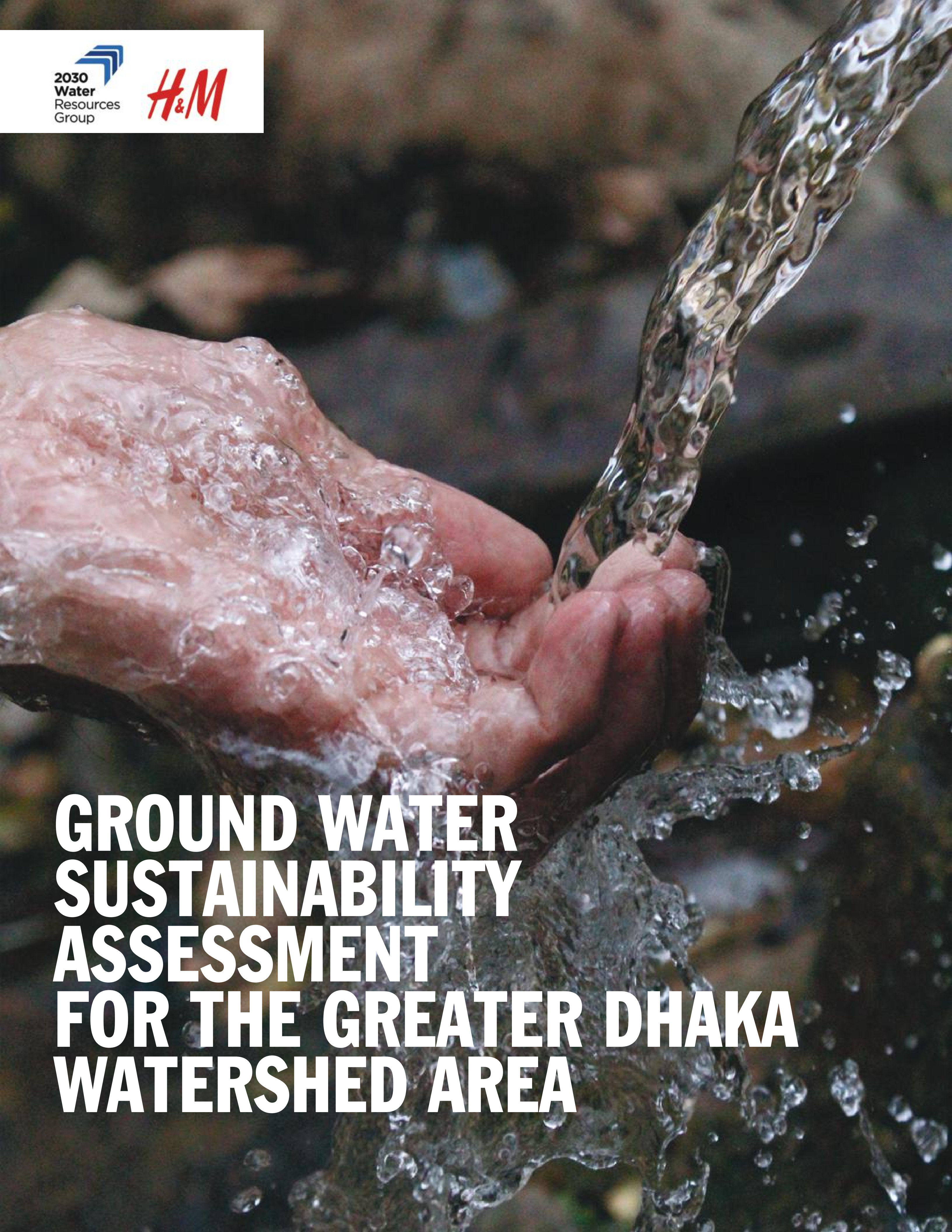

GROUND WATER SUSTAINABILITY ASSESSMENT FOR THE GREATER DHAKA WATERSHED AREA

CONTENT

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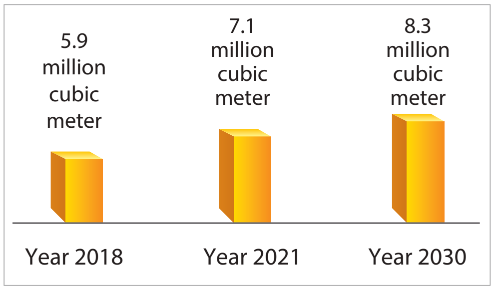
EXECUTIVE SUMMARY

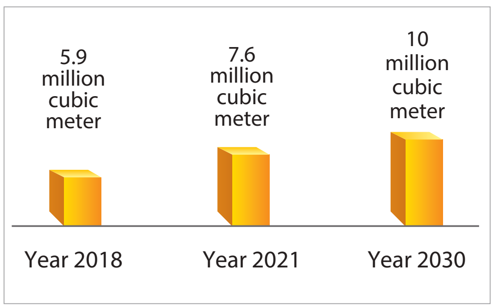
In the context of the changing global environment and socio-political and economic conditions of Bangladesh, especially in the greater Dhaka, resources management with its optimum use is one of the biggest concerns for business sustainability. The analysis of groundwater abstraction and water levels reveals that the aquifer hydrology is almost entirely controlled by excessive abstraction of water in the area. The study has conducted groundwater sustainability assessment considering business as usual case (considering current growth rate) and business plus case (considering forecasted growth rate based on national development trend). The rate of groundwater water decline has reached 3 m/year in recent years in the main part of the city which may reach to 3.4 in 2021, 4.4 in 2030 in business as usual case and 3.9 in 2021, 5.1 in 2030 in business plus case.

Figure 1 : Water abstraction rate at BAU Case



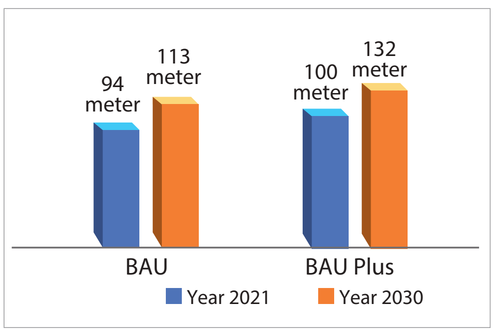
The business as usual case (BAU) assumes a steady state growth in industrial expansion. To project the groundwater level in 2021 and 2030 at BAU, the study considers the industrial growth rate 8.9 (present growth rate) and irrigation growth rate 5%. The present growth rate of population is also considered for demographic projection. This means that the total groundwater abstraction will reach to 7.1 million cubic meter per day in 2021 and 8.6 million cubic meter per day in 2030 in contrast to the present rate of abstraction (5.9million cubic meter per day). The lowest depth of upper aquifer will be 94 meter in 2021 and 113 meter in 2030. At present the lowest depth of upper aquifer is about 78 meters.

Figure 2 : Water abstraction rate at BAU Plus



Business plus scenario assumes the industrial growth will not be steady state as it was for BAU case. It considers 9.6% and 11% annual growth rate for industrial expansion for the year 2021 and 2030 respectively. For irrigation the study considers 10% annual growth. Demographic change is considered to be 21 million population in 2021 and 27.4 million population in 2030. Thus, the demand of domestic water has been calculated accordingly. Analysis reveals that the elevation ofgroundwater level will decline to about -100 meter in the central part of the Dhaka City in 2021 and -132 meter in 2030. The current rate of Ground Water decline will increase to 4.2 meter/year from 3 meter/year. The total water abstraction rate will also increase to 7.6 million cubic meter par day in 2021 and 10 million cubic meter par day in 2030. The existing cone of depression in the water table will increase its area to be a mega cone of depression.The mega cone of depression will attain an area of about 1962 square kilometer which is more or less double than the present value. As a result, a huge number of wells located in the city or outside the city will be affected as well as the abstraction cost will be higher to extract water from the deeper aquifer. On the other hand, this huge declination can also produce subsidence or other environmental degradation in or around Dhaka City.

Figure 3 : Projected depth of water table



The cones of depression are lowering vertically and widening horizontally owing to the increased installation of production wells and to the spread of the production wells into new areas. The positions of the depression are largely ruled by the concentrated pumping locations of DWASA at the city part and thus similar cone of depression is likely to develop at the industrial zones at Savar, Ashulia, Tongi and Narayanganj.

BACKGROUND

The textile industries are playing an important role in Bangladesh's economy for a long time which comprises a mix of small to large scale companies. Currently, the textile industry in Bangladesh accounts for 45% of all industrial employment and contributes 5% to the total national income[1] . The industry employs nearly 4 million people, about 80% of whom are woman[2]. A huge 80.7% of the country's export earnings and 12.36% of the GDP come from textiles and apparel according to the latest figures available[3]. Bangladesh's exports earning stood at $34.83 billion in FY2017 to the United States, European Union (EU), Canada and other countries of the world[4] and sets the target as $37.5 billion by the year 2018[4]. It is the sixth largest supplier to the United States and EU countries. Previously, the domestic market was dependent upon imported goods; now the local industry meets over 90% of domestic fabric demand[5]. Bangladesh is the second largest apparel exporter in the world, after China. The market share of Bangladesh, in the $503 billion global garment items is 5.1 percent, according to data from the International Trade Statistics of the World Bank[6].

Due to increase in population and demand of industrial product, greater Dhaka[7] experiences a rapid industrialization and commercial activities. The city struggles to provide enough drinking water for its population despite the fact that it sits on or near four major rivers in a wide delta region. There is plenty of blame to go around for this paradox. But one of the key concerns is around 800 washing and dying factories for Bangladesh's booming textile industry[8] . Most of them are located in Dhaka and on its fringe. These factories, known as "wet processors," consume as much as 300 liters of water[9] to produce one kilogram of fabric. That's about six times more water than what is considered international best practice. According to the Institute of Water Modeling, underground water levels around the city center are dropping at an alarming rate; two to three meters per year[10]. That not only portends future water shortages but also increases the risk of land subsidence. The city's water supply agency, DWASA, pumps 78% of its water supplies for both domestic and industrial uses from underground and textile factories take their own water from underground without any regulation[11].

Bangladesh Water Partnership in association with Water Resources Group 2030 with financial support from H&M, World's one of the leading Apparel and Fashion brands, has been commissioned to conduct a preliminary ground water sustainability projection for the Greater Dhaka Watershed Area. Groundwater modeling, a process to characterize the quantity, quality and sustainability of ground water in aquifers, gives an accurate and comprehensive micro-level picture of groundwater system. The paradigm shift from "groundwater development" to "groundwater management" in Bangladesh as laid out in Bangladesh Water Act 2013 through aquifer mapping in different hydro-geological settings requires robust groundwater management plans at the appropriate scale to be devised and implemented. This means an advanced investigation and understanding of the system beneath the surface. As one of the major sources of water for the country and an inevitable part of the hydrological system, this needs to be seen as a limited resource and therefore the management plan of it should associate the specification of sustainable abstraction limit. In a groundwater system, management decisions are related to rates and location of pumping, recharge and changes in water quality.

1 *Islam, Md. Mazedul and et. al., 2013, "Textile Industries in Bangladesh and Challenges of Growth", Research Journal of Engineering Sciences, Vol. 2(2), 31-37 ISSN 2278 – 9472*
2 *Paul, Ruma; Quadir, Serajul (4 May 2013). "Bangladesh urges no harsh EU measures over factory deaths". Dhaka: Reuters. International Journal of Textile Science 2016, 5(3): 39-48, DOI:10.5923/j.textile.20160503.01*
4 *http://www.textilepact.net/publications.html and bdnews24.com, 30th July 2017*
5 *http://fashion2apparel.blogspot.com/2017/06/bangladesh-textile-industry.html*
6 *https://www.thedailystar.net/country/bangladesh-remains-second-largest-garments-exporter-against-all-odds-1255084*
7 *Dhaka City Corporation area and Savar Upazila and Keraniganj Upazila of Dhaka District, Narayanganj Sadar Upazila, Bandar Upazila and Rupganj Upazila of Narayanganj District, Gazipur Sadar Upazila and Kaliakair Upazila of Gazipur District, as defined by BBS*
8 *An analysis of industrial water use in Bangladesh with a focus on the leather and textile industries, ARUP, Bangladesh Water PaCT, http://www.textilepact.net/publications.html .*
9 *Cleaner Production Factory Audit, Bangladesh Water PaCT, 2014*
10 *Rahman, M. Azizur, Rusteberg, Bernd, Sauter, Martin, 2010, "Hydrogeological evaluation of an over-exploited aquifer in Dhaka, Bangladesh towards the implementation of groundwater artificial recharge", Geophysical Research Abstracts Vol. 12, EGU2010-10042-1, 2010*
11 *DWASA Annual Report 2015-16*

OBJECTIVES OF THE STUDY

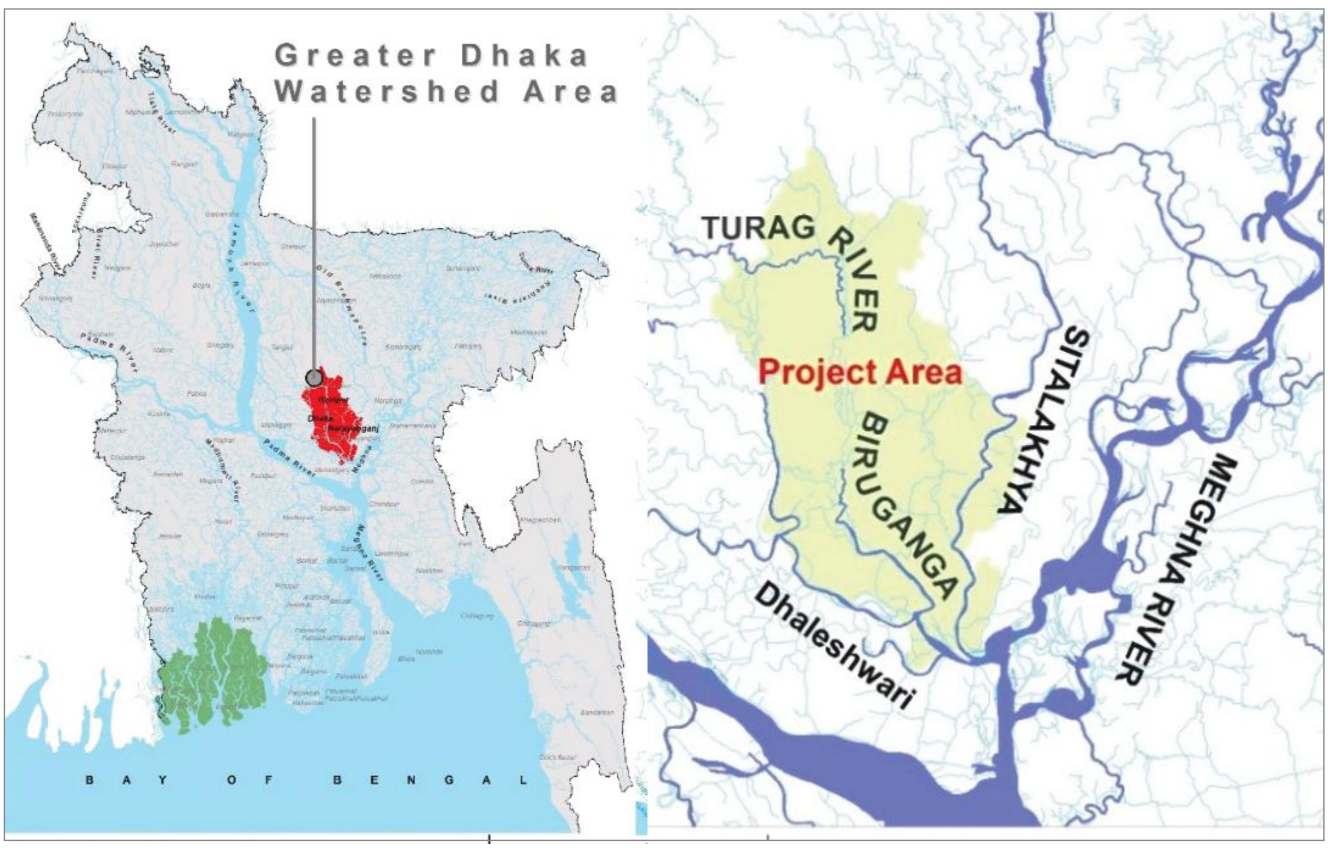
The current study aims at laying out a generalized scenario on existing groundwater situation covering information on the level of groundwater head, groundwater declination scenario over the year and long-term sustainability projection in and around Dhaka. Furthermore, the study will map the aquifer more holistically in a simplified version. However, the following are two specific objectives of this study as envisioned:

1. Conduct preliminary ground water sustainability projection for the Greater Dhaka Watershed area up to 2030
2. Prepare design of Stakeholder Information Network for coordinated streaming of groundwater data from all relevant stakeholders.

DESCRIPTION OF THE STUDY AREA

Greater Dhaka, the conurbation surrounding the capital city of Dhaka, which has grown into one of the world's largest megacities, and shows a very rapid rate of expansion, is the study area of this research project. The area of greater Dhaka is around 1853 square kilometers, of which Dhaka City Corporation occupies approximately 300 square kilometers at the 2011 census. The greater Dhaka covers the Dhaka City Corporation area and Savar Upazila and Keraniganj Upazila of Dhaka District, Narayanganj Sadar Upazila, Bandar Upazila and Rupganj Upazila of Narayanganj District, Gazipur Sadar Upazila and Kaliakair Upazila of Gazipur District , and Narsingdi Sadar Upazila and Palash Upazila of Narsingdi District . However, this research will exclude Narsingdi district part to have special focus on industrial clusters.

Figure 4 : Location of the project area and river system



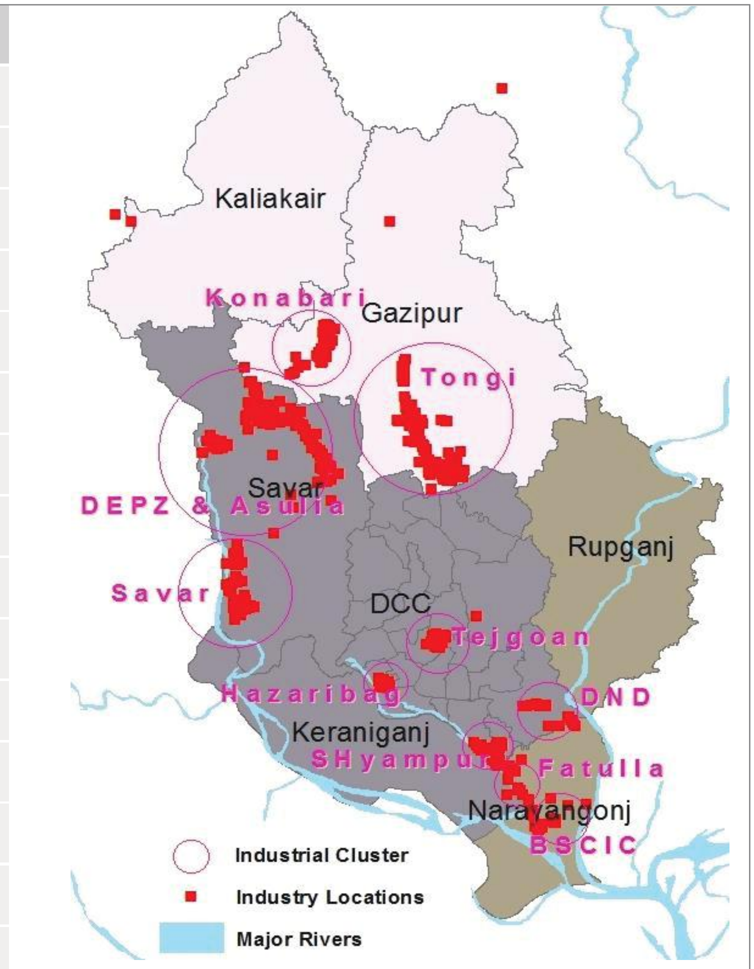
INDUSTRIAL ESTABLISHMENT

Over the years, large number of water-consuming and polluting industries have been established all over the greater Dhaka areas. In some cases this development is localized such as Tejgaon Industrial area but in most cases they have grown sporadically in residential, rural and forest areas. In absence of any zoning or land use law, the phenomenon is occurring with rapid pace within the greater Dhaka area.

Presently it is estimated that there are over 2100 industries in the greater Dhaka area. Most of these industries are located mainly in ten clusters: Tejgaon, Savar, Dhaka EPZ, Konabari-Kasimpur (Gazipur), Tongi, Hazaribagh, BSCIC Narayanganj, Shyampur, Fatullah and DND. In the Final Report of the Dhaka Water Resources Management Programme (DWRMP) study, a list of 2179 industries in and around the Greater Dhaka has been identified of which many of them are highly water intensive including composite textile industries, tanneries etc., which is summarized in table below:

Figure 5 : Location and type of the industries in the project area

Type of Industry	Number [13][14]
Textile, Garments, Jute, etc.	738
Paper, Pulp, Wood, etc.	171
Dyeing, Painting, Printing, etc.	241
Electrical, Electronics, Computer, etc.	129
Metal, Iron, Aluminium, Steel, etc.	289
Plastic, Polythene, Glass, Cosmetics, Jewellery, etc.	142
Food, Confectionary, Hotels, etc.	140
Dairy, Poultry, Fishery, etc.	28
Tannery, Shoe, etc.	75
Pharmaceutical, Hospital, Soap, etc.	61
Chemical, etc.	95
Ceramics, etc.	5
Building construction related, etc.	49
Handicrafts,	16
Total	2179



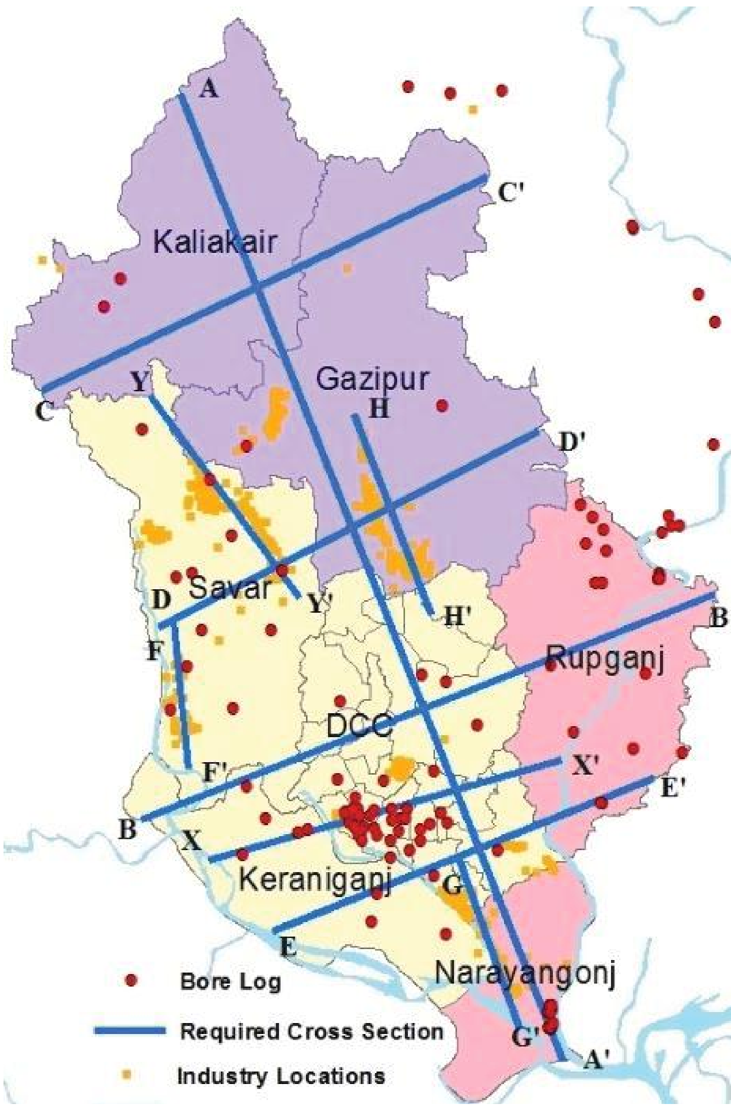
[12] *BBS, 2011. Bangladesh Statistical Bureau. http://www.bbs.gov.bd/*
[13] *Department of Environment, 2008, Survey and Mapping of Environment Pollution from Industries in Greater Dhaka and Preparation of Strategies for Its Mitigation (SMEP-GD) Project*
[14] *Primary survey conducted by H&M, 2018*

LITHOLOGICAL MAPPING

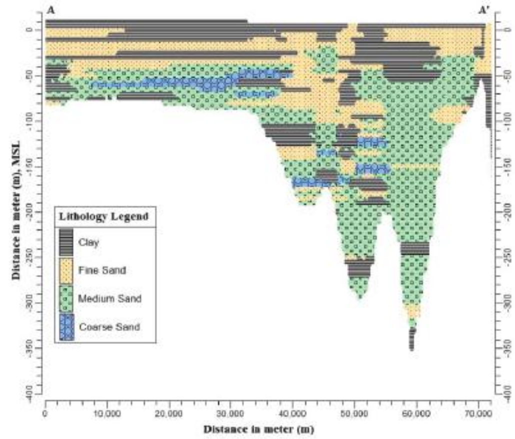
Lithology cross-section descriptions of DupiTila (one kind of geological formation which is composed of yellow to light brown, coarse to fine moderately hard to loose clay, sand and silt) sediments disclosed that, the rocks forming the aquifers and aquitards have very scattered distribution in the area. Based on the collected borehole information, a complex lithological setting is found. In order to simplify this complexity, the lithological descriptions were generalized into top soil, clay (clay, silty clay and silt), fine sand (fine sand to very fine sand, fine to medium sand), medium sand (medium sand, medium to fine sand and medium to coarse sand) and coarse sand (coarse sand, coarse to medium sand, gravels). At a depth of ~ 400 meter below mean sea level, a thick clay deposit covers the whole area.

Figure 6 : Lithological cross section of the study area

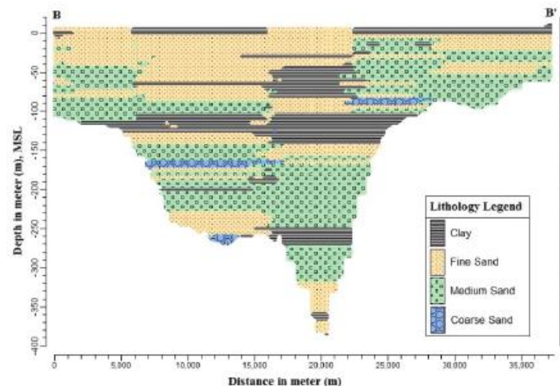
Location of the cross sections



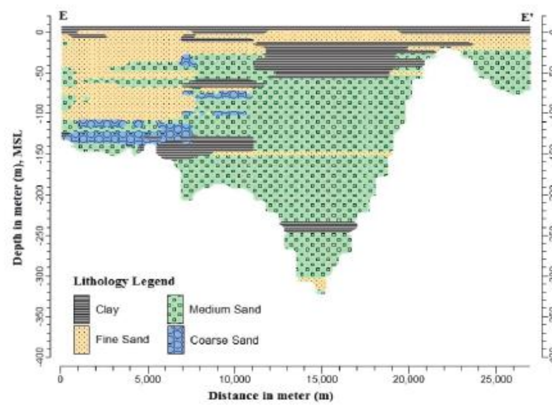
Lithologic Cross Section along Line A-A' at Dhaka Division



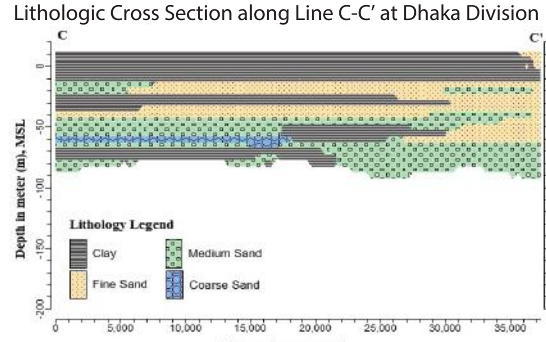
Lithologic Cross Section along Line B-B' at Dhaka Division



Lithologic Cross Section along Line C-C' at Dhaka Division



Lithologic Cross Section along Line C-C' at Dhaka Division



GROUNDWATER FLOW SYSTEM, ABSTRACTION AND HEAD DISTRIBUTION

Groundwater flow in the Dhaka region is composed of several interconnected and complex flow systems. Groundwater flow occurs in two aquifers, that are relatively shallow and with localized flow paths that are superimposed on deeper, regional flow paths. Regional groundwater flow is predominantly through the lower DupiTila aquifer and tends to follow the regional topographic gradient; water generally flows towards Shitalakhya River. Most groundwater recharge results from the following: infiltration of precipitation during the late monsoon in the form of widespread flooding, river discharge and bank infiltration, leakages from urban water supply, and from pluvial drainage as well as sewers and unsewered sanitation. In the Dhaka Metropolis area, the effect of pumping is larger than the variations in natural recharge. From 1985 to the beginning of 2000, the GWL depression spread widely all over the Dhaka area and it ranged from -10 to -30 mean sea level.[15] Two distinct patterns were observed within the Dhaka region in terms of water levels: outside of Dhaka metropolis, the seasonal variation due to natural recharge in groundwater levels is still higher than the yearly decrease due to abstraction. In 2018, the GWL showed a wider and deeper cone of depression at about -65 mean sea level. The eastern part of the city next to Balu River extracts less groundwater compared to Dhaka City, and the GWL is variable, between -12 and -19 mean sea level.[15] Dhaka Water Supply and Sewerage Authority (DWASA) is responsible for water supply for Dhaka and Narayanganj city area, while in Savar and Gazipur areas the water supply is managed by the respective local authority.

Figure 7 : Abstraction and Natural Recharge

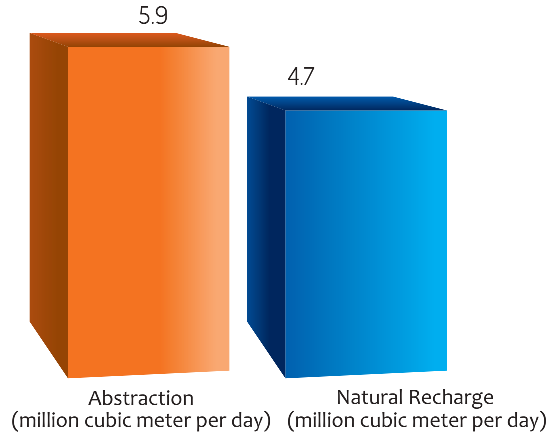


Figure 8 : Sector wise ground water abstraction

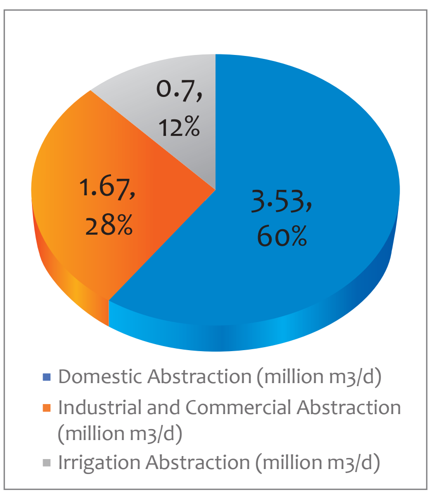
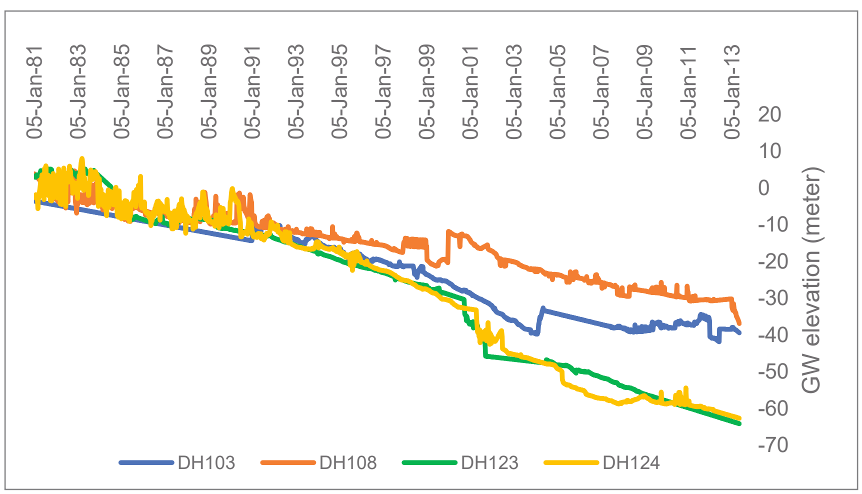


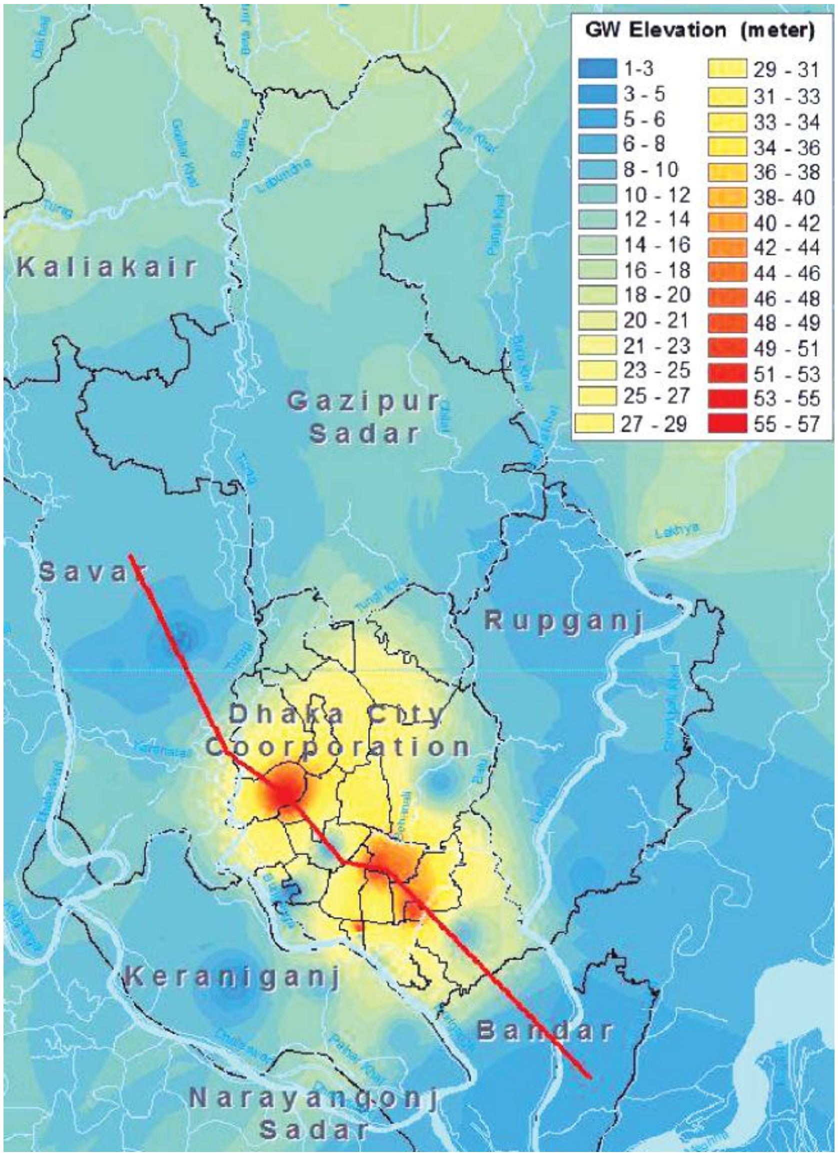
Figure 9 : Long term Groundwater level fluctuation

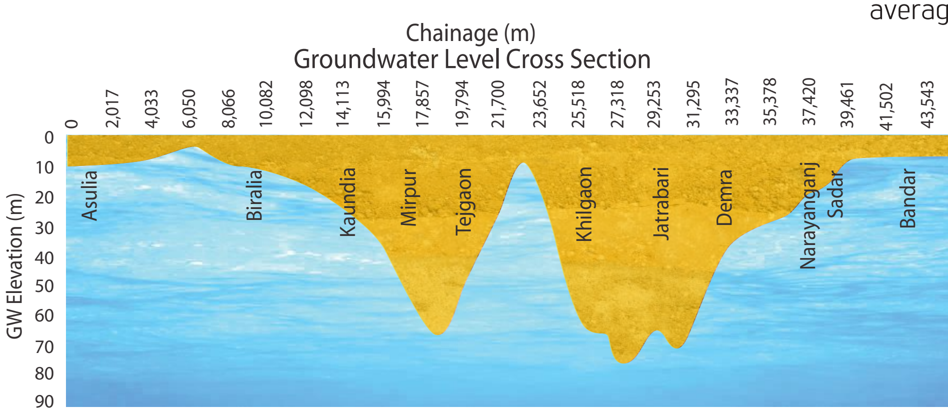


Dhaka Water Supply and Sewerage Authority (DWASA) is responsible for water supply for Dhaka and Narayanganj city area, while in Savar and Gazipur areas the water supply is managed by the respective local authority (Municipality). Total estimated abstraction of the entire Dhaka region was about 5.9 million cubic meter per day, in which DWASA supplies around 2.4 million cubic meter per day of water from approximately 760 deep tube wells (DTW) with a 3,040- km-long pipeline network, where system loss is assumed to be around 25%[16]. The second largest abstraction was from private abstractions which include mainly the industrial and commercial abstraction and account for about 1.67 million cubic meter per day[15].

[15] Islam, Md. Bayezidul, Firoz, ABM, Foglia, Laura, Marandi, Andres, Khan, Abidur Rahman, (2017), A Regional Groundwater-Flow Model For Sustainable Groundwater-Resource Management In The South Asian Megacity Of Dhaka, Hydrogeology Journal • January 2017

Figure 10 : Existing groundwater head distribution in the study area





Preliminary assessment of the greater Dhaka groundwater elevation based on the water level monitoring stations constructed by Bangladesh Water Development board reveals that the city is having a large cone of depression in its water table, the bottom of which lays as far as 60 meters below mean sea level (80-85 meter in reference to surface level). One exception is observed between Tejgaon and Khilgaon - a sudden flux in water table. Because of Hatirjheel, local GW mound/perched water level could be there, may not GW level. However, this result is partially supported by previous studies. The studies conducted by IWM (2008)[17], Hoque et al (2007)[18] and Akther et al (2009)[19] suggested the drawdown should be around -70 meters in 2007/2008, with an annual decrease of 2 meters, suggesting it should be around -86/-88 meters in 2016. Considering these were quite rough estimations, the result is relatively similar. The fact that the drawdown according to the model is smaller also supports the suggestion by Wit (2016)[20], who suggested the groundwater level will decrease in a slower pace towards an equilibrium at the present rate of development.

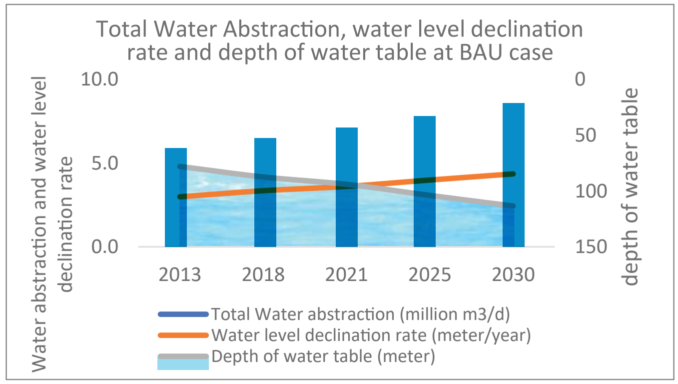
The cone of depression as depicted in the figure above may have caused the additional resistance to natural recharge in the center of Dhaka region. Dupi Tila Aquifer is confined by the leaky silty clay of Madhupur Formation, which has an average thickness of about 10 m. As the groundwater level fell from a few meters to -25 m in the late 1990s, the aquitard has been drained and the upper part of the Dupi Tila became dewatered.

[16] *DWASA (2017) Management information system (MIS) report. Dhaka Water Supply and Sewerage Authority (DWASA) and Institute of Water Modelling (IWM), Dhaka, Bangladesh.*
[17] *IWM. (2008), RESOURCE ASSESSMENT AND MONITORING OF WATER SUPPLY SOURCES FOR DHAKA CITY. Dhaka*
[18] *Hoque, M. A., Hoque, M. M., & Ahmed, K. M. (2007), Declining groundwater level and aquifer dewatering in Dhaka metropolitan area, Bangladesh: cause and quantification. Dhaka:Hydrogeological Journal*
[19] *Akther, H., Ahmed, M., & Rasheed, K. (2009), Spatial and Temporal Analysis of Groundwater Level Fluctuation in Dhaka City, Bangladesh. Dhaka: Asian Journal of Earth Sciences.*

GROUNDWATER SUSTAINABILITY ASSESSMENT

GROUNDWATER SCENARIO AT BUSINESS AS USUAL CASE - 2021 and 2030

Figure 11 : Total Water Abstraction, water level declination rate and depth of water table at BAU case



The business as usual case (BAU) assumes a steady state growth in industrial expansion. To project the groundwater level in 2021 and 2030 at BAU, the study considers the industrial growth rate 8.9 (present growth rate) and irrigation growth rate 5%. The present growth rate of population is also considered for demographic projection. This means that the total groundwater abstraction will reach to 7.1 million cubic meter per day in 2021 and 8.6 million cubic meter per day in 2030 in contrast to the present rate of abstraction (5.9 million cubic meter per day). The lowest depth of upper aquifer will be 94 meter in 2021 and 113 meter in 2030. At present the lowest depth of upper aquifer is about 78 meters. The average rate of GW table declination will also be affected. On an average the rate will increase to 3.8 meter per year (at present the rate is 3 meter/year) .

Figure 12 : Cross section of the Projected GW head in BAU case

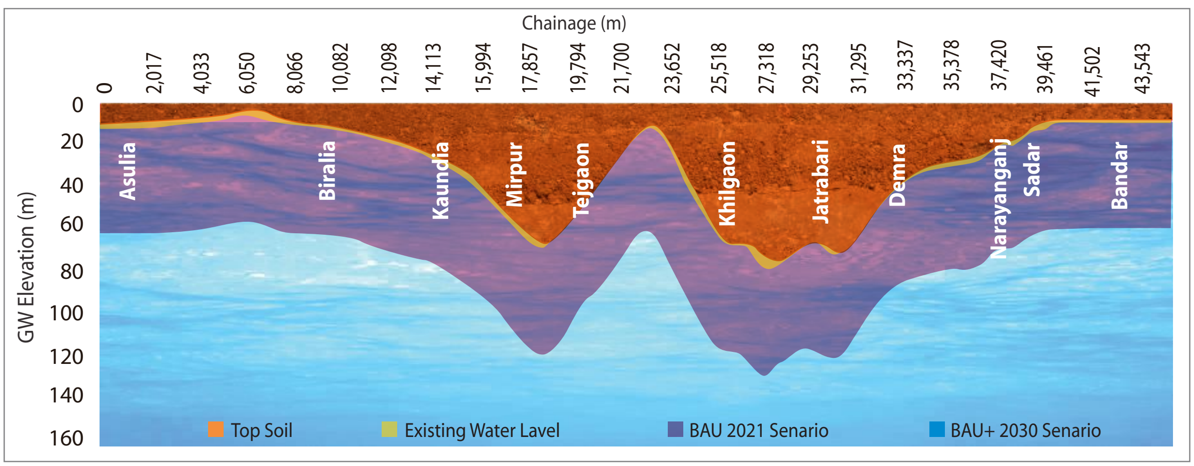
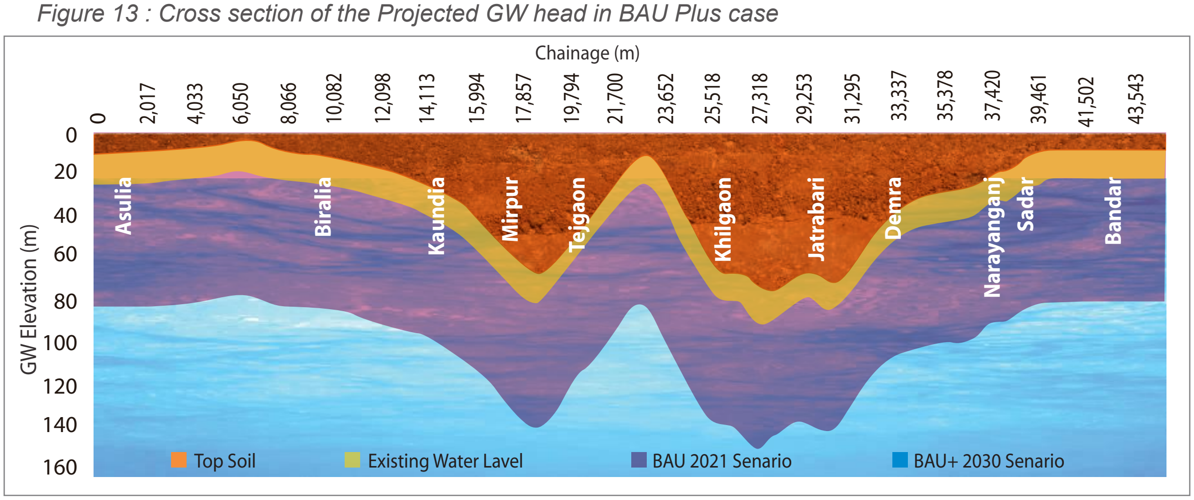


Figure 13 : Cross section of the Projected GW head in BAU Plus case



GROUNDWATER SCENARIO AT BUSINESS PLUS CASE - 2021 and 2030

Figure 14 : Water demand over years at BAU plus case

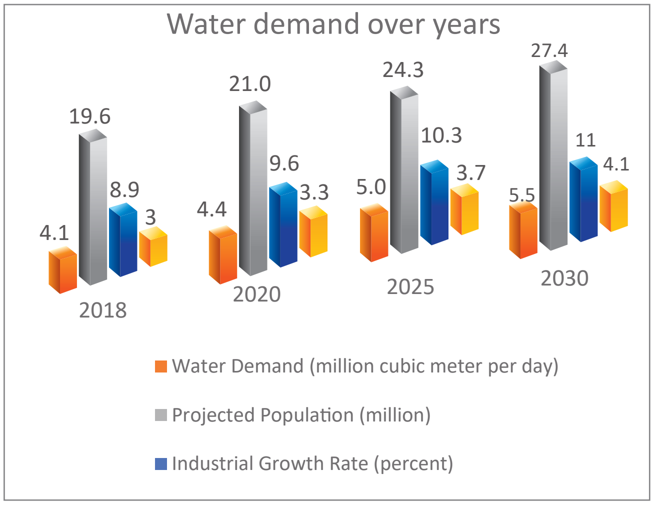
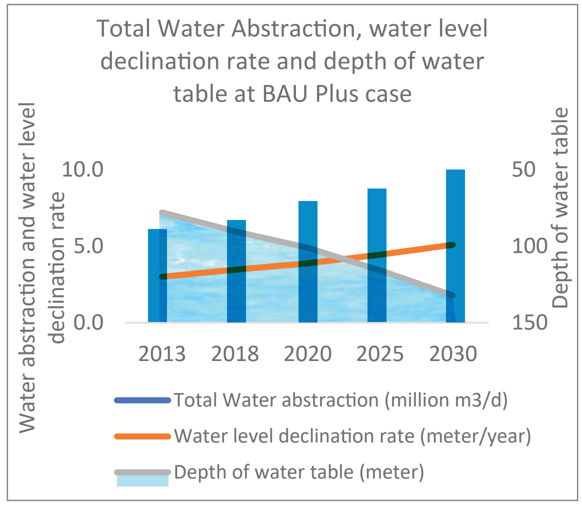


Figure 15 : Total Water Abstraction, water level declination rate and depth of water table at BAU plus case



Business plus scenario assumes the industrial growth will not be steady state as it was for BAU case. The considers 9.6% and 11% annual growth rate for industrial expansion for the year 2021 and 2030 respectively. For irrigation the study considers 10% annual growth. Demographic change is considered to be 21 million population in 2021 and 27.4 million population in 2030. Thus, the demand of domestic water has been calculated accordingly. Analysis indicated that the elevation of groundwater level will decline to about -100m in the central part of the Dhaka City in 2021 and -132 meter in 2030. The current rate of GW decline will increase to 5.1 meter/year from 3 meter/year. The total water abstraction rate will also increase to 7.6 million cubic meter per day in 2021 and 10 million cubic meter per day in 2030. The existing cone of depression in the water table will increase its area to be a mega cone of depression. The mega cone of depression will attain an area of about 1962 square kilometer which is more or less double than the present value. As a result, a huge number of wells located in the city or outside the city will be affected as well as the abstraction cost will be higher to extract water from the deeper aquifer. On the other hand, this huge declination can also produce subsidence or other environmental degradation in or around Dhaka City.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUDING REMARKS

The analysis of groundwater abstraction and water levels reveal that the aquifer is almost entirely controlled by excessive abstraction of water in the area. The rate of decline has reached 3 meter/year in recent years in the main part of the city which may reach to 3.8 meter in 2021 and 5.1 m in 2030 in business plus case. The area has been experiencing massive abstraction of groundwater for the last two decades and the density of the wells is increasing with time. The water level in the aquifer is declining because withdrawals are exceeding recharge. Large and prolonged abstraction has modified groundwater flow directions by reversing water slope towards the city center

producing cones of depression (huge vacuum) in and around the large pumping centers. The cones of depression are lowering vertically and widening horizontally owing to the increased installation of production wells and to the spread of the production wells into new areas. The positions of the depression are largely ruled by the concentrated pumping locations of DWASA at the city part and thus similar cone of depression is likely to develop at the industrial zones at Savar, Ashulia, Tongi and Narayanganj. The recent development of such vacuum in the Dhanmondi area is most likely due to the impact of high pumping associated with the high-rise apartment boom, which started in the early 1990s. This converted the once low-density residential area to a high-density area along with installation of many private abstraction wells for uninterrupted water supply.

With the increase in population and its water demand, DWASA will require to install more production well, which is also true for industrial expansion. The industrial zones located at Savar, Ashulia, Tongi and Narayanganj is expected expand at higher rate in the coming years, most of which are water intensive specially the wet processing industries. The pace of expansion must match with the groundwater abstraction leading to the installation of new production wells. The massive groundwater abstraction in the industrial zone may cause developing cone of depression.

On the other hand, the vertically deeper and horizontally expanded cone of depression will also have adverse effect on regional groundwater flow system. It may significantly alter the existing flow regime causing the flow from all directions to the central part of the depression. Groundwater flows from higher water table to lower water table areas in response to the hydraulic gradient and the velocity of the flow is directly proportional to the steepness of the gradient. Before the formation of the cone of depression, ground water generally flowed from the north to south i,e from Savar to Narayanganj. But the development of depression in the central part of the Dhaka city has changed the gradient and diverted the flow towards central area of the city.

RECOMMENDATION FOR THE NEXT COURSE OF ACTION

The study has very clearly demonstrated that even at the present rate (BAU) of ground water development and use is not sustainable. In the BAU+ scenario, major adverse environmental impacts like land subsidence, severe shortage of potable and agricultural water, aquifer contamination from arsenic and salinity etc. will have severe socio-political, economic and environmental impacts. Based on the result of this study the following are some of the recommendations made for the client:

1. Recommendations for National Government

Creating enabling environment as well as having necessary instruments is one of the keys to bring changes in water use patter in textile which the national government must take the lead. The following are the initiatives for the government to take:

a) Incentive based regulation on water use and volumetric water allocation
b) Implementation of Polluter Pay Principles
c) Zero discharge of hazardous chemical
d) Implementation of DWASA Master Plan

a) Incentive based regulation and volumetric water allocation

The government should initialize incentive based regulatory system towards reduces use of groundwater, increase the recharge amount by MAR and reusing the treated water. The incentives can be in the form of monitory value or recognition and rewarding greater contract to the factories. The followings are some of the specific recommendations:

I. Mandatory installation of digital water meters at the factories and monitoring of the data accuracy
II. Advocacy and encouraging the factories to reuse the water.
III. Provide incentives (like tax exemption etc.) to the industries who install and operate water treatment system for reusing the water.
IV. Provide incentives to the industries that introduce higher technology and various enamines/catalyzers to reduce water requirement at various stages of wet processing
V. Introduce incentives to the industries that install Managed Aquifer Recharge at the factory premises and establish monitoring system of Ground Water.
VI. Promote and encourage the factories to use surface water and redue dependency on Ground Water.
VII. Advocacy with the factories to introduce Managed Aquifer Recharge all level, institutionalizing the incentive based regulatory system, tax remedy for the factory that adopt measure water reuse, recycle and reduction of GW.
VIII. Volumetric water allocation for each industry that will regulate the total abstraction. This means the industries must restrict their water abstraction within the limit set by the government.

b) Implementation of Polluter Pay Principles

The 'polluters pays' principle is the commonly accepted practice that those who produce pollution should bear the costs of managing it to prevent damage to human health or the environment. For instance, a factory that produces a potentially poisonous substance as a byproduct of its activities is usually held responsible for its safe disposal. The functionalization of this principle will eventually reduce the abstraction of the water to reduce the pollution.

c) Zero Discharge of Hazardous Chemical

Zero discharge initiatives are gathering momentum in Bangladesh. The implementation of a zero-discharge standard has appeal to both the government and brands. It provides easier means of enforcing compliance and reducing discharges of chemicals into the environment. From a water perspective, zero discharge measures could reduce water abstractions by up to 75%, however, they do not affect non-consumptive use and have the potential to reduce return flows to the environment. Their implementation must be considered carefully at a local, location specific, context.

d) Implementation of DWASA Master Plan

DWASA master plan assessed that the future production capacity needs to be upscaled up to 5.2 million cubic meter per day by the year 2035. To meet the demand, option for DWASA are limited to the harnessing the water resources of Meghna and Padma river. Resources Assessment Study by IWM 2006 showed that sufficient water of adequate quality is available in these two rivers. The two feasibility studies conducted for the Padma and Meghna Water Treatment Plant also shows that these two plants are technically, socially and economically viable. DWASA planned for total supply from the Padma and Megha is 900 and 2400 million liter per day respectively by the year 2035. As the plan assessed further, the allowable limit of groundwater abstraction from the upper Dupitila aquifer is around 1640 MLD. The lower Dupitila aquifer is considered not dependable. Therefore, DWASA will rely only on the groundwater resources of upper dupitila aquifer only. The master plan recommended that around 75% of the resources in the upper Dupitila aquifer is harnessed for water supply for Dhaka Metropoliton area. Rest of the extractable groundwater resource should be reserved for any future uncertainties, which might arise due to increase of demand of delay in commissioning of large bulk surface water supply sources. Around 96 million liter per day will be available by rehabilitation and expansion of the three Water Treatment Plant at Chandighat, Godnail and Sonakanda. However, the recommendation is made to promote surface water use at all sphere, the effective implementation of which will ease the burden on the Ground Water resources of the study area.

2. Recommendations for Trade Association like BGMEA, BKMEA

The trade associations like BGMEA, BMKMEA etc. are to play critical role in policy advocacy in the government level. In addition to that the associations should take the following steps:

a) Policy advocacy with the government
b) Sensitizing and mobilizing the factories towards water abstraction reduction
c) Detail Investigation on Pollutant transport and flow system

a) Policy advocacy with the government

The textile associations may work with government to establish an enabling environment by formulating policy that will govern water abstraction by factories. The following steps are recommended in line with this:

I. Formulation of high-level committee and start dialoguing with the concerned ministry
II. Having discussion with the factories and brands to laying out the expectation and practically
III. Bringing the govt, factories and brands together to policy dialogue
IV. Drafting the policy papers on sustainable water use by factories
V. Finalizing and initiating to implement

b) Detail Investigation on Pollutant transport and flow system

It is imperative to understand how the pollution will affect the groundwater quality in the long run. Towards this end a pollutant transport modeling study is essential. The study will trace the pollutants on their origin/occurrence, transport and exchange with groundwater. So far only assumptions are made on such happenings with no credible scientific evidence. Therefore, a detail investigation on pollutant transport is essential to clarify the assumptions. The study will also explore the existing flow system of the groundwater. Generation of flow net is a prerequisite to understand the pollutant transport. The present study has found out the development of cone of depression at the central part of Dhaka city and projected a further development of such cones in industrial areas in the near future. In addition to it assumes a disturbed flow system with in the aquifer. However, the actual representation of the system is required to understand how and to what extant the pollution can have its adverse effect on the aquifer.

3. Recommendations for industries

The textile industries are the most important stakeholder in the whole process. The business to sustain for a longer term, they must come forward to take few initiative which can be listed as below:

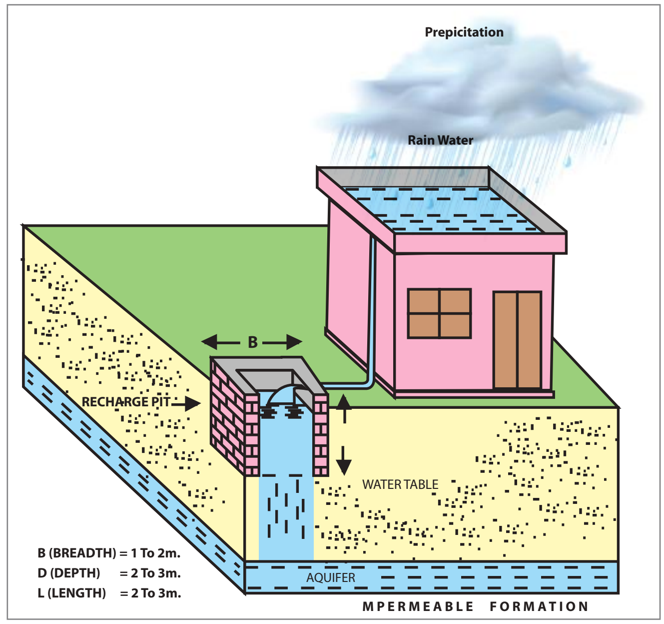
a) Managed Aquifer Recharge (MAR) and Rain Water Harvesting
b) Introducing reuse and recycle of waste water by the industries and promotion of surface water use

a) Managed Aquifer Recharge (MAR) and Rain Water Harvesting

MAR in conjunction with IWRM would help to restore groundwater resources in Dhaka city by using, for example, collected urban monsoon runoff and excess surface water from rivers. The method has been successfully implemented in different parts of the world such as USA; Australia, Israel, U.K etc. Depending on the aquifer type and water availability several MAR techniques (such as Infiltration basin, recharge well, river bank filtration etc.) are being practiced now. The artificial recharge of ground water aims at augmentation of ground water reservoir by modifying the natural movement of surface water utilizing suitable civil construction techniques.

On a pilot basis, introducing low cost MAR in the factories and at some of the households located in the industrial areas is prescribed. The learnings and output can be projected nationally to advocate and sensitize other stakeholders in taking appropriate measures. Along with piloting, policy advocacy with the government is also required to adopt nationally.

Figure 16 : Conceptual diagram of MAR

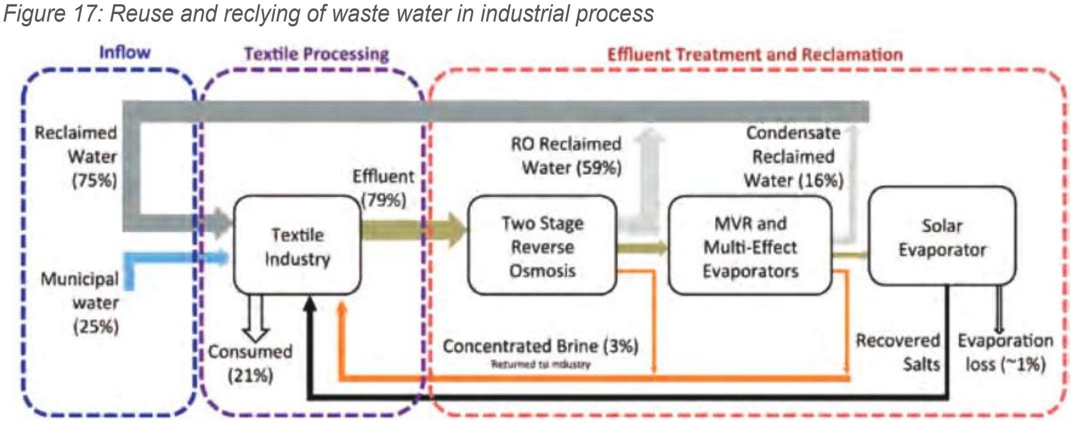


b) Introducing reuse and recycle of waste water by the industries and promotion of surface water use

Greater Dhaka, the largest amalgamation of industries in the country, has around 7000 industrial establishment located mainly in 10 clusters: Tejgaon, Savar, Dhaka EPZ, Konabari-Kasimpur (Gazipur), Tongi, Hazaribagh, BSCIC Narayanganj, Shyampur, Fatullah and DND. The accumulated water demand is estimated to 5.9 million cubic meters per day of which 1.67 million cubic meter per day is supplied to the industrial sector, that is approximately 28% of total abstraction. Approximately 75% of this total demand can be met up by introducing water reuse mechanism. It is recommended that the factories effectively start to treat the effluent water by adopting reverse osmosis technique and multi effect evaporator system to treat the wastewater. However, other available and as appropriate technologies can also be adopted. In Tiruppur, India, the system has been implemented and the outcome includes the following:

1. Water abstraction has been reduced by 75% (from 1200000 cubic meter per year to approximately 300000 cubic meter per year .
2. 96% of the effluent recovered for re-supply as freshwater to the industry.
3. Capture of dye salts from effluent stream for reuse by the industry.
4. Zero discharge of effluent to the river with consequent impact on water quality.
5. Payback period of 15 years

Figure 17: Reuse and reclying of waste water in industrial process



ANNEX 1: REVIEW OF LITERATURE

The water resources that supply most of the megacities in the world are under increased pressure because of land transformation, population growth, rapid urbanization, and climate-change impacts. Dhaka, in Bangladesh, is one of the largest of 22 growing megacities in the world, and it depends on mainly groundwater for all kinds of water needs. A number of studies have been conducted till today, on groundwater level trend, recharge potentials and aquifer characteristics of Dhaka revealing its vulnerability. This section describes the findings of the studies, those of having relevance with the ongoing project. Large abstraction by production -wells has been causing a linear to exponential drop in groundwater level and, substantial aquifer dewatering in Dhaka. The city is almost entirely dependent on groundwater, which occurs beneath the area in an unconsolidated Plio-Pleistocene sandy aquifer. Analysis shows that the pattern of water-level change largely replicates the patterns of change in the rate of groundwater abstraction. The abstraction has caused a sharp drop in water level throughout the city and created two cones of depression in the water level. Upper parts (primary aquifer) of the aquifer have already been dewatered throughout the area, with the exception of part of the northeast and southeast corner of the city. It has been estimated that about 41 million cubic meters (MCM) of the aquifer dewatered by the year 1988, which increased to 2,272 MCM in the year 2007. Water-level decline may increase non-linearly due to limiting vertical recharge in areas where the aquifer is dewatered and may severely threaten the sustainability of the aquifer [22] .

To address this water supply issue in Dhaka, a groundwater model was developed by Kai Manuel Hermann in 2016 to acquire a better understanding of the effects of interventions in the water supply. The aim of this study was to improve the groundwater model and explore its possible application in a scenario study. To improve the model, input data about the wells, recharge from precipitation and rivers was integrated in the model. Thereafter the heads of the model were fitted to observed groundwater levels by adjusting the vertical hydraulic conductivity, horizontal hydraulic conductivity and the vertical anisotropy. Finally, the improved model was applied by computing the effects of three possible policies with the model. The improved input data and calibration resulted in a more accurate illustration of the cone of depression by the model. The cone of depression in Dhaka goes as low as 80 meters below surface level with a radius up to 40 km according to the improved model. The model was able to map precise changes in groundwater level caused by possible water abstraction.

Islam and et. Al., (2017) in their study "A regional groundwater-flow model for sustainable groundwater-resource management in the south Asian megacity of Dhaka [24] discussed the existing status of the aquifer beneath Dhaka city. The regional groundwater-flow model MODFLOW-2005 was used to simulate the interaction between aquifers and rivers in steady-state and transient conditions during the period 1981– 2013, to assess the impact of development and climate change on the regional groundwater resources. Detailed hydro-stratigraphic units are described according to 150 lithology logs, and a three-dimensional model of the upper 400 m of the Dhaka area was constructed. The results explain how the total abstraction (2.9 million m3/d) in the Dhaka megacity, which has caused regional cones of depression, is balanced by recharge and induced river leakage. The simulated outcome shows the general trend of groundwater flow in the sedimentary Holocene aquifers under a variety of hydrogeological conditions, which will assist in the future development of a rational and sustainable management approach.[23]

Akter and Hossain (2017) constructed a groundwater model for Dhaka city and its surrounding areas and evaluated the effect of artificial recharge to aquifers[25]. The study found, massive withdrawal of water from this aquifer which caused fall of water table at an alarming rate which might cause land subsidence, ecological and environmental hazards. The long-term hydrographs for the observation wells within the Dhaka City shows a sharp decline of water level with little or even no fluctuation which indicates over exploitation of aquifers. The water table contour maps of wet and dry season show a pointed cone of depression in the central part of the study area.

22 Hoque, Mohammad A.,
Hoque, M. Mozzammel, Ahmed, Kazi Matin, 2007, Declining Groundwater Level And Aquifer Dewatering In Dhaka Metropolitan Area, Bangladesh: Causes And Quantification, Hydrogeology Journal • January 2007, Received: 28 May 2006 /Accepted: 20 September 2007.
23 Hermann, Kai Manuel, 2016, Groundwater Model of Dhaka, A Study to Improve an Existing Groundwater Model of Dhaka and to Explore Its Applications, University of Twente
24 Islam, Md. Bayezidul, Firoz, ABM, Foglia, Laura, Marandi, Andres, Khan, Abidur Rahman, 2017, A Regional Groundwater-Flow Model For Sustainable Groundwater-Resource Management In The South Asian Megacity Of Dhaka, Hydrogeology Journal • January 2017, DOI 10.1007/s10040-016-1526-4
25 Akhter, Shireen, Hossain, Md. Sarwar, 2017, Groundwater Modelling of Dhaka City and Surrounding Areas and Evaluation of the Effect of Artificial Recharge to Aquifers, World Journal of Research and Review (WJRR), ISSN:2455-3956, Volume-5, Issue-3, September 2017

Islam (2017) conducted a research on spatial disparity of groundwater depletion in Dhaka city[26] which showed that the continuous over withdrawal of ground water and irregular and insufficient recharge causes depletion of groundwater. Rapidly growing urbanization in the past 30 years also contributed to the present condition of Dhaka City. It was observed that the declining trend of groundwater in Dhaka City is 3 meters per year. Throughout the Dhaka City, depletion of groundwater level is observed. There are variations in current groundwater level and in the rate of its decline in different areas of the city. Due to difference in volume of withdrawal topography, geology, environment, population and other factors this difference is observed. The areas which are more populated showed higher depth of water table than that of the less populated areas. Rapid and alarming depletion of water table was found in the Mirpur and Dhanmondi where the depletion ranged from 65.97 to 8.36 and from 10.12 to 66.32 meters respectively for the period 1980 to 2010. Second highest depletion was found in the Sabujbag which varied from 3.13 to 54.4 meters during the same period. Sutrapur, Cantonment and Mohammadpur areas had comparatively less depletion rates.

Rahman (2010) in his research classified the aquifers of greater Dhaka in three major categories: Holocene Deposit, Pleistocene Deposit and Plio-Pleistocene Deposit. He further mentioned that the aquifers are generally thick and multilayered with relatively high transmissivity and storage coefficients. He suggested for artificial recharge due to the fact that these aquifers are alluvial aquifers which characteristically have moderate to high hydraulic conductivity. Spatial analysis of the region has showed that Karaniganj, Kotoali, Savar, Dhamrai, Singair upazila, which are situated in greater Dhaka region and close to Dhaka City, could serve as recharge sites (Infiltration galleries) for recharging. The study involving the use of a 3-D mathematical model shows that the abstraction or recharge in the area within and around Dhaka City does not affect the groundwater level below the city. Therefore, in order to improve the groundwater storage, artificial groundwater recharge directly in the city area would be most appropriate. As the thickness of the surface impermeable layer varies from 5 m to 45 m, the combination of infiltration and injection technology would be a preferred choice. Detailed studies are required using the most appropriate state of the art spatial analysis to support the final selection and ranking of suitable locations for the AR facilities which should be based on, flood risk, urbanization trend, aquifer characteristics, water sources, AR technology and subsequent use of the recovered water. Rahman further investigated the Groundwater quality which revealed that the upper aquifer of the City contains relatively high concentrations of dissolved ions, quite variable in space. The ground water is predominantly of Ca-Mg-HCO3 type. Cation exchange and oxidation may enhance the biogeochemical processes in the aquifer under the existing conditions. He concluded that the groundwater chemistry of the upper aquifer has been influenced by various anthropogenic processes, showing wide variations of groundwater quality depending on the area, which would complicate the implementation of AR projects [27]. Kamrul Hasan (1999) expressed serious concerns about the impact of urban growth on groundwater quality. Intensive abstraction from the Dupi Tila aquifer has led to induced recharge from rivers and enhanced vertical leakage from regions containing contaminated land. Low quality water has also contaminated the aquifer from the polluted stretches of rivers[28] . Through the vertical hydro-chemical profiles he showed that urban pollution has reached the upper levels of the aquifer within the city. Contaminant transport modelling also demonstrated that a general deterioration of groundwater quality is inevitable even if all sources of contamination are removed immediately. The model could be used to guide groundwater quality monitoring as

part of a protection policy for this strategically important aquifer. Karim, Mir Fazlul et. al. (1999) investigated the geology and geomorphology for ground improvement in the Dhaka city – Tongi area. They found that, geologically Dhaka-Tongi area consists older sediments hosting the major parts of the city and surrounded by very young riverine sediments occupying the surrounding valleys. The drainage patterns of this high tract consist of two types, dendritic and trellis. The older sediment sequence consists of sandstone of the Dupi Tila Formation overlain by the Madhupur Clay. The Clay is overlain by alluvium but is locally exposed in stream valleys. The region can be divided into three types of landforms – a central high area, a complex of high and low areas and a complex of low areas[29].

26 Islam, Dr. Md. Serajul, Farzeen Farhana, 2017, Spatial Disparity of Groundwater Depletion in Dhaka City, 15th International Conference on Environmental Science and Technology, Rhodes, Greece, 31 August to 2 September 2017

27 Rahman M. Azizur, Rusteberg, Bernd, Sauter, Martin, 2010, Hydrogeological Evaluation of an Over-Exploited Aquifer in Dhaka, Bangladesh Towards the Implementation of Groundwater Artificial Recharge, Geoscience Center, University of Goettingen, Germany, Vol. 12, EGU2010-10042-1.

28 Hasan, M Kamrul, Burgess, William, 1999, The Vulnerability of the Dupi Tila Aquifer of Dhaka, Bangladesh, Impacts of Urban Growth on Surface Water and Groundwater Quality (Proceedings of IUGG 99 Symposium HS5, Birmingham, July 1999). IAHS Publ. no. 259, 1999

29 Karim, Mir Fazlul, Chowdhury, Mokbul-E-Ala, Kabir, Sohail, 1999, Engineering Geology and Geomorphology For Ground Improvement In The Dhaka City – Tongi Area, Geological Survey of Bangladesh, Dhaka, Atlas of Urban Geology – Volume 14.

Hoque (2004) studied the Hydro-stratigraphy and Aquifer Piezometry of Dhaka City and computed the lithological and geophysical resistivity log information to build hydro-stratigraphy of Dhaka. The study used Dhaka WASA groundwater abstraction and well design information, and BWDB Groundwater level data to reconstruct the piezometry of the aquifer. A thick column of unconsolidated sediments composed of sands, silts and clays build the hydro-stratigraphy of the region and provisionally subdivided into 7 units up to a depth of 450m. These units are organized into three aquifers systems separated by clay, silt dominated horizons. The average thickness of the first aquifer ranges100-150m while second aquifer range from 50-100m. A thick clay layer of 37 to128m is followed by the second aquifer and capping the third aquifer of uniform thickness (40m). Third aquifer is based by another clay dominated layer. Long term hydrograph from the different part of the city specify the increasing trend of drop in water level throughout the city. Groundwater abstraction in the city has increased more than 1200% from 1970 to 2003.This increased abstraction causing sharp drop of water level throughout the city and excessive high rate of production in the south-central and south-western region formed cones of depression. The Hydro-stratigraphy and piezometry of the first aquifer indicates higher vulnerability of groundwater in the central city area. Information on quality and quantity of water in the lower aquifer (second and third aquifer) are still inadequate [30].

In a research on Managed aquifer recharge (MAR) in Dhaka city conducted by Pervin (2015) the potentiality and challenges of MAR and its role on water resources management, in particular drinking water supply sub sector was analyzed. The study indicated that population growth would create additional drinking water demand in the near future for a projected population of 22 million by the year 2025. According to previous studies, due to over-exploitation of the regional aquifer the current groundwater resources is non-sustainable. It resulted in very fast decrease in groundwater levels of about 2 to 3 m/y. New water resources management strategies are needed to confirm drinking water supply and sustainable groundwater development (i.e., halt of groundwater decline). MAR would help to restore groundwater resources in Dhaka city by using, for example, collected rainwater. The study briefly explored the potential, viability, and challenges with respect to the implementation of Managed Aquifer Recharge (MAR) as a contribution to sustainable water resources development in Dhaka City. It was further mentioned that rainwater harvesting together with water capturing from the open spaces can meet up to 20%-30% of the present water supply demand in Dhaka. Though the peripheral rivers are polluted, nearby big rivers (such as Meghna) can be a source of water during the monsoon. The estimated volume of storage for the upper Dupitila aquifer is about 1120 Mm3. Hydraulic conductivities of the Dhaka City aquifer would allow for the dispersion of recharged water with low costs of recovery, making MAR viable. Lithologs and 3D block diagrams prepared by the study reveals that the top most clay layer ranges between 8 and 52 m in most places. Considering the top impermeable layer thickness (TIL) and land cover classification, four primary MAR techniques have been suggested: (1) infiltration basin (TIL thickness: 0-10 m), (2) cascade type recharge trench/pit (TIL thickness: 10-32 m), (3) Aquifer storage, transfer and recovery, ASTR (32-52 m), and (4) use of natural wetlands to recharge the water collected from open spaces. The regional groundwater flow direction, from North-West and North-East towards Dhaka City, may allow the use of the aquifer as a treatment facility and transport medium for groundwater development, if spreading basins are installed in the greater Dhaka City area. Preliminary hydrogeochemical investigations reveal that in some places groundwater is already polluted by industrial waste. Therefore, the study suggested for a comprehensive geochemical model to identify potential geochemical processes related to the infiltration or injection of storm water[31] .

[30] Hoque, Mohammad Abdul, 2004, Hydro-stratigraphy and Aquifer Piezometry of Dhaka City, Institute of Water and Flood Management, Bangladesh University of Engineering and Technology, 2004

[31] Parvin, Mollika, 2015, Potential And Challenges Of Managed Aquifer Recharge In An Over Exploited Aquifer of Dhaka City, Department of Water Resources Engineering, Bangladesh University of Engineering and Technology, 2015.

ANNEX 2: METHODOLOGY

The study has been done in two steps: building a lithological model to examine the aquifer system, secondly developing a mathematical model to assess the existing groundwater scenario and to estimate the groundwater level for year 2021 and 2030. Several analytical processes as followed is described in the section below:

DESK REVIEW AND DATA COLLECTION

This stage is designed to review available research works, articles on groundwater published in scientific journals both nationally and internationally primarily in the greater Dhaka and then for the part of the world having similar conditions. The aim is to generate adequate knowledge and information related to the study. The output of this section has been presented in the literature review section of the main report.

The study collected information on lithology, geophysical logs (resistivity), groundwater abstraction, existing groundwater levels, recharge area, surface water discharge, rainfall and evaporation from BWDB, DWASA and BADC. Historical dataset was be collected for groundwater level, rainfall, evaporation and surface water discharge. The aquifer parameter was collected from the scientific journals published on groundwater of Dhaka city and its surroundings (table).

LITHOLOGICAL MODEL CONSTRUCTION

A number of studies on groundwater system of Dhaka city has been done so far and most of them identified the existence of a multilayer aquifer in and around Dhaka. These studies have been done at local level and information was collected from observation wells constructed by BWDB. Based on the bore log information collected from BWDB, a lithological model will be constructed at the initial stage, the result of which has been described in the following chapter.

NUMERICAL MODELLING- STEADY STATE CONDITION

Following the lithological model, the study has conduct computer aided numerical model to visualize the existing groundwater head distribution at different layer and its geographical extent as well as the vulnerability of the aquifer in the long run in non-static condition. Followings are the steps planned for this stage:

- Generating the model mesh- discretization of the model area into approximately 1000 cluster for the designated area
- Giving input of groundwater observation wells from BWDB
- Calculating recharge area (based on GIS mapping) and potential recharge rate (secondary source from IWM study)
- Fixing the boundary conditions: the average river stages has been considered as boundary head
- Setting up of the aquifer properties- after defining the mesh size and boundary condition in the model domain different hydraulic parameter like initial hydraulic head, aquifer type (derived from the conceptual model), aquifer top and bottom (derived from the conceptual model), hydraulic conductivity, transmissivity, effective porosity, groundwater recharge rate, specific flow like infiltration etc. will be given as input in the model domain.
- Final modeling at different setting/assumption.

AQUIFER SYSTEM

The aquifer systems underlying the study area is the Dupi-tila sand formation overlain by Madhupur clay. These deposits are of Plio-Pleistocene age. The deeper aquifers under greater Dhaka is yet to be fully explored. The hydro-stratigraphy of this area, up to 350 meter (approx.) depth, has been defined based on lithological information (please see chapter four), the layered hydro-stratigraphy of the area is mostly homogeneous and assemblage of sands, silts and clays. Subsurface sediment formation has been classified for different hydro-stratigraphic units based on the bore-log probability, geo-electrical profiles and lithological characterization. Uniformity of lithological composition, presence of textured sediments and the stratigraphic position has been considered for differentiating the Aquifer and Aquitard units including their various depth locations in the study area. Accordingly, up to the studied depth, total 8 hydro-stratigraphic units were defined. It was found from bore-log analysis the aquitard are not continuous, therefore the upper and lower aquifers are connected and exchange water with each other.

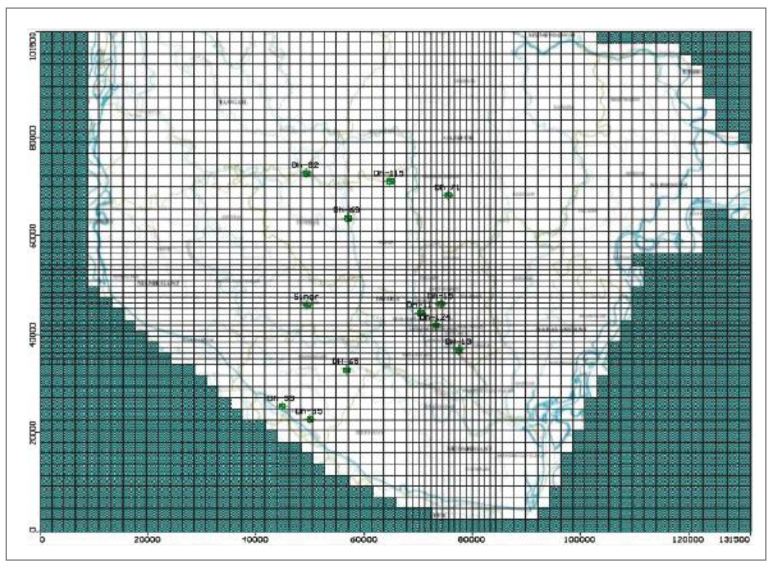
Table 1: Aquifer system of the study area

Aquifer System	Hydro-stratigraphic Unit	Average Thickness (m)	Average Bottom Depth (m)
	Top soil/Clay	10	10
Upper Dupitila Aquifer - I	Aquitard 1	60	70
	Aquifer-1	40	110
Upper Dupitila Aquifer - 2	Aquitard 2	30	140
	Aquifer-2	90	230
Lower Dupitila Aquifer-1	Aquitard 3	40	270
	Aquifer-3	80	350
	Aquitard 4	15	365

Selection of Model

For ground water flow and recharge modelling, ASMWin has been selected as the software. It is an environmental simulation version for Microsoft Windows. A model is constructed by using ASMWin with the most intuitive and powerful graphical interface available. The simulation methods used in the model is based on the Integrated Finite Difference Method (IFDM). The mathematical approach to model simulation is conceptually simple and involves the conversion of different equations which describes the groundwater flow into water balance equations for the element of the model grid network.

Figure 17 : Model grid reference



Model Preparation

The model required an extensive database. Most of the model parameters needed to be defined for each of the model grid. In construction of the model, the first stage was to define the modeled area and boundary condition with natural physical features and limits. The model covered the entire study area defined by UTM coordinated system. All kinds of data related to hydro- geological parameters and aquifer geometry were used to build the model grid network. The whole study area is represented in grid reference. Data needed to import in the model is prepared according to grid reference. It was based on the repeated subdivision of a regular square mesh. The area of a single square mesh is 2 km2 (figure 7). For the purpose of simple model, complex geological conditions have been approximated by simplified hydraulic equivalents. Eight layers were identified in the aquifer system (Table 6) from the lithological modeling which are comprised with fine, medium, coarse sand and clay. Different hydro geological parameters are assigned for each of the modelled layer (table 5).

Table 2: Hydro geological parameters as assigned in modelled layer[32]

Hydro-stratigraphy	Kx (m/s)	Ky (m/s)	Kz (m/s)	Ss (1/m)	Sy	Total porosity
Aquitard-1	2E-08	2E-08	3E-8	.000 1	.03 5	.5
Aquifer-1	.0002	.0002	4E-5	.0012	.15	Hj .2
Aquitard-2	5.8E-07	5.8E-07	5.8E-7	.00015	.05	.48
Aquifer-2	.0003	.0003	4E-5	.00107	.21	.3
Aquitard-3	1.2E-7	1.2E-7	1.2E-7	.0002	.08	.40
Aquifer-3	.00043	.00043	4.3E-5	.00109	.23	.33
Aquitard-4	1.2E-8	1.2E-8	1.2E-8	.0002	.084	.41

Indicators: Kx, Ky, Kz = Conductivity, Ss =Specific storage, Sy= specific yield

32 *Akhter, Shireen, Hossain, Md. Sarwar, 2017, Groundwater Modelling of Dhaka City and Surrounding Areas and Evaluation of the Effect of Artificial Recharge to Aquifers, World Journal of Research and Review (WJRR), ISSN:2455-3956, Volume-5, Issue-3, September 2017*

For boundary conditions, the Padma in the south east, Jamuna in the west, Meghna in the east and The Old Brahmaputra River in the north are considered as external boundaries for modelling purposes. The boundary condition has been defined as constant head boundary. Parameters that have been incorporated to the model are mean horizontal and vertical permeability of each layer, storage co- efficient, specific yield and porosity of each layer. Type of aquifer (e.g. confined, unconfined or semi confined) also declared before the model calibration. The aquitards are not continuous throughout the area (based on lithologs) i.e. aquifers are generally connected hydraulically, therefore the aquifer permeability has been used on the place of cracks in aquitard layers. It is assumed that the rainfall, river water level and other climatic factors would not change in the next 12 years. Groundwater abstraction for irrigation has been specified as cluster grid cell and water supply to industry has been specified for individual grid cells.

DEVELOPMENT OF NON-STATIC CONDITION

The non-static condition therefore pumping scenario has been developed based on the existing deep tube well locations and their discharge. Location, operation hour and pumping rate has been used as water abstraction values and the model ran under following assumption:

- Water abstraction scenario on business as usual case till 2021
- Water abstraction on business as usual plus case till 2021
- Water abstraction on business as usual case till 2030
- Water abstraction on business as usual case plus till 2030

SUSTAINABILITY PROJECTION

One of the major thrusts of this assessment exercise is to find out sustainable groundwater abstraction limit for the study area. Empirical studies on groundwater system in Dhaka illustrate the spatiotemporal dynamics of recharge and reveal that current groundwater abstraction for various purpose seeks sustainability assessment especially industrial abstraction. Analysis has been conducted between potential recharge, actual recharge and pumping rate and has been given input in non-static condition to determine sustainable abstraction limit. On the model environment pumping rate has been calibrated to examine the changes over time.