 85% of the Barind area has low and rest has moderate groundwater recharge potentiality. This finding is similar with a previous study conducted by Shamsudduha *et al.*[17] which concluded that seasonality dominates observed variance in groundwater levels but declining groundwater levels (>1 m year^{-1}) are detected in urban and peri-urban areas around Dhaka as well as in north-central, northwestern and southwestern parts of the country (0.1-0.5 m year^{-1}) where intensive abstraction of groundwater is conducted for dry-season rice cultivation. The linear fashion of the annual extreme distance to the GWT from the surface in different upazillas reveal the depths are way below the suction limit in recent times[27]. The groundwater based irrigation system of the area has now reached a critical stage. According to the Bangladesh Agricultural Development Corporation, with the maximum water level dropping below shallow wells in many places. The extraction of groundwater in the study area is still carried out on the practice of one-third rainfall recharge hypothesis of BMDA[20] which delineates the sustainable yield[28]. The study showed that on average the maximum and minimum depth to ground water table during the period 1991-2010 present a declining trend of 4.51 and 4.73 m. The long-term likelihood for the period 2020-50 supposing the current rate of withdrawal for maximum and minimum groundwater depths will be 1.16-1.59 and 1.07-1.82 times more respectively with respect to the present. Exploitation of groundwater for the purpose of irrigation along with decreasing rainfall lead to declining trend of GWT. The country's food security will be hampered and ultimately the socio-economic sustain ability will be threatened [29].

Rainfall variation: The monthly rainfall variations in five Upazilas of Chapai Nawabganj district in the Barind area during 2007-2016 are considered. The maximum rainfall was found throughout June-September during the rainy season of the area. The minimum rainfall was found between February and April and very little or no rainfall occurred during November and January. The study results illustrated that the maximum rainfall recorded at the five stations are 716 mm at Nawabgonj in July 2007, 901 mm at Shibgonj in July 2007, 533 mm at Gomostapur in July 2016, 645 mm at Nachol in 2007 and 699 mm at Bholahat in 2007 (Table 1). The maximum annual rainfall recorded was 2029 mm in 2007 at Nachol. Since then, rainfall was gradually decreasing for consecutive three years but it was increased 439 mm in 2011 from 1015 mm recorded in the previous year. The results showed that Nachole Upazila received the highest rainfall 2029 mm in 2007 and Gomastapur Upazila received the lowest rainfall 147 mm in 2009 during the study period. The average rainfall received in Chapai Nawabganj district was 1372 mm during 2007-2016. A previous report showed that the rainfall recorded was about 1738 mm in 1981 and 798 mm in 1992 in the Barind area suggesting yearly rainfall variations. The rainfall data of the study also showed a wide variation of rainfall depending on area and year. The study results reveal a good relation between rainfall and water table fluctuations. The groundwater table was evidently being recharged by the rainfall. The overall yearly water table declining trend indicate that unsustainable withdrawal of groundwater for irrigation and domestic purposes would be played a vital role in water table fluctuations in the study area.

The analysis of yearly average groundwater depth and the yearly amount of total rainfall shows that the level of ground water table tends to vary with the variation in rainfall. The plots in Fig. 5 and 6 showed a trend of higher levels of ground water with increased rainfall and vice versa for any given year within the study period in Barind tract.

Analysis of deep tubewell data: This part of the research aims to perform a comparative analysis of the deep tubewell data acquired from BMDA. The analysis primarily shows that BMDA has been placing deep tubewells in this region. But placing new deep tubewells have been stopped since 2012, as the ground water table is affected severely. The tubewell data includes the number of existing and newly bored tubewells every year for the years 2003, 2004 and 2005 consecutively and lastly the current count in 2017 (Table 2).

Table 1: Annual total rainfall (mm) of five Upazilas in Chapai Nawabganj district during 2007-2016 total rainfall (mm)

Years	Nawabganj	Gomastapur	Shibganj	Nachol	Bholahat	Average
2007	1964.00	1147.00	1910.00	2029.00	1722.01	1754.40
2008	1302.00	1324.00	1524.30	1195.10	1101.27	1289.33
2009	946.00	147.00	1099.00	1228.00	1199.74	923.95
2010	971.00	1248.00	1024.00	987.00	896.70	1025.34
2011	1313.50	1551.00	1790.00	1496.00	1598.00	1549.70
2012	971.00	969.00	1154.00	742.00	1158.00	998.80
2013	1102.00	1055.00	1462.00	943.00	1180.00	1148.40
2014	1112.00	1266.00	1246.00	1224.00	1249.00	1219.40
2015	1645.00	1503.00	1977.00	1740.00	1304.20	1633.84
2016	830.00	1196.00	1503.00	1065.00	1177.00	1154.20

Table 2: Number of tubewells exists in the study area

	2003		2004		2005		2017	
Districts	Commissioned	Used	Commissioned	Used	Commissioned	Used	Commissioned	Used
Chapainawabganj	189	141	192	187	194	162	207	207
Shibganj	268	168	244	244	242	178	238	238
Gomostapur	289	232	309	295	302	235	399	399
Nachole	287	241	320	304	313	269	540	540
Volahat	176	153	176	175	175	157	218	218

Fig. 5: Variation in yearly average depth of groundwater level (from surface) over study period

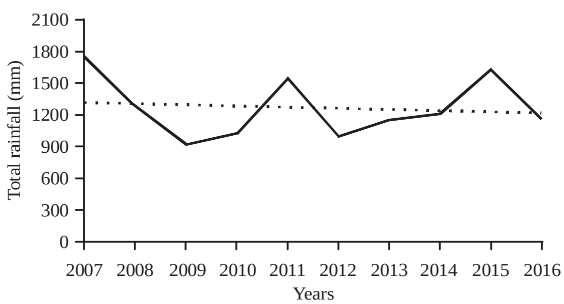

Fig. 6: Variation in yearly average rainfall (mm) over the study period

From 2003-2005, the number of existing tube wells has been decreasing every year. It is known from the BMDA officials that the reason behind this is the breakdown or malfunction of pumps, mainly due to excess pressure on pumps as a result of ground water depletion and increased demand of irrigation water. It also showed as the gap between commissioned and used pumps. Some of the commissioned pumps had to be kept off operation, as it would have put excess pressure on groundwater. New deep tubewells had to be placed every year as a number of existing tubewells got exhausted.

The data shows that the number of tubewells increased in 2004 compared to 2003, this is due to the increase in irrigation water demand. Consecutively, the number decreased in 2005 probably because of the over exploitation of groundwater in the previous year.

CONCLUSION

It can be concluded from the present study that the relationship between ground water fluctuation and rainfall is very much conclusive. The maximum water table depletion was found between February to May and elevated water tables were found throughout July-October due to monsoon and post-monsoon recharge of groundwater. Consecutively, higher amount of rainfall is found in the July-October months and lower rainfalls recorded at the February-May months. The results also illustrated the minimum water level depletion recorded was about 6.33 m below the surface at Shibgonj Upazila in 2008 and maximum water level depletion recorded was about 109.40 m below the surface at Nachol Upazila in 2016.

A good trend of water table fluctuations of Chapai Nawabganj district was found during 2007-2016. A wave like fluctuation curves was observed. There is a quiet close relationship between the ground water levels and rainfall variation. Higher amount of rainfall seemed to coincide with higher ground water tables. The relationship between water table fluctuations and number of tubewells in the area is also seen probable. However, this study could not make a strong conclusion as the number and size of data acquired from BMDA were not to be labeled largely. This is because the number of tubewells owned by BMDA in this area is only a fraction of the total number of tube wells extracting water in Barind tract. This research suggested for future study in this field with larger number of tubewell data to get a more accurate and concrete conclusion about the relationship with ground water fluctuations.

The study results reveal possibility of a good relation between rainfall and water table fluctuations as the groundwater table is recharged through the rainfall. The overall yearly water table declining trend indicate that unsustainable withdrawal of groundwater for irrigation and domestic purposes would play a vital role in water table depletion in the study area. Fluctuation of groundwater level was different in magnitude depending on the extraction and recharge in different locations. Thorough field investigation and immediate action is suggested in order to see the grand picture of the current groundwater situation in the Barind Tract.

ACKNOWLEDGMENTS

The authors would like to thanks Barind Multipurpose Development Authority (BMDA) and Institute of Environmental science, Rajshahi University for their support throughout this research project.

REFERENCES

1. Gronwall, J. and S. Oduro-Kwarteng, 2018. Groundwater as a strategic resource for improved resilience: A case study from peri-urban Accra. Environ. Earth Sci., Vol. 77, No. 6. 10.1007/s12665-017-7181-9
2. Deng, L., W. Wang and Y. Cai, 2017. A 70-year groundwater recharge record from sandy loess in Northwestern China and its climatic implications. Environ. Earth. Sci. Vol. 76, No. 24. 10.1007/s12665-017-7155-y
3. Rosegrant, M.W. and S.A. Cline, 2003. Global food security: Challenges and policies. Science, 302: 1917-1919.
4. Lilienfeld, A. and M. Asmild, 2007. Estimation of excess water use in irrigated agriculture: A data envelopment analysis approach. Agric. Water Manage., 94: 73-82.
5. Scott, C.A. and B. Sharma, 2009. Energy supply and the expansion of groundwater irrigation in the indus-ganges basin. Int. J. River Basin Manage., 7: 1-6.
6. Siebert, S., J. Burke, J.M. Faures, K. Frenken, J. Hoogeveen, P. Doll and F.T. Portmann, 2010. Groundwater use for irrigation-a global inventory. Hydrol. Earth Syst. Sci., 14: 1863-1880.
7. BADC., 2003. Survey report on irrigation equipment and irrigated area in Boro 2003 season. Survey and Monitoring Project for Development of Minor Irrigation, Bangladesh Agricultural Development Corporation, Sech Bhaban, Dhaka.
8. Hasan, M.R., M.G. Mostafa and I. Matin, 2013. Effect of rainfall on groundwater level fluctuations in chapai nawabgonj district. Int. J. Eng. Res. Technol., 2: 2800-2807.
9. Shamsudduha, M., R.G. Taylor, K.M. Ahmed and A. Zahid, 2011. The impact of intensive groundwater abstraction on recharge to a shallow regional aquifer system: Evidence from Bangladesh. Hydrogeol. J., 19: 901-916.
10. BMDA., 2006. Borandro Authority Past-Present. Barendra Multipurpose Development Authority, Rajshahi, pp: 35.
11. Rahman, M.M. and A.Q.M. Mahbub, 2012. Groundwater depletion with expansion of irrigation in Barind Tract: A case study of Tanore Upazila. J. Water Resourc. Prot., 4: 567-575.
12. Aziz, M.A., M.A.K. Majumder, M.S. Kabir, M.I. Hossain, N.M.F. Rahman, F. Rahman and S. Hosen, 2015. Groundwater depletion with expansion of irrigation in barind tract: A case study of Rajshahi district of Bangladesh. Int. J. Geol. Agric. Environ. Sci., 3: 32-38.
13. Adhikari, S.K., S.K. Das, G.C. Saha and T. Chaki, 2013. Groundwater drought assessment for barind irrigation project in Northwestern Bangladesh. Proceedings of the 20th International Congress on Modelling and Simulation, December 1-6, 2013, Adelaide, Australia, pp: 2917-2923.
14. Agrawala, S., T. Ota, A.U. Ahmed, J. Smith and M. van Aalst, 2003. Development and climate change in Bangladesh: Focus on coastal flooding and the Sundarbans. Organisation for Economic Co-operation and Development, Paris, France. http://www.oecd.org/env/climatechange/21055658.pdf.
15. Harvey, C.F., K.N. Ashfaque, W. Yu, A.B.M. Badruzzaman and M.A. Ali *et al*., 2006. Groundwater dynamics and arsenic contamination in Bangladesh. Chem. Geol., 228: 112-136.
16. Stute, M., Y. Zheng, P. Schlosser, A. Horneman and R.K. Dhar *et al*., 2007. Hydrological control of as concentrations in Bangladesh groundwater. Water Resourc. Res., Vol. 43, No. 9. 10.1029/2005WR004499
17. Shamsudduha, M. and A. Uddin, 2007. Quaternary shoreline shifting and hydrogeologic influence on the distribution of groundwater arsenic in aquifers of the Bengal Basin. J. Asian Earth Sci., 31: 177-194.
18. Islam, M.T., M.M. Hossain and A.F.M.A. Hossain, 2014. Integrated water resources management: A case study for Barind area, Bangladesh. IOSR. J. Mech. Civil Eng., 11: 01-08.
19. Jahan, C.S., Q.H. Mazumder, A.T.M.M. Islam and M.I. Adham, 2010. Impact of irrigation in Barind area, NW Bangladesh-an evaluation based on the meteorological parameters and fluctuation trend in groundwater table. J. Geol. Soc. India, 76: 134-142.
20. BMDA., 2001. Project proforma (Rebound) for the barind integrated area development project, phase-II (4th revision). Barind Multipurpose Development Authority, Rajshahi.
21. IWM., 2006. Project brief on groundwater model study for deep tubewell installation project on barind area. Draft Final Report, Institute of Water Modeling, Dhaka.
22. Mamunul, H., C. Jahan, Q. Mazumder and S. Nawaz, 2012. Hydrological condition and assessment of groundwater resource using visual mud ow modeling, Rajshahi city aquifer, Bangladesh. J. Geol. Soc. India, 79: 77-84.
23. Shamsudduha, M., R.G. Taylor and L. Longuevergne, 2012. Monitoring groundwater storage changes in the highly seasonal humid tropics: Validation of GRACE measurements in the Bengal Basin. Water Resourc. Res., Vol. 48, No. 2. 10.1029/2011WR010993.

24. Harvey, C.F., C.H. Swartz, A.B.M. Badruzzaman, N. Keon-Blute and W. Yu *et al*., 2002. Arsenic mobility and groundwater extraction in Bangladesh. Science, 298: 1602-1606.
25. Hossain, M., 2009. The impact of shallow tube wells and boro rice on food security in Bangladesh. IFPRI Discussion Paper 00917-2020 Vision Initiative, International Food Policy Research Institute. http://www.ifpri.org/millionsfed
26. Adham, M.I., C.S. Jahan, Q.H. Mazumder, M.M.A. Hossain and A.M. Haque, 2010. Study on groundwater recharge potentiality of Barind tract, Rajshahi district, Bangladesh using GIS and remote sensing technique. J. Geol. Soc. India, 75: 432-438.
27. Rahman, A.S., M. Kamruzzama, C.S. Jahan and Q.H. Mazumder, 2016. Long-term trend analysis of water table using 'MAKESENS' model and sustainability of groundwater resources in drought prone Barind area, NW Bangladesh. J. Geol. Soc. India, 87: 179-193.
28. Dey, N.C., S.K. Bala and A.K.M.S. Islam, 2015. Environmental and economic sustainability of groundwater for irrigation: Implications for ensuring food security in the Northwest region of Bangladesh. Research Monograph Series No. 62, BRAC Research and Evaluation Division.
29. Dey, N.C., R. Saha, M. Parvez, S.K. Bala, A.K.M.S. Islam, J.K. Paul and M. Hossain, 2017. Sustainability of groundwater use for irrigation of dry-season crops in Northwest Bangladesh. Groundwater Sustainable Dev., 4: 66-77.