2030 Water Resources Group

Global Water Partnership South Asia

Bangladesh Water Partnership

RAPID ASSESSMENT OF GREATER DHAKA GROUNDWATER SUSTAINABILITY

April 2019

PREFACE

The Industrial sector, especially the apparel sector (including textile), of Bangladesh has been expanding at a fast pace and in the last three decades the country has become the second largest global exporter of ready-made garments (RMG). In the process, the sector has also become the largest forex earner and a major contributor to the country's GDP. Most projections also indicate that the sector has the potential to grow further as demand continues to increase both at home and abroad, necessitating accelerated expansion of the related infrastructure, both hard and soft.

The sector is highly dependent on ground water as surface water is not perennially available. This reliance on groundwater may seriously affect sustainability both in the medium and long term. It had therefore, become necessary to conduct a rapid assessment of the availability of groundwater for the short and medium term considering the present trend of present trend of socio-economic growth and related water demand, as well as for any increased demand that may have to be catered to meet future needs.

Bangladesh Water Partnership (BWP) has been commissioned by Bangladesh Water Multi-Stakeholder Partnership (MSP) to conduct a rapid assessment of the groundwater sustainability of Greater Dhaka Area. BWP is the country partnership of the Global Water Partnership Organization (GWPO) headquartered in Stockholm, Sweden, and in this regard, was supported by 2030 Water Resources Group (2030 WRG).This assessment was made possible from generous funding from H&M. To know more about H&M's water initiatives, please visit http://about.hm.com/en/sustainability/sustainable-fashion/water.html. This report has consolidated secondary information from various relevant studies and provides general estimations of groundwater resource availability, its challenges and ways to overcome them to accommodate sectoral growth aspirations.

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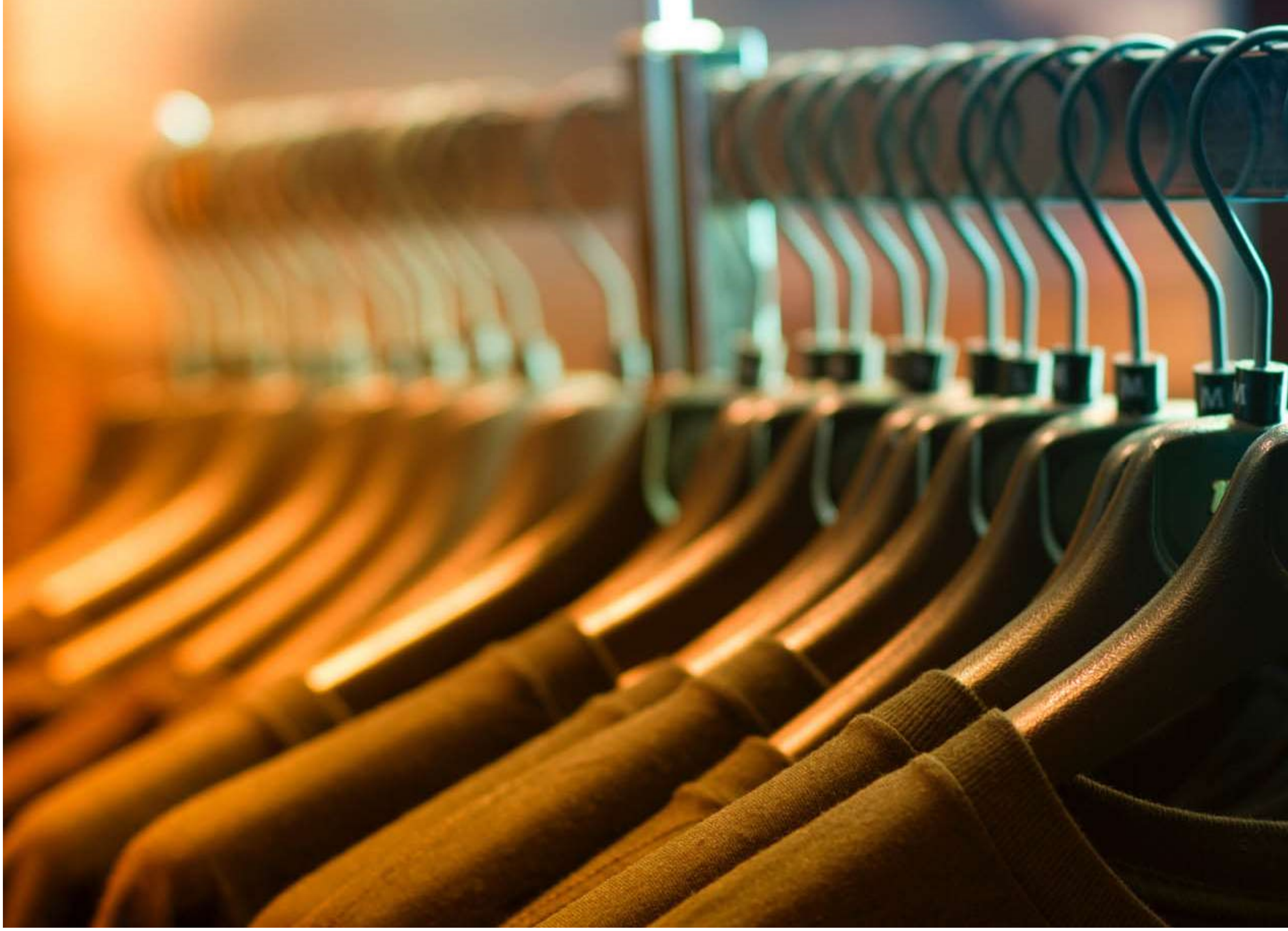
ABBREVIATIONS

BADC	Bangladesh Agricultural Development Corporation
BAU	Business as Usual
BAU +	Business as Usual Plus (Industrial growth is higher than usual, please refer to page 12 for details)
BGMEA	Bangladesh Garments Manufacturers and Exporters Association
BKMEA	Bangladesh Knitwear Manufacturers and Exporters Association
BTMA	Bangladesh Textile Mills Association
BWDB	Bangladesh Water Development Board
BWP	Bangladesh Water Partnership
CIA	Central Intelligence Agency
DND	Dhaka Narayanganj Demra
DWASA	Dhaka Water Supply and Sewerage Authority
EPZ	Export Processing Zone
EU	European Union
FY	Financial Year
FYP	Five Year Plan
GDA	Greater Dhaka Area
GDP	Gross Domestic Products
GIS	Geographical Information System
GoB	Government of Bangladesh
GW	Groundwater
IFC	International Finance Organization
IWM	Institute of Water Modeling
IWRM	Integrated Water Resources Management
km	Kilometer
km^2	Square kilometer
LGED	Local Government Engineering Department
m	Meter
m/y	Meter per year
m^2	Square meter
m^3/d	Cubic meter per day
m^3/y	Cubic meter per year
MAR	Managed Aquifer Recharge
MLD	Million liters per day
NWRD	National Water Resources Database
PaCT	Partnership for Cleaner Textile
STW	Shallow Tube-well
UNFPA	United Nations Population Fund
WRG	Water Resources Group
WTO	World Trade Organization



EXECUTIVE SUMMARY

The textile sector has become the largest export earner for Bangladesh with an impressive contribution of around 83%, which accounts for over 14% of gross domestic product (GDP). The sector has the potential and the need to grow at a faster rate in the coming years to meet sectoral growth aspirations. However, one of the major constraints that might impede such dynamic growth is the availability of sustainable water supply, especially groundwater, which is the largest single source of water for the industry.

The principal objective of the study is to conduct a high-level assessment of ground water sustainability of the Greater Dhaka Area (GDA) for the period leading to 2030. This assessment has been based exclusively on secondary data collected and consolidated from multiple relevant sources (including public and private sector entities, research organizations and development partners). The analysis was done by using groundwater modeling tools to estimate quantity as well as sustainability of the aquifers (underground layers of water-bearing sediments) in providing water to meet the increasing demands of expanding industry.

The major findings of the study are as follow:

- The annual decline of the groundwater level is projected to worsen from current 3 meters per year to 5.1 meters per year by 2030 (approximately 70% higher than existing rate).
- Groundwater abstraction rates may increase from 5.9 million cubic meters per day to 10 million cubic meters per day by year 2030 in business-as-usual plus (BAU+) case, which is nearly double the current rate.
- At present, the average depth (below ground level) of the groundwater table is about 78 meters, which may sink down to 132 meters in the next 10-12 years. This will likely have a substantial impact on the access to groundwater for industries. This is expected to also cause irreversible environmental consequences.
- Due to unregulated water-use resulting in over abstraction of groundwater, the upper aquifer of the assessment area may run out of water, especially in the dry season, by year 2030. This will likely affect the industrial zones at Savar, Ashulia, Tongi and Narayanganj (an area of approximately 1,600km^2) leading to widespread land subsidence and severe shortfall in drinking water supply from groundwater sources.

The linkage between over abstraction of groundwater and earthquakes was also examined. Scientists have found linkages between declining ground water tables and over-abstraction attributable to increased incidence of earthquakes in certain geological settings similar to California and Spain. In Dhaka and its surrounding areas, due to its unique geological settings, the probability of earthquakes is minimal. However, the rapid declination in groundwater levels can produce land subsidence accompanied with other environmental degradation including additional resistance to natural recharge of aquifers in Greater Dhaka Area.

Based on the findings of the rapid assessment, it is recommended that a comprehensive study with primary data will be initiated to enable planning of long-term groundwater resources management and thus to ensure a sustainable expansion of the textile sector. In parallel, the government should immediately start common-sense initiatives to create an enabling environment for IWRM; trade associations should act upon policy advocacy and support advanced research to develop appropriate solutions; brands and factories should adopt measures that address over-abstraction and help to be 'water smart'.

INTRODUCTION

BACKGROUND

The textile sector, comprising of a mix of small to large scale exporting companies, has been playing an important role in Bangladesh's economy for a long time. An overwhelming 83% of the country's export earnings and 14.07% of the gross domestic product (GDP) in FY 2017-18 came from this sector[1]. Initially the sector was dependent upon imported raw materials (including cotton, yarn, fabric etc.); now local industries contribute to over 90% of value addition[2] to textile exports. According to the World Trade Organization (WTO), Bangladesh remains the second largest apparel exporter in the world, after China, and accounts for 6.5% of the global market share in FY 2017-18[3].

Due to national population growth and increase in global demand for industrial goods, Greater Dhaka4continues to experience rapid industrialization and an influx of commercial activities. The city struggles to provide sufficient drinking water for its inhabitants even though it sits in proximity of four major rivers in a wide delta region. There are many drivers discussed for this paradox. However, one of the key concerns is about the current water-use practices of 800 washing, dyeing and finishing (WDF) factories of the sector[5]. These factories, known as "wet processors," consume as much as 300 liters of water[6] to produce one kilogram of fabric, which is about six times more water than the international best practice[7]. According to the Institute of Water Modeling, groundwater levels around the city center are dropping at an alarming rate; two to three meters per year[8]. This warns us to act on groundwater conservation[9], which is currently one of the major sources of water for domestic, agricultural and industrial supply in the Greater Dhaka Area.

Bangladesh Water Partnership with support from 2030 WRG and H&M, one of the leading global Apparel and Fashion brands, has been commissioned to conduct a rapid groundwater sustainability assessment for the Greater Dhaka Area. The paradigm shift from groundwater "'development" to "management" in Bangladesh as laid out in *Bangladesh Water Act 2013* through *aquifer mapping*[10] requires a comprehensive groundwater management plan to be devised and implemented. For this, an advanced investigation and understanding of the hydro-geological[11] systems beneath the ground surface are required. As one of the major sources of water and an inevitable part of the hydrological system[12], groundwater needs to be seen as a limited resource and therefore its management plan should be based upon its availability and may require a specification of its sustainable abstraction limit.

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[1]*BGMEA 2019*
[2]*http://fashion2apparel.blogspot.com/2017/06/bangladesh-textile-industry.html*
[3]*https://www.textiletoday.com.bd/bd-remains-2nd-largest-rmg-exporter-accounting-6-5-percent/*
[4]*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 in BBS*
[5]*An analysis of industrial water use in Bangladesh with a focus on the leather and textile industries, ARUP, Bangladesh Water PaCT,*
[6]*Cleaner Production Factory Audit, Bangladesh Water PaCT, 2014*
[7]*https://www.textilepact.net/focus-areas/supporting-factories/implementing-change.html*
[8]*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*
[9]*Groundwater conservation alone may not be sufficient to address future water demand, tapping of surface water sources will be inevitable*
[10]*Aquifer mapping refers to the characterization of the water layers beneath the earth surface which includes the quantity and the quality of groundwater in a particular area, including: vertical and lateral extent of layers.*
[11] *Hydro-geology refers to the distribution and movement of groundwater in the soil and rocks of the Earth's crust*
[12]*The entire cycle of water movement, also known as the "water cycle"*

OBJECTIVES OF THE ASSESSMENT

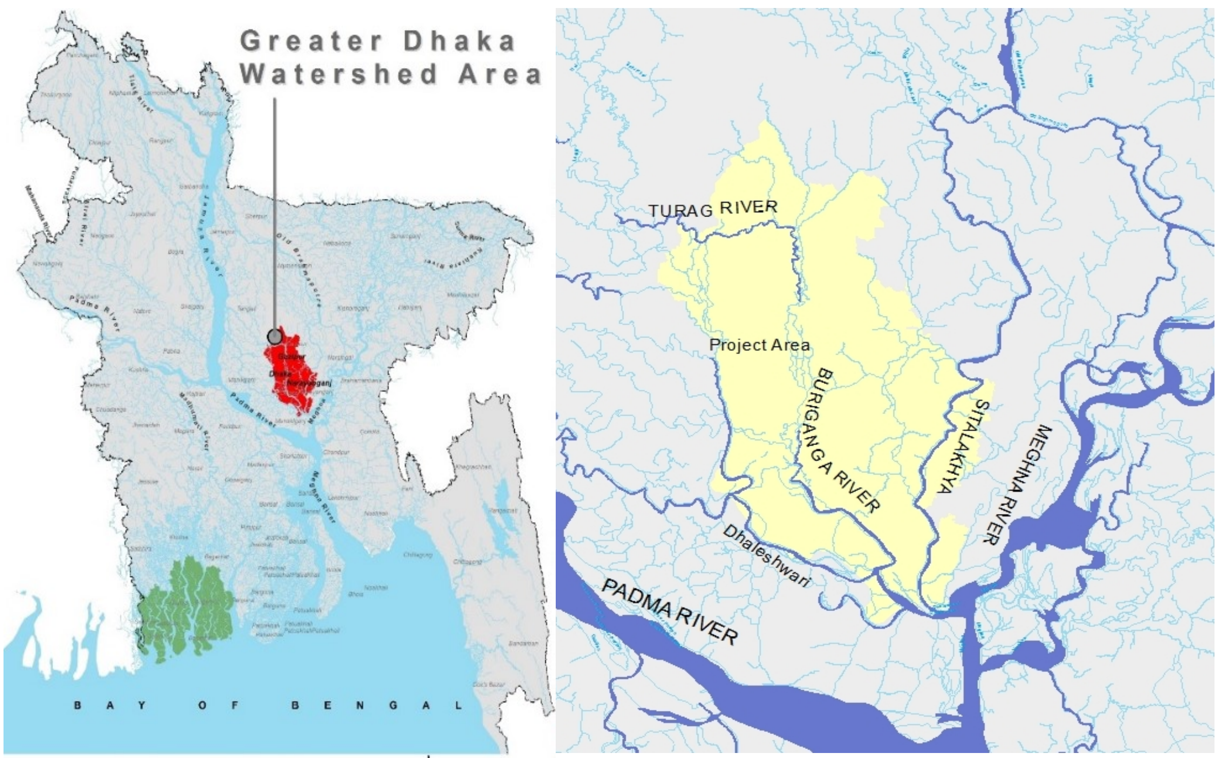
The overall objective of this study is to provide an overview of the current groundwater situation, including groundwater levels, and to develop scenarios around falling groundwater tables over the years and the related assessment on the long-term sustainability for the Greater Dhaka Area. The specific objectives include:

1. Conduct rapid assessment of groundwater sustainability for the Greater Dhaka Watershed area up to the year 2030.
2. Provide recommendations for mitigating the risks related to over-abstraction of groundwater.

DESCRIPTION OF THE ASSESSMENT AREA

The assessment area focuses on Greater Dhaka, which has an area of around 1,800 square kilometers, and shows a very rapid rate of expansion. It includes Dhaka City Corporation, Savar upazila, Keraniganj upazila of Dhaka district, Narayanganj Sadar upazila, Bandar upazila, Rupganj upazila of Narayanganj district, Gazipur Sadar upazila, and Kaliakair upazila of Gazipur district, and Narsingdi Sadarupazila and Palash upazila of Narsingdi district[13]. As of 2016, over 18 million people live in the assessment area, while Dhaka city itself has a population of an estimated 11 million with a growth rate about 3.6% annually[14]. In the last few decades, land use patterns in Dhaka Metropolitan area and its outskirts have rapidly changed due to unplanned urbanization coupled with occupation of agricultural land by real estate companies, industries, recreational facilities etc. The overview of the assessment area including demographic information, land-use patterns, and river system is provided in Annex 1.

Figure 1: Location of the Assessment Area and River System (Developed from LGED GIS database)



METHODOLOGY

The assessment was conducted based on secondary information on aquifer properties, water level, water abstractions, groundwater recharge etc. that were collected from Bangladesh Water Development Board, DWASA and other relevant peer reviewed articles published in various international journals. Afterward, the consolidated information were analyzed in GIS, RockWroks and Aquifer Simulation Model (ASMWin) to perform various geo-spatial analysis and to develop the lithological profiles and groundwater projection scenarios respectively. The details of the methodology are given in Annex 4.

[13] *BBS, 2011. Bangladesh Bureau of Statistics.*
[14] *Bangladesh Bureau of Statistics - Dhaka information and statistics and UNFPA 2018*

INDUSTRIAL MAPPING OF GREATER DHAKA WATERSHED AREA

Over the years, large number of water-consuming and polluting industries have been established all over the Greater Dhaka Area. In some cases, this industrial development is localized, such as in Tejgaon industrial area, however, in most cases, they have grown sporadically in residential, rural and forest areas. In the absence of any zoning or land-use law, this phenomenon is occurring with a rapid pace. Currently, it is estimated that there are around 2,179 factories[15] in the assessment area. Most of these factories are located in ten main clusters, namely:

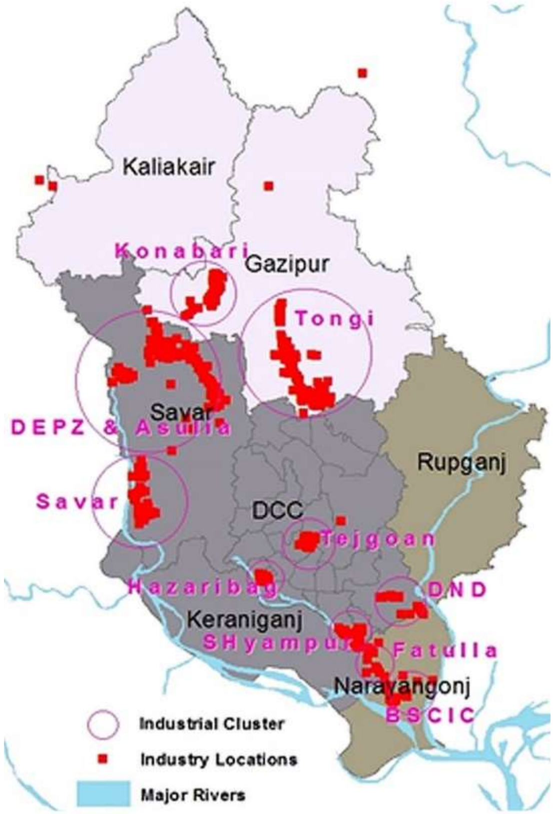
- Tejgaon,
- Dhaka Export Processing Zone (EPZ),
- Tongi,
- BSCIC Narayanganj,
- Fatullah and
- Savar,
- Konabari-Kasimpur (Gazipur),
- Hazaribagh,
- Shyampur,
- Dhaka Narayanganj and Demra (DND).

In the final report of the Dhaka Water Resources Management Programme *(DWRMP)* study, a list of 2,179 factories has been identified, many of which are highly water intensive i.e., composite textile factories, tanneries, etc. The types of factories identified are summarized in the table below:

Table 1: Type of Factory Located in the Assessment Area (DoE, 2008)

Type of factory	Number[15]
Textile	738
Paper, Pulp, and Wood	171
Dyeing, Painting, Printing, etc.	241
Electrical and Electronics	129
Metal, Iron, Aluminum and Steel	289
Plastic, Glass, Cosmetics, Jewelry etc.	142
Food, Confectionary, Hotels, etc.	140
Dairy, Poultry, Fishery, etc.	28
Tannery, Shoe, etc.	75
Pharmaceutical, Hospital, Soap, etc.	61
Chemical	95
Ceramics	5
Building construction related, etc.	49
Handicrafts	16
Total	2,179

Figure 2: Location of the Industrial Clusters (Generated in GIS)

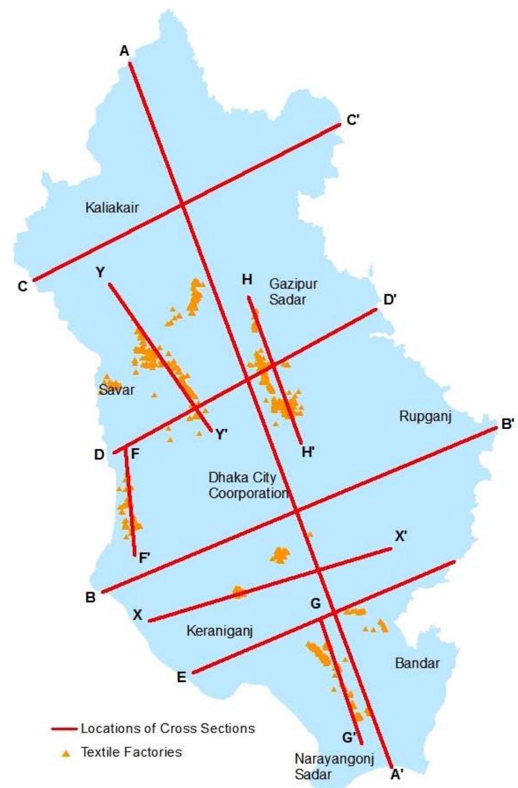


[15] *Department of Environment, 2008, Survey and Mapping of Environment Pollution from Industries in Greater Dhaka and Preparation of Strategies for Its Mitigation (SMEP-GD) Project*

GROUNDWATER SYSTEM IN THE ASSESSMENT AREA

LITHOLOGICAL MAPPING

Figure 3: Location of Lithological Cross-section in the Assessment Area (Generated in GIS)



The investigation on physical characteristics of sediment layers beneath the ground surface (generally known as lithological mapping) of the assessment area discloses that the layers forming the aquifers[16] and aquitards[17] have a very scattered distribution. This is a more complex setting[18] compared to other areas in Bangladesh. In order to simplify this complexity, the deposits were generalized into five layers: top soil, clay, fine sand, medium sand and coarse sand. In the assessment area, two different aquifer systems can be broadly distinguished, namely: 1) Dupi-Tila sands beneath the Madhupur clays, forming a *confined aquifer*[19] to *semi confined aquifer*[20], and 2) Recent alluvium of the floodplains (both east and west side of the Dhaka City) containing a *shallow aquifer in semi-confined conditions*[21].At a depth of approximately 400 meters beneath the ground surface, a thick clay deposit (known as Modhupur clay) covers the whole area. The deeper aquifer (also known as *confined to semi-confined aquifer*) starts at this depth and the recharge of this aquifer is theoretically not possible due to the presence of the confined bed (clay layer)[22]. Therefore, any unregulated and over-abstraction of groundwater from this aquifer may lead to irreversible damage, as the aquifer cannot be recharged. The details of the investigation have been given in Annex 1. Figure 3 shows the locations of the investigation, which include the industrial clusters and existing pumping stations.

In the Greater Dhaka Area, groundwater flow is composed of several interconnected and complex flow systems. The flow occurs in two aquifers, that are relatively shallow and mostly with localized flow paths that overlap with deeper regional flow paths. Regional groundwater flow is predominantly through the lower Dupi-Tila[23] aquifer and tends to follow the regional slope of the earth surface (known as 'topographic gradient'); water generally flows towards Shitalakhya River from northern part of the assessment area. Most of the groundwater recharge results from infiltration[24] of rainwater during the late monsoon in the form of widespread flooding, river flow and leakages from urban water supply pipelines.

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[16]Underground layer of water-bearing unconsolidated sediments
[17]A layer of low permeabilityalong an aquifer which is a solid, impermeable area underlying or overlying an aquifer
[18]It consists of sporicidal leaks, cracks, overlapping layers and ununiformed composition
[19]Confined aquifers are those in which an impermeable layer exists that prevents water from seeping into the aquifer from the ground surface located directly above
[20]An aquifer that is partly confined by layers of lower permeability, also known as leaky aquifer.
[21]IWM and DWASA (2007) Resource assessment and monitoring of water supply sources for Dhaka City, Final report on resourceassessment, vol 2. Dhaka Water Supply and Sewerage Authority and Institute of Water Modelling, Dhaka
[22]A layer of unconsolidated sediments, that retards the movement of water in and out of an aquifer
[23]One kindofcomposition of sediment layers beneath the earth surface which is composed of yellow to light brown sand, silt and clay
[24]The process by which water on the ground surface enters the soil

EXISTING GROUNDWATER SCENARIO OF THE ASSESSMENT AREA

In the assessment area, the rapid change in land-use pattern has significantly reduced the area of natural 'infiltration galleries' with severe negative impact on ground water recharge. In the Dhaka Metropolis, the groundwater abstraction rate is about 25% higher than the natural recharge (see Figure 4)[25]. Dhaka Water Supply and Sewerage Authority (DWASA) is responsible for water supply for Dhaka and Narayanganj city area, while in Savar and Gazipur area, water supply is managed by the local authorities i.e., municipality and city corporation. Total estimated groundwater abstraction in the Greater Dhaka Area is about 5.9 million cubic meters per day, of which DWASA supplies around 2.4 million cubic meters of water per day or about 40% of the total abstraction. DWASA uses approximately 760 deep tube wells (DTW) with a 3,040 km-long pipeline network, where system loss is assumed to be at around 25%[26]. The industrial and commercial sectors are the second largest water user and accounts for approximately 1.67 million m^3/d, which is about 28% of the total abstraction (see Figure 5).

Figure 4: Abstraction and Natural Recharge of Groundwater (Modified after Islam 2017)

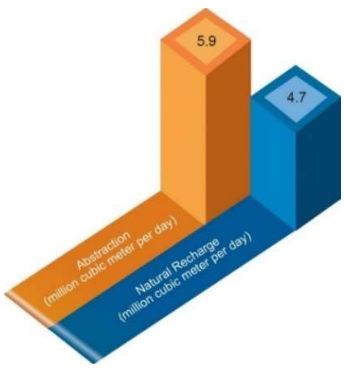
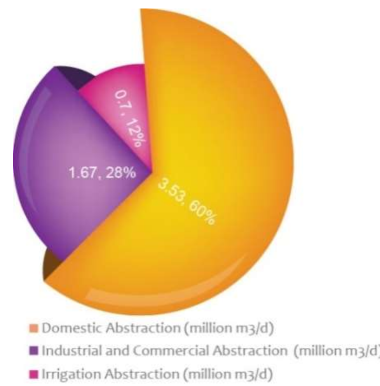
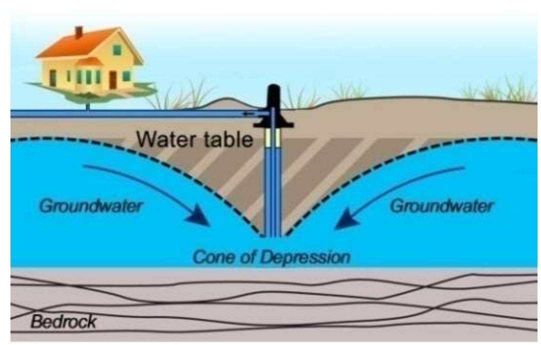


Figure 5: Current Groundwater Abstraction, by Sector (DWASA, 2017)



Long term monitoring of the groundwater level (GWL) within Dhaka City has shown a significant decrease of the GWL in the central and western region of Dhaka City since 1983. Between 1985 and the beginning of 2000, the GWL in the Greater Dhaka Area declined significantly from 10 meters to 30 meters below the ground surface[24]. This fall of the GWL resulted in the start of the development of a 'cone of depression'[27] (a 'dried up' space beneath the ground surface, see Figure 6) within the city. As groundwater abstraction rates continued to exceed the natural recharge rates, the 'cone of depression' got deeper and reached up to 78 meters below the ground surface over the last years.

Figure 4: Typical Cone of Depression under Heavy Pumping Well (Navalkar, 2018)



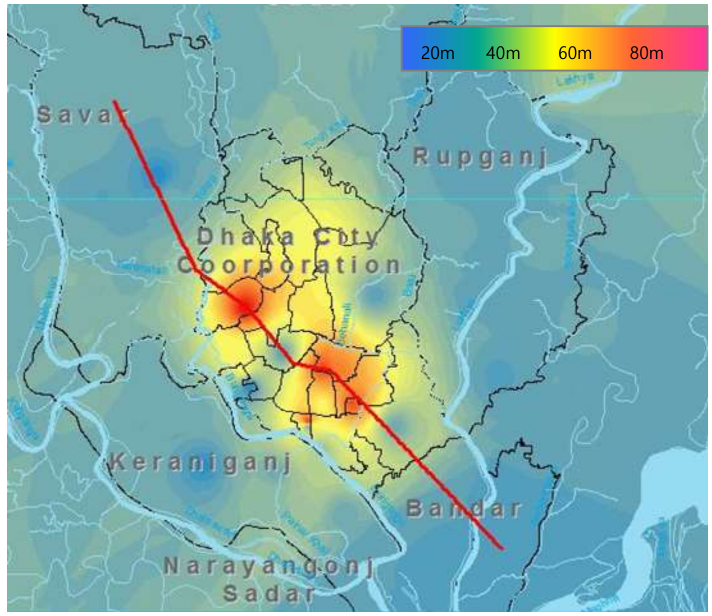
[25]Islam, Md. Bayezidul, Firoz, ABM, Foglia, Laura, Marandi, Andres, Khan, Abidur Rahman, (2017), A Regional Groundwater-Flow Model for Sustainable Groundwater-Resource Management in the South Asian Mega city of Dhaka, Hydrogeology Journal · January 2017, DOI 10.1007/s10040-016-1526-4

[26]DWASA (2017) Management information system (MIS) report. Dhaka Water Supply and Sewerage Authority (DWASA) and Institute of Water Modeling (IWM), Dhaka, Bangladesh.

[27]An airy space in the aquifer developed due to heavy pumpingresulting in a large sunken area.

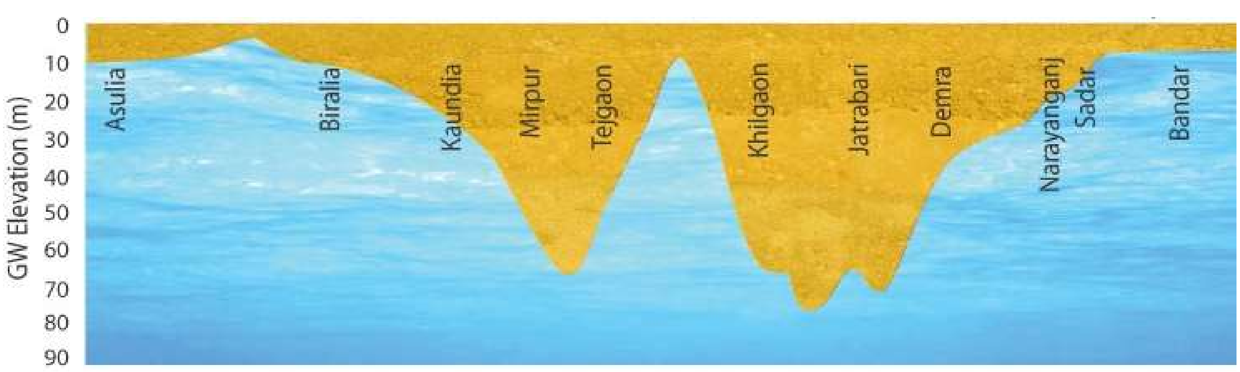
Based on data from the water level monitoring stations constructed by Bangladesh Water Development Board (BWDB), a preliminary assessment of the groundwater level in the Greater Dhaka Area reveals that the nearest groundwater water level within the city can be found at the depth of 78 meters below the ground surface. This is basically the depth of the semi-confined aquifer. Interestingly, the large abstractions by the textile industries are also mostly from the semi-confined aquifer (with average depth of abstraction wells approximately 150 meters[28]). This poses a greater risk of permanent drying up of the shallow aquifer. In the long run, this may also result in large scale land subsidence and severe shortfall in drinking water supply.

Figure 5: Existing Groundwater Levels of the Assessment Area (Generated in GIS)



Between Tejgaon and Khilgaon, however, a sharp and significant rise in water table is observed. This may have resulted from local surface water leakage from Hatirjheel, which may not represent the actual groundwater table. However, this result (groundwater level distribution) is partially supported by the studies conducted by IWM (2008)[29], Hoque et al (2007)[30] and Akther (2009)[31] suggesting that the groundwater level was around 70 meters in 2007/2008, with an annual decrease of 2 meters. Considering that these were quite rough estimations, the results are relatively similar to this study's findings. The cone of depression, as depicted in Figure 8, may also change the natural recharge system in the center of Dhaka region.

Figure 6: Cross-section of the Aquifer and Cone of Depression (Generated in GIS)



[28] *H&M, 2018*

[29] *IWM. (2008), Resource assessment and monitoring of water supply sources for Dhaka city.*

[30] *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: Hydro geological Journal.*

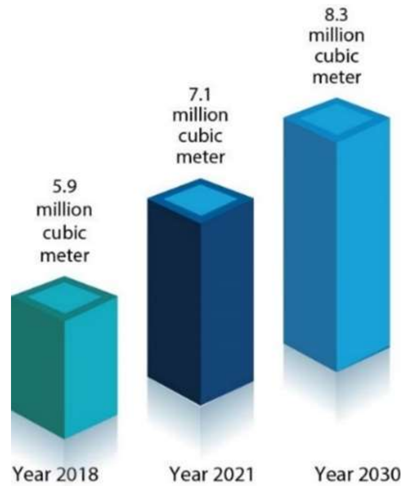
[31] *Akther, H., Ahmed, M., & Rasheed, K. (2009), Spatial and Temporal Analysis of Groundwater Level Fluctuation in Dhaka City, Bangladesh. Dhaka: Asian Journal of Earth Sciences.*

PRELIMINARY GROUNDWATER SUSTAINABILITY ASSESSMENT

GROUNDWATER SCENARIO AT BAU

The business as usual scenario (BAU) assumes a steady state growth in industrial expansion. According to CIA World Factbook, the current industrial growth rate in Bangladesh is 8.9%, and population growth rate is 3.6%. These growth rates are considered for the BAU assessment (see Annex 2 for details). The BAU assessment estimates that total groundwater abstraction will reach 7.1 million cubic meters per day in year 2021 and 8.3 million cubic meters per day in 2030, when compared to the current of groundwater abstraction of 5.9 million cubic meters per day (Figure 9). Thus, in the BAU scenario, groundwater abstractions will be increased by 20% by year 2021 and by 45% by 2030. As a consequence, the depth of static groundwater level is estimated to go down from the current level of 78 meters to up to 94 meters by 2021 and up to 113 meters by 2030, an approximate 44% further depletion from the existing level.

Figure 7: Water Abstraction Rate per Day at BAU (Calculated)



Under the assumptions made in business as usual case, the study finds the declining rate of groundwater possess huge threat even at a constant industrial growth rate. The amount of water withdrawn from the aquifer, at present, is significantly high which is subject to be even higher in the near future. Figure 10 depicts the groundwater declination pattern at BAU for the year 2021 and 2030.

Figure 8: Cross-section of the Aquifers at BAU (Generated in GIS)

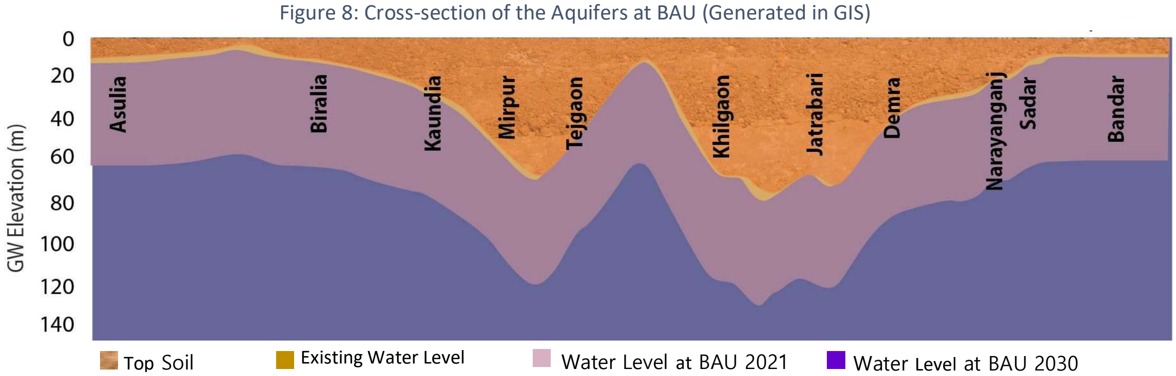
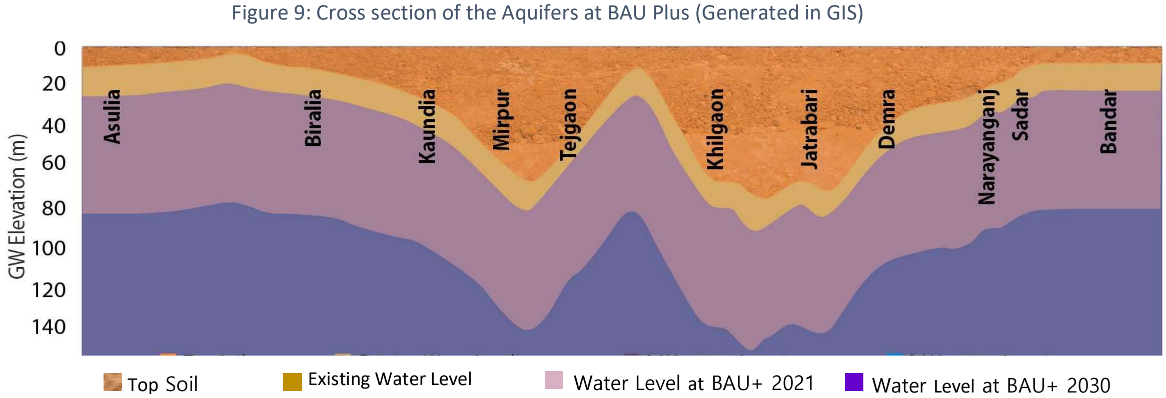


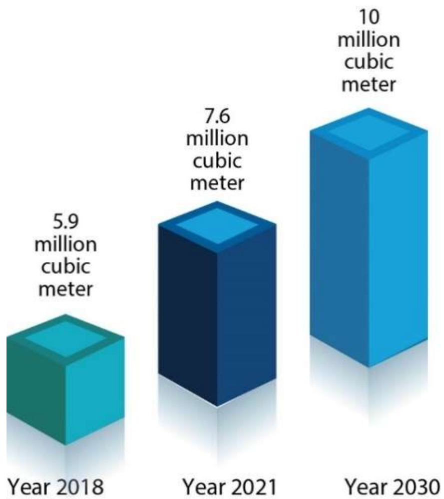
Figure 9: Cross section of the Aquifers at BAU Plus (Generated in GIS)



GROUNDWATER SCENARIO AT BAU PLUS

The BAU plus scenario assumes that the industrial growth trajectory will be steeper compared to the BAU scenario. Based on the projections made by UNFPA and CIA World Factbook, the following assumptions are made for the BAU plus scenario (see Annex 2 for details):

Figure 10: Water Abstraction Rate per Day at BAU Plus (Calculated)

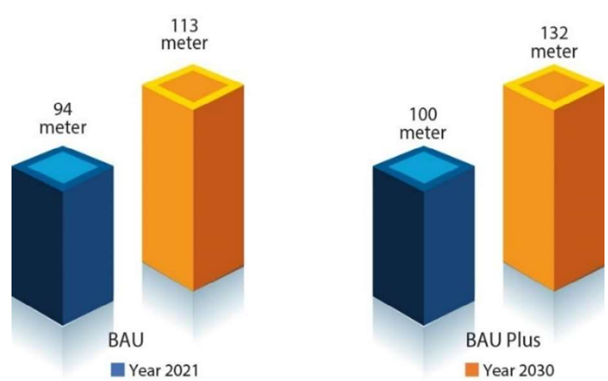


- 9.6% annual industrial growth rate for the year 2018-2021 and 11% for the year 2022-2030[32].
- 5% annual growth in irrigation abstraction until year 2030.
- Estimated population is 21 million in year 2021 and 27.4 million in year 2030[33].

The results of the BAU plus scenario assessment show sharper decline of the existing groundwater level than in BAU. The calculated total groundwater abstraction in BAU plus is 7.6 million cubic meter/day in 20121 and 10 million cubic meter/day in 2030, nearly double the current rate (Figure 12). It is likely that the groundwater level will be at 100m below the surface level in the central part of the Dhaka City in year 2021 and at 132 meters in year 2030 (Figure 13) which is about 16% lower than BAU and 70% lower than current level. The current rate of groundwater table decline will almost double, from 3 meters/year to 5.1 meters/year and total groundwater abstraction will be 69% higher than the current groundwater abstraction rate (5.9 million cubic meters per day) by the year 2030.

The BAU plus scenario will further increase the existing '*dried up space*' in the aquifer (Figure 11) which will make the upper aquifer more vulnerable for the long-term water supply. According to the calculation performed in GIS, the depression beneath the ground surface will attain an area of about 1,600km^2, which is more or less double of the current area. As a result, a huge number of wells located in the city and outside of the city will be affected, while groundwater abstraction cost will increase due to the deeper groundwater level. The capital and operational costs to meet the water demand and effluent discharge standards to 2030 are estimated to be around $25-39 billion[34].

Figure 11: Projected Groundwater Levels at BAU and BAU Plus (Calculated)



[32] *CIA World Factbook, 2018*
[33] *United Nation Population Fund*
[34] *https://www.textilepact.net/pdf/publications/reports-and-award/an_analysis_of_industrial_water.pdf*

CONSEQUENCES OF GROUNDWATER DEPLETION

The decline in groundwater table is likely to have adverse impacts on the natural environment and socio-political atmosphere of the assessment area. At the same time, the factories may have to face financial consequences resulting from depleting water levels. Given below are some of the potential threats that will have to be addressed:

ENVIRONMENTAL IMPACT

Land subsidence: The basic cause of land subsidence is the loss of support below ground, although a great deal of it also depends on the geology. When water is taken out of the soil beyond sustainability levels, the surface will tend to collapse. According to a study at the Earth Observatory Centre, Dhaka University, Dhaka is sinking over half an inch a year on average because of excessive extraction of groundwater and inadequate recharging of the vacuum it creates below the surface[35].

Due to rapid decline in groundwater levels, this phenomenon may affect all kinds of infrastructure in the assessment area and also may end up affecting the course of surface water bodies.

Reduction of water in nearby rivers, lakes, and wetlands: Natural release of Groundwater into river beds will probably be reduced resulting in the reduction of river water levels, especially in the dry season. In the assessment area, this may further dry up the surface water bodies and the wetlands in the close proximity of Turag and Balu River.

Degradation of plant health: The plant habitats near the lakes and rivers largely depend on groundwater, the depletion of which may adversely affect their lifecycle.

Earthquake: Scientists have found linkages between declining ground water tables and over-abstraction attributable to increased incidence of earthquakes in certain geological settings similar to California and Spain. In Dhaka and its surrounding areas, due to its unique geological settings, the probability of earthquakes is minimal.

BOX 1: LAND SUBSIDENCE IN LOS ANGELES

Groundwater accounts for as much as 90% of the water supply for agricultural and urban uses in the Antelope Valley in the western Mojave Desert east of Los Angeles. In the city of Lancaster where the population multiplied between 1977 and 2010, extensive pumping contributed to groundwater level declines of as much as 91.4 m since the 1930s. A regional relationship between land subsidence and groundwater-level declines in the central Antelope Valley was established on the basis of geodetic and hydrologic monitoring during 1926-1992. Subsidence of 2 m near Lancaster and more than 1 m at the southern edge of Rogers Lake resulted from groundwater pumping that vastly exceeded recharge to the aquifer system. A 600-meter-long, 2.3-meter-deep fissure located about 11 km east-northeast of Lancaster was first noticed in 1978. The formation of the fissure was attributed to historical water-level declines of 75 m that had occurred prior to its appearance. In addition to earth fissures, other negative consequences of land subsidence in Antelope Valley include altered drainage gradients; increased flooding and erosion; failed well casings; and structural damage to roads, buildings, pipelines, canals, homes, and other structures.

[35] *Akhter, Prof Syed Humayun, 2012, Earth Observatory Centre, Dhaka University*

ECONOMIC IMPACT

Drying up of wells: The existing pumping wells of the industries may dry up in near future, which may require relocation or re-sinking of wells. The resultant investment requirements, in this regard, will be higher than usual.

Higher water treatment cost: As depleted water tables affect water quality[36], the industries may need to invest more on water treatment before they can use the abstracted groundwater.

Increased abstraction cost: Water abstraction from deeper aquifers will result in higher energy consumption compared to the current scenario.

SOCIAL IMPACT

Shortfall in drinking water supply: The potential threat of drying-up of upper aquifer may create substantial shortfalls in drinking water supply for the inhabitants living in the assessment area.

Social unrest: The shortfall in drinking water supply may cause social unrest, which can be a significant threat to the industries and may have economically disastrous consequences.

Table 2: Impacts of Groundwater Depletion in the Assessment Area (Adopted from USGS Sustainability of Ground-Water Resources--Circular 1186[37])

Vulnerability	Threat	Level of Risk
Environmental impact	Land subsidence	High
	Reduction of water in nearby rivers, lakes and wetlands	Medium
	Degradation of plant health	Low
	Earthquake	Low[38]
Economic impact	Drying up of wells	High
	Higher water treatment cost	Medium
	Increased abstraction cost	High
Social impact	Shortfall in drinking water supply	High
	Social unrest	High

[36] *U.S Geological Survey Fact Sheet 103-03*

[37] *https://pubs.usgs.gov/circ/circ1186/html/gw_storage.html*

[38] *Based on the geological assessment of Greater Dhaka, the risk of occuring earthquake due to GW depletion is low, however the incidence of earthquake may lead to wide spread land subsidance due to depleted GW table.*

RECOMMENDATIONS

The study finds that even the current groundwater abstraction rate (BAU) is not sustainable, while a projected increase in socio-economic growth (BAU plus) is predicted to have even worse impacts. In both scenarios, adverse environmental, economic, and socio-political impacts need to be expected in future (see Table 2). Based on the results of this study, the following recommendations are made to mitigate the impending risks associated with over-abstraction of groundwater and falling groundwater tables.

RECOMMENDATIONS FOR GOVERNMENT

Creation of enabling environment and regulatory frameworks are essential to bring positive changes in water-use pattern in textile and other water-intensive sectors on which the government is the best positioned to take the lead. The following are some of the initiatives for the government to consider:

a) Incentive based regulation of water-use and volumetric water allocation (water valuation and budgeting)
b) Implementation of Polluter Pay Principles
c) Full and accelerated implementation of Surface Water Treatment Plants under DWASA Master Plan

a) Incentive based regulation and sectoral water allocation (water valuation and budgeting)

The government may initiate incentive based regulatory system towards reduction of groundwater abstraction through implementation of Managed Aquifer Recharge (MAR) and reuse of treated water. Under the proposed system, the factories, that adopt the recommended measures addressing groundwater conservation, will enjoy additional benefits from the government. The incentives can be in the form of economic assistance and/or national recognition of the compliant factories. This will encourage the factories to become more water efficient, abstract less groundwater and become compliant plus factory.

Sectoral water allocation can also be an additional solution that can address over-abstraction of groundwater. This means the factories must restrict their water abstraction to mutually agreed benchmarks with the government or pay a higher price for additional abstraction.

b) Implementation of Polluter Pay Principles

The 'polluters pay' principle is the commonly accepted practice that is aimed at pollution-generating-industries who are made to bear the costs of managing the environmental damages and its effect on other socio-economic factors. For instance, a factory that produces a potentially hazardous substance as byproduct of its activities is usually held responsible for its safe disposal. The effective implementation of this instrument will encourage the factories to increase its water use efficiency, which eventually will reduce the abstraction. In principle, the lesser the consumption, the lesser the abstraction and pollution. In case of textile industries, the use of chemicals and enzymes should also be regulated in this conjunction.

c) Full and accelerated implementation of Surface Water Treatment Plants under DWASA Master Plan

In order to reduce the over-dependency on groundwater, the promotion of surface water use is essential. The city's water supply and sewerage agency- DWASA- has developed master plan and assessed that the future water production capacity needs to be increased to 5.2 million cubic meters per day by the year 2035 from current production 2.4 million cubic meter per day. Nonetheless to mention that the GW will not be sufficient to meet up this huge demand. Therefore, a major shift from GW to surface water is recommended and the master plan has proposed to build 6 new surface water treatment plants, which will utilize raw water from the river Padma, Meghna and Dhaleshwari. The successful construction and operation of the proposed surface water treatment plants will ease the burden on the groundwater of the assessment area. However, the re-sinking of the existing '*dried up*' deep tube wells is also recommended to meet the short-term demand of the city dwellers.

RECOMMENDATIONS FOR RELEVANT TRADE ASSOCIATIONS

The trade associations such as BGMEA, BKMEA, BTMA etc. need to play critical role in bringing change in water consumption pattern of the textile factories. The following are some of the steps which the associations may take forward:

a) Policy advocacy with the government
b) Sensitizing and mobilizing the factories towards reduction of groundwater abstraction
c) Detailed Investigation on pollutant transport and flow system for better understanding, planning and implementation of advanced solutions

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 of the factories. The following steps are recommended in this regard:

I. Formation and operationalization of high-level committee to start dialogue with the concerned ministries.
II. Discussion with the factories and brands to laying out the expectations
III. Consultation with the government, factories and brands together for incentivizing sustainable production practice
IV. Drafting of the policy papers on sustainable water-use by factories

b) Sensitizing and mobilizing the factories towards reduction of groundwater abstraction

The trade associations (with guidance from relevant multi-stakeholder platforms) may take the lead in sensitizing and mobilizing the textile factories towards reduction of groundwater abstraction by organizing appropriate trainings and workshops. Lack of information related to the low-cost water efficient technologies sometimes hinder the factories from becoming 'water-smart'. Trade associations can develop information hubs to disseminate best practice knowledge among the factories. Newsletters containing success stories within the sector that demonstrate business models with higher profit-line will motivate and inspire the factory owners to adopt the advanced technologies.

c) Detailed Investigation on pollutant transport and flow system for better understanding, planning and implementation of advanced solutions

It is imperative to understand how pollution affects the groundwater quality in the long-run. The trade associations may design required studies/research projects aiming to trace the pollutants on their origin, transport, and interaction with groundwater. So far only assumptions are made on such kinetics with no credible scientific evidence. Therefore, detailed investigations on pollutant transport are essential to clarify and validate the assumptions. The research projects may also explore the existing flow system of the groundwater associated with the generation of 'flow net'[39]. Construction of a 'flow net' is often used for solving groundwater flow problems. The proposed studies may assist to design and identify the location of new pumping stations also the location for managed aquifer recharge (MAR) so that the 'water void' in the aquifer (cone of depression) gets room for replenishment and thus the permanent damage of the aquifer can be avoided.

RECOMMENDATIONS FOR FACTORIES

The textile factories are the most important stakeholders in the whole process. For the factories to be sustainable in terms of water utilization, they may consider the following initiatives:

a) Managed Aquifer Recharge (MAR)
b) Implementation of circular economy, (3'R' – reduce, reuse and recycle)

a) Managed Aquifer Recharge (MAR)

Managed Aquifer Recharge (MAR) in conjunction with integrated water resources management (IWRM)[40] would help to restore groundwater level in Greater Dhaka Area by harvesting roof top rain-water. The method has successfully been implemented in different parts of the world such as USA, Australia, Israel, UK etc. In Bangladesh, MAR has been implemented in the coastal areas and also in Barind area, currently the water-stressed area of the country. Depending on the aquifer type and water availability, several MAR techniques (such as infiltration basin[41], recharge well, river bank filtration etc.) are being practiced now. The artificial recharge of ground water also aims at augmentation of ground water level by modifying the natural movements of surface water through utilization of suitable civil construction techniques.

On a pilot basis, low-cost Managed Aquifer Recharge (MAR) in the factories and at some households located in the industrial areas can be implemented. The learning and output of the pilots can be utilized to promote and scale up nationally. Along with piloting, policy advocacy for sensitizing government agencies is also required for nation-wide scaling up of MAR.

b) Implementation of circular economy (3'R' – reduce, reuse and recycle)

As has been mentioned earlier, Greater Dhaka Area has approximately 2,179 industries located in 10 clusters. The combined water demand is estimated to be 5.9 million cubic meters per day of which 28% is supplied to the industrial sector. Approximately 75% of this industrial water demand can be reduced by adoption of 3'R' *(reduce, reuse and recycle)* practices[42]. Factories may invest in cost effective advanced technologies for their washing dyeing and finishing (WDF) processes that will reduce water consumption,

[39]Flow net refers to the groundwater flow paths through aquifers.
[40] As defined by Global Water Partnership, IWRM is a process which promotes the coordinated development and management of water, land and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems and the environment.
[41]An infiltration basin (also known as a recharge basin), is a type of device that is used to manage storm water runoff, prevent flooding and downstream erosion, and improve water level in the aquifer.
[42] https://www.waterscarcitysolutions.org/wp-content/uploads/2015/08/Water-reuse-in-textile-sector-Tiruppur-India.pdf

eventually producing less or no water to treat. On the other hand, reduction of groundwater abstraction can also be achieved through recycling of treated waste water.

CONCLUSION

The Greater Dhaka 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 aquifers is declining because withdrawal is exceeding recharge. Large and prolonged abstraction of groundwater has modified the flow direction by reversing water slope towards the city center producing huge *'dried-up'* space in the aquifer in and around the large pumping centers. This dry hollow space is deepening vertically and widening horizontally owing to the increased installation of pumping-wells including the spread of the pumping-wells into new areas. The short-term (till 2021) impact of the indiscriminate GW abstraction is the rapid declination of the GW levels leading to a wide cone of depression as well as increased water abstraction cost whereas the medium-term impact (till 2030) of GW level declination may include large scale land subsidence and serious shortfall in water supply. In addition to that this can have adverse impact on regional groundwater flow system by altering the existing flow regime and by causing the flow from all directions to the central part of the city. The impact on pollutant transport into the groundwater storage and water supply along with other environmental, social, political, and economic impacts are likely to be much higher. Bangladesh has a rich and diverse mixture of policies and regulations covering water management. The strengthening of regulatory provisions for groundwater allocation, licensing, monitoring, and charging as part of the rules supporting the Bangladesh Water Act, 2013 would be a step towards promoting smarter water-use by industries.

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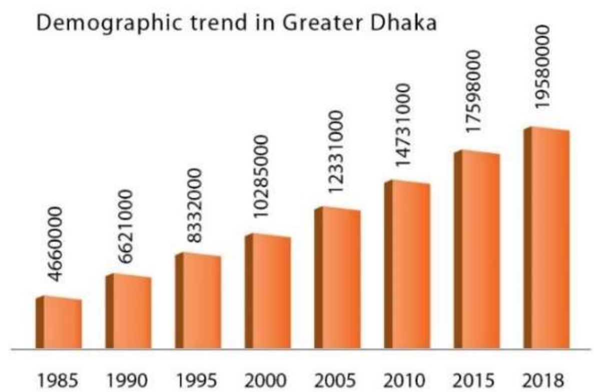
ANNEX 1: DETAILS OF THE ASSESSMENT AREA

EXISTING DEMOGRAPHIC OVERVIEW

Dhaka, a diverse city located in central Bangladesh along the Buriganga River, is not only the capital of the country but also one of the largest mega cities in the world. It is one of the most densely populated areas in the world, with a density of 23,234 people per square kilometer within a total area of 300 square kilometers[43]. The vibrant culture and thousands of Bangladeshi businesses and international corporations have contributed to migration and population growth. However, like many other metropolises in the world, the growing population has led to an increase in demand of urban facilities, pollution, congestion, and poverty, amongst other problems.

Figure 12: Demographic Trend of Greater Dhaka [45]



According to the latest revision of the UN World Urbanization Prospects[44], the population of the assessment area is estimated at 19,580,000 in 2018. The population has grown by 1,982,000 since 2015, which represents a 3.62% annual change. These estimates represent the urban agglomeration of Dhaka, which includes Dhaka's population in addition to adjacent suburban areas.

EXISTING LAND USE PATTERN

In the last few decades, land use pattern has rapidly been changed due to unplanned urbanization coupled with occupation of agricultural land by real estate companies in Dhaka Metropolitan area and its outskirts. As a result, the assessment area is facing enormous conversion of land from agricultural to nonagricultural use. The built-up area is the predominant land use pattern, accounting for more than 50% of the total area, followed by agricultural land (26%), and wetlands& water bodies (11%) (see Table 3).

Three sectors, namely the public, commercial, and domestic sectors, are responsible for all of the land developments in Dhaka and its surroundings. Most of the development projects are undertaken on an ad-hoc basis by the public sector, primarily in areas that were previously used for agriculture and were free from inundation; examples of such developments include Gulshan Model Town, Banani, Uttara Model Town and Dhanmondi. But during the later part of the century, natural low-lying water bodies were also filled up and converted into built up area, which significantly changed the water flow patterns and natural infiltration (see Table 3).

[43] *Bangladesh Bureau of Statistics - Dhaka information and statistics*
[44] *World Urbanization Prospects 2018, United Nation Population Division*

Table 3: Land-use Change in the Assessment Area over the Years[45]

Land Use/Cover Types	Percent of land used in different years			
	Year 1975	Year 1992	Year 2003	Year 2018
Water bodies	7	6	5	4
Wetland/lowlands	32	28	22	8
Cultivated land	29	19	20	26
Vegetation/forest	16	14	10	
Built-up	13	28	39	56
Bare soil/landfill	3	5	4	6

In recent years, property development has proliferated in Dhaka, and property developers have developed both wetlands and agricultural areas without due consideration of the environmental costs. In addition, individual households have started to develop in the peripheral areas. In response to increasing land prices and growing demand for housing, lowlands and agricultural areas in the fringes were rapidly being built-up by the individuals and property developers. While suburban development is a very complex process that is known to be influenced by a variety of factors, including speculation and land prices, these factors may not adequately explain the process of suburban development in the assessment area. A more detailed study is therefore required in order to understand the various factors influencing suburban development in the Greater Dhaka Area. Furthermore, poor coordination among executive agencies is also responsible for the reduction of natural resources in the assessment area. For example, in the Dhaka–Narayangonj–Demra (DND) project, despite approximately 6000 ha being set aside for agricultural production in the 1960s, the area has been used by local and migrant people for residential purposes since 1990s without any approval from the authorities concerned[46]. Instances like this illustrate the lack of effective coordination among the organizations involved in the planning and development of Dhaka.

EXISTING SURFACE WATER AND RIVER SYSTEM

There are more than 40 natural canals in the assessment area such as Boalia Khal, Gobindapur Khal, Nali Khal and Uzanpur Khal. The canals drain to the rivers flow through the assessment area: the Turag, the Balu and the Sitalakya river. An area of 32 Km^2 is drained to the Balu which is the largest drainage system in the area while 9 Km^2 to the Tongi Khal. The other important drainage system is Boalia Khal with a drainage area of 22 Km^2 [47]. The storm runoff is accumulated in the low-lying areas, flows through canals and ultimately is discharged to the rivers. The lowlands and wetlands perform important drainage functions by storing storm water and keeping the relatively higher lands free from rainfall induced flood. The water level in the peripheral rivers remains high during monsoon and flood water enters the area through the canal system. During flood season, almost the entire peripheral zone of the assessment area looks like a lake with settlement areas as islands connected by roads. The canals are not distinguishable during this period. They become visible during dry season. Water level in the boundary river is a controlling factor in storm drainage in the greater Dhaka. Among the peripheral rivers Turag is the longest river with 71 km reach (catchment area 1201 Km^2, Table 4). The 2^{nd} longest river is the Buriganga with 45 Km length[48] and 235 Km^2 Catchment area. Among the major rivers Turag comes from the north and joins the Buriganga River (Tidal River) near Mirpur, Balu comes from north-east and joins Shitalakhya River near Demra, and Tongi Khal receives water

[45]*The land use information has been developed by merging the land use map of the Dhaka metropolitan area prepared by Rajdhani Unnayan Kartipakkha (RAJUK) under the Detailed Area Plan (DAP) project with Gazipur district's land use map from the Center for Environmental and Geographic Information Services (CEGIS) and Bangladesh Water Development Board (BWDB)*
[46]*Dhaka detailed area plan*
[47]*DWASA, 2006, Resource assessment, Final report, Volume 1, study conducted by Institute of Water Modeling, Dhaka, Bangladesh*
[48]*BWDB 2005*

from Turag River and discharges it into Balu River. Dhaleshwari takes water from Brahmaputra in the north and flows to the east. Most of these streams and canals are seasonal, poorly drained and fed by the Monsoon rainfall flow both from in and outside catchment. All these streams and rivers contribute to the recharging of the aquifers of the area.

Table 4: Major Characteristics of the Peripheral Rivers (DWASA, 2006)

Name of the River	Length (km)	Avg. Depth (m)	Catchment area (km^2)
Buriganga	45	14	253
Turag	71	13.5	1201
Balu	45	9.63	722
Shitalakhaya	52	10	-
Dhaleshwari	61	37	-

GEOLOGY AND STRATIGRAPHY OF THE ASSESSMENT AREA

The Greater Dhaka Area is situated in the Meghna and Old Brahmaputra Flood Plains. Quaternary alluvial sequences, a part of the Brahmaputra-Jamuna Flood Plain and Madhupur Tract, construct the geological features of Dhaka city[49] [50] (Table 2). The city is situated at the southern tip of the Madhupur tract. Two characteristic geological units cover the city and surroundings: Madhupur Clay of the Pleistocene age and alluvial deposits of recent age. The Madhupur Clay is the oldest sediment exposed in and around the city area having characteristic topography and drainage. The major geomorphic units of the city are: the high land or the Dhaka terrace, the low lands or floodplains, depressions and abandoned channels. Low lying swamps and marshes located in and around the city are other major topographic features.

The subsurface sedimentary sequence, up to the explored depth of 300m, shows three distinct entities: one is the Madhupur Clay of the Pleistocene age which stands higher than the surrounding floodplain and characterized by light-yellowish grey or orange or red plastic clay to silty-clay and silt. This Madhupur Clay overlies the Dupi-Tila formation of the Plio-Pleistocene age, composed of medium to coarse yellowish brown sand and occasional gravel, and is generally subdivided into two distinct units: lower sandstone and upper clay-stone unit[51]. The sandstone is yellow, ferruginous, medium- to coarse-grained poorly consolidated massive sand, which contains quartz granules and pebbles with subordinate. The clay-stone consists of mostly grey plastic clay, containing occasional lignite with subordinate and yellow, poorly consolidated sandstone. The incised channels and depressions within the city are floored by recent alluvial floodplain deposits and are further subdivided into Lowland Alluvium and Highland Alluvium.

Table 5: Stratigraphy of Dhaka Region[52]

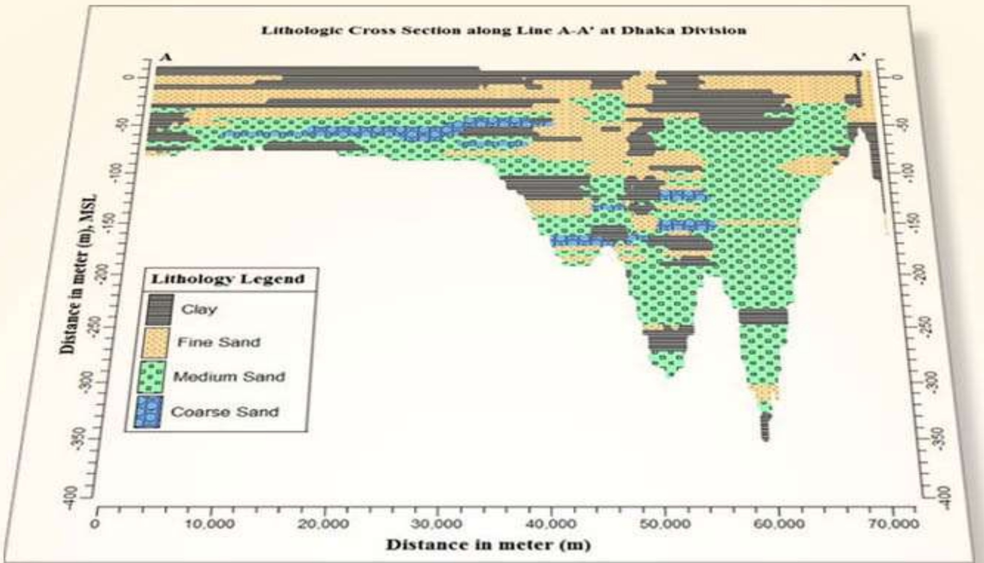
Stratigraphic age	Stratigraphic name	Lithological description	Thickness (m)

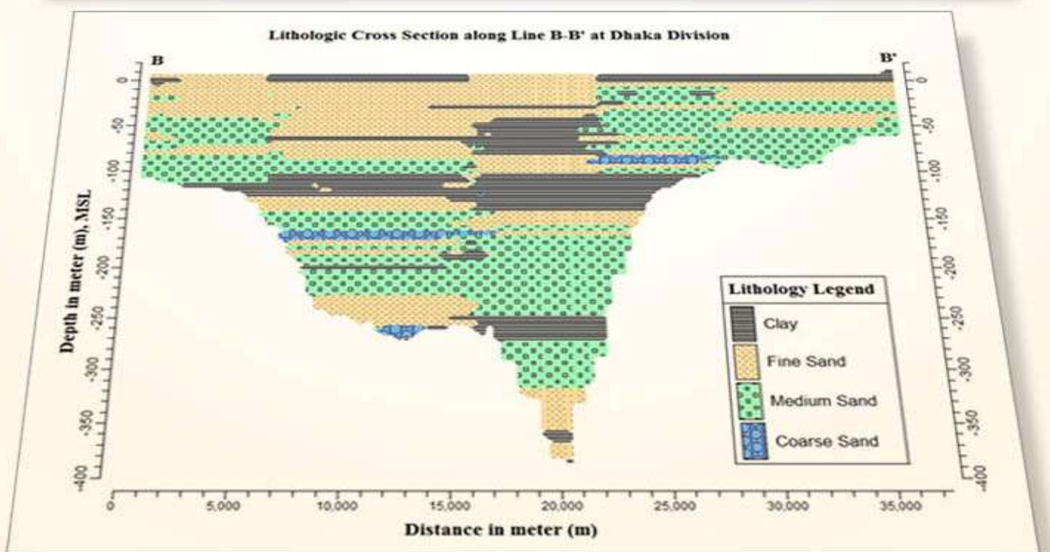
[49] *Hoque MA, Hoque MM, Ahmed KM (2007) Declining groundwater level and aquifer dewatering in Dhaka metropolitan area, Bangladesh: causes and quantification. Hydrogeol J 15(8):1523– 1534.*
[50] *Rahman MA, Wiegand BA, Badruzzaman ABM, Ptak T (2013) Hydrogeological analysis of the upper Dupi-Tila Aquifer, towards the implementation of a managed aquifer-recharge project in Dhaka City, Bangladesh. Hydrogeol J 21(5):1071–1089.*
[51] *Hiller K, Elahi M (1984) Structural development and hydrocarbon entrapment in the Surma Basin, Bangladesh (northwest Indo-Burmanfold belt). Fifth Offshore Southeast Conference, Singapore, February 1984, pp 6-50–6-63*
[52] *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*

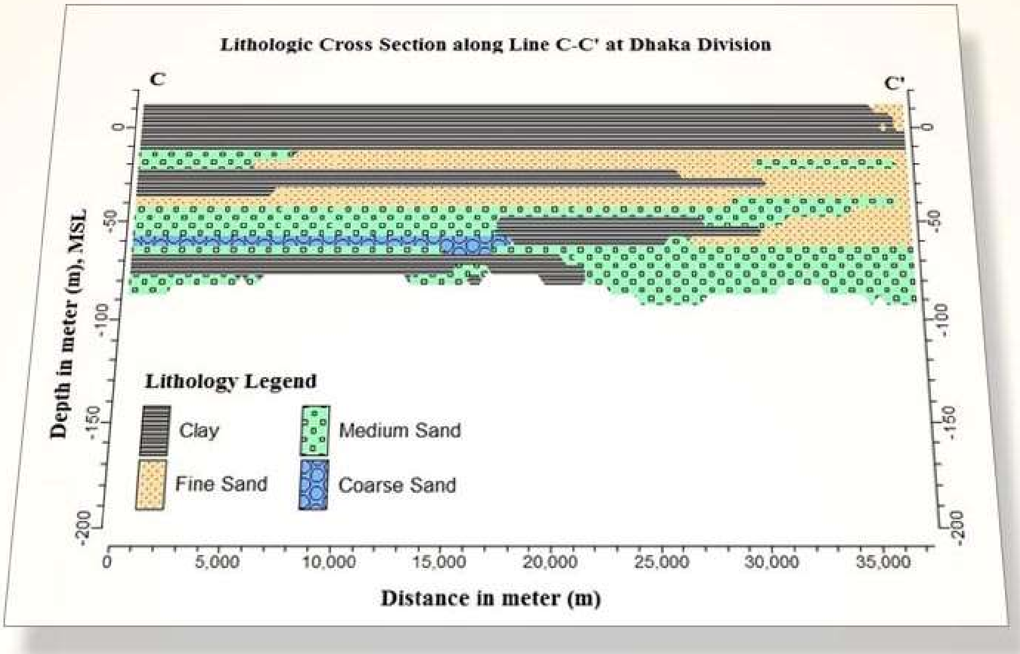
Flood plain area			
Holocene	Flood plain	Yellowish very sticky clay with light brown top soil	6–15
Pleistocene to Holocene	Dhamrai Formation	Yellow red silty-clay to alluvial sand	100–200
Madhupur tract area			
Holocene	Lowland alluvium	Yellowish brown with light brown sandy clay	0–5
Holocene	Bashabo Formation	Light brown sandy clay to sand	3-25
Pleistocene	Madhupur Clay Formation	Light brown sand-silt-clay to deltaic sand	6-25
Pliocene - Pleistocene	Dupi-Tila Formation	Reddish brown fine-grained to coarse sand	100-180
Miocene	Girujan Clay	Yellowish brown and bluish silty clay	50-100

LITHOLOGICAL CROSS-SECTIONS

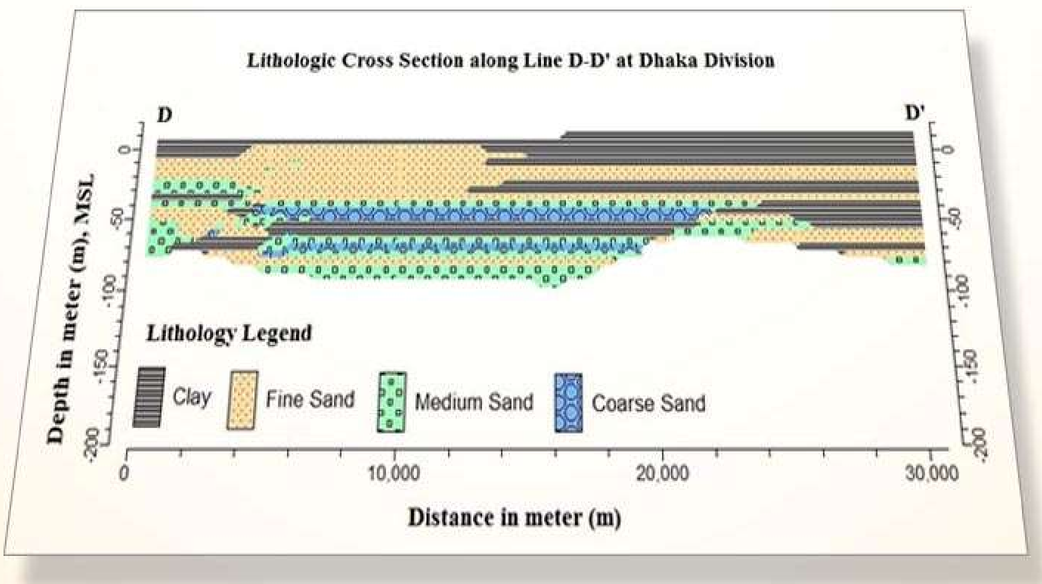
All the cross-sections were generated in RockWorks-15 using BWDB bore-log profile.



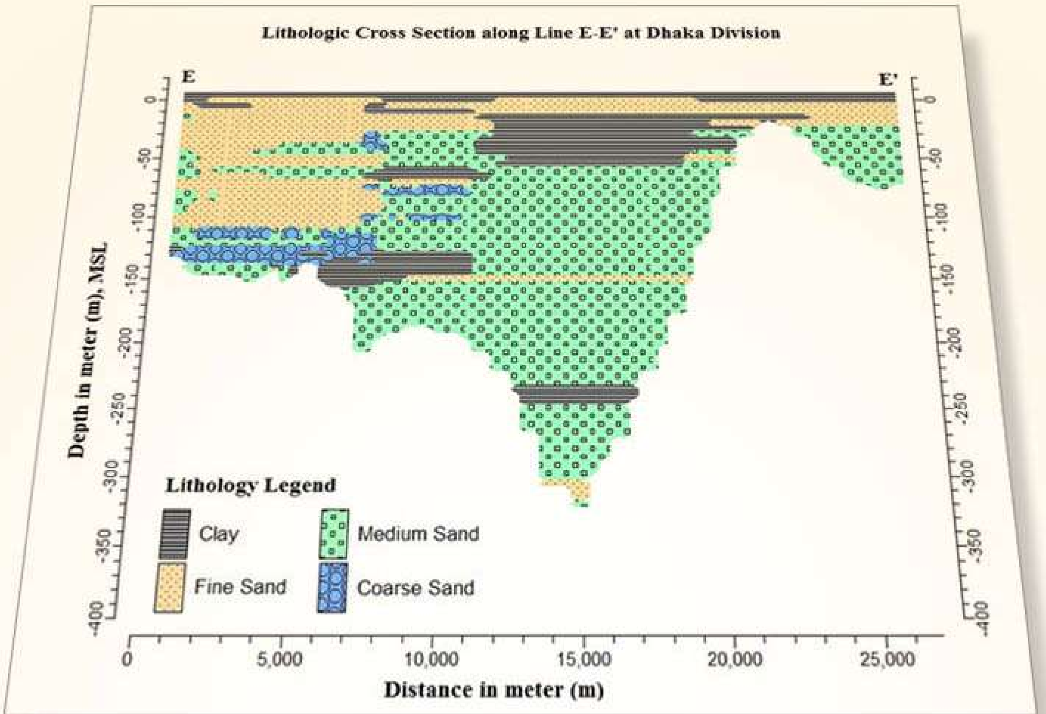


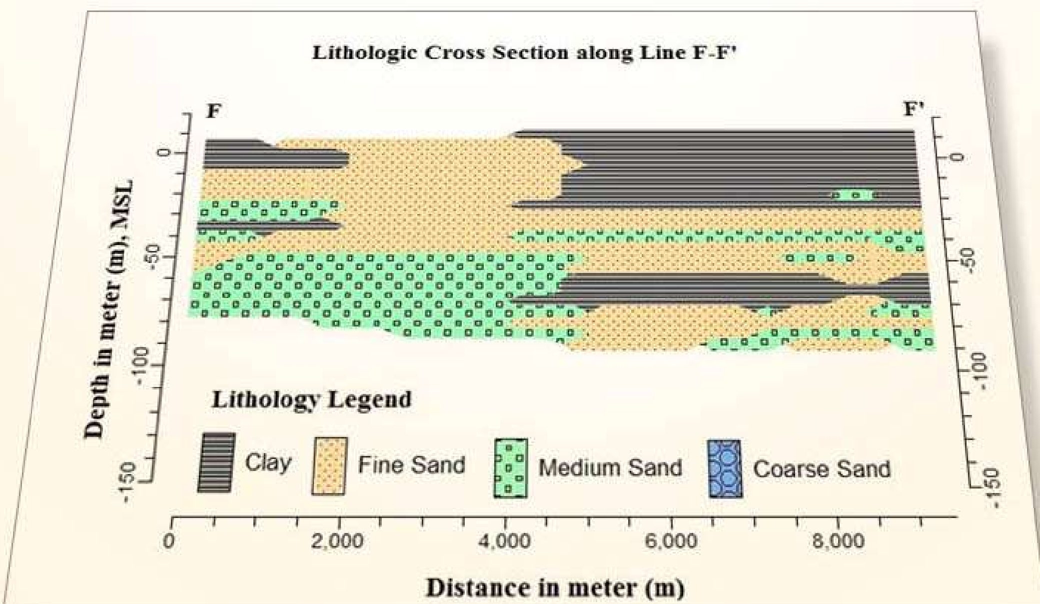


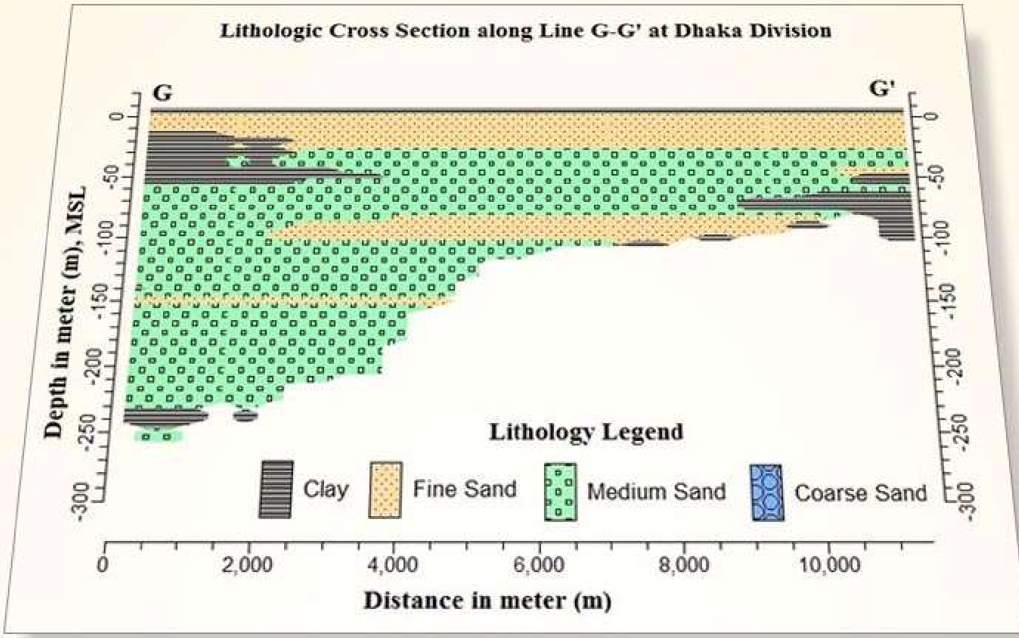
Lithologic Cross Section along Line C-C' at Dhaka Division
C
C'
Depth in meter (m), MSL
Lithology Legend
Clay
Medium Sand
Fine Sand
Coarse Sand
0
-50
-100
-150
-200
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
Distance in meter (m)

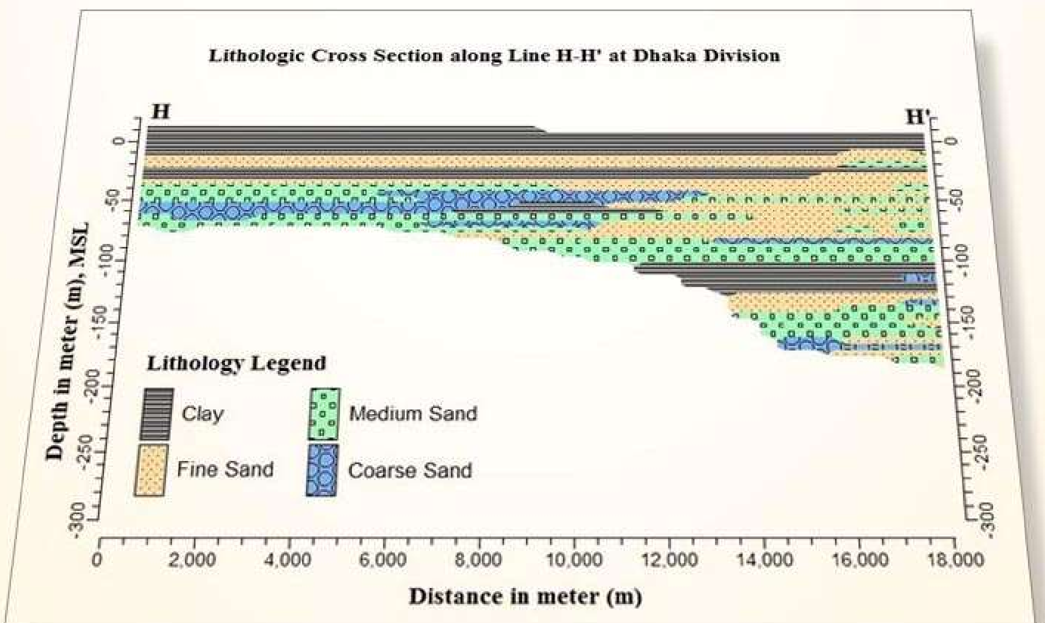


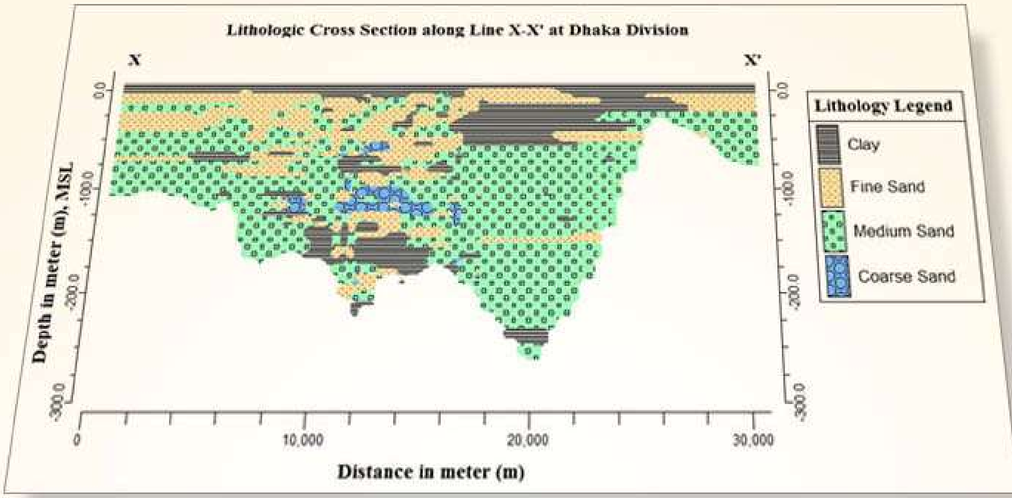
Lithologic Cross Section along Line D-D' at Dhaka Division
D
D'
Depth in meter (m), MSL
Lithology Legend
Clay
Fine Sand
Medium Sand
Coarse Sand
0
-50
-100
-150
-200
0
10,000
20,000
30,000
Distance in meter (m)

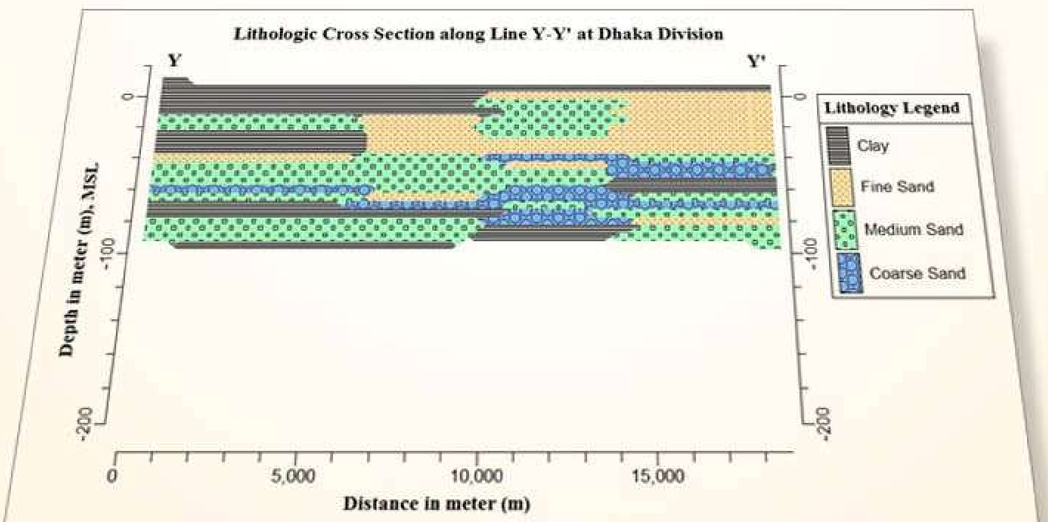

Lithologic Cross Section along Line E-E' at Dhaka Division
E
E'
Depth in meter (m), MSL
0
-50
-100
-150
-200
-250
-300
-350
-400
Lithology Legend
Clay
Fine Sand
Medium Sand
Coarse Sand
0
5,000
10,000
15,000
20,000
25,000
Distance in meter (m)


Lithologic Cross Section along Line F-F'
F
F'
Depth in meter (m), MSL
0
-50
-100
-150
Lithology Legend
Clay
Fine Sand
Medium Sand
Coarse Sand
0
2,000
4,000
6,000
8,000
Distance in meter (m)


Lithologic Cross Section along Line G-G' at Dhaka Division
G
G'
Depth in meter (m), MSL
Lithology Legend
Clay
Fine Sand
Medium Sand
Coarse Sand
0
2,000
4,000
6,000
8,000
10,000
Distance in meter (m)


Lithologic Cross Section along Line H-H' at Dhaka Division
H
H'
Depth in meter (m), MSL
Lithology Legend
Clay
Medium Sand
Fine Sand
Coarse Sand
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000
Distance in meter (m)


Lithologic Cross Section along Line X-X' at Dhaka Division
X
X'
Depth in meter (m), MSL
0.0
-100.0
-200.0
-300.0
Distance in meter (m)
0
10,000
20,000
30,000
Lithology Legend
Clay
Fine Sand
Medium Sand
Coarse Sand

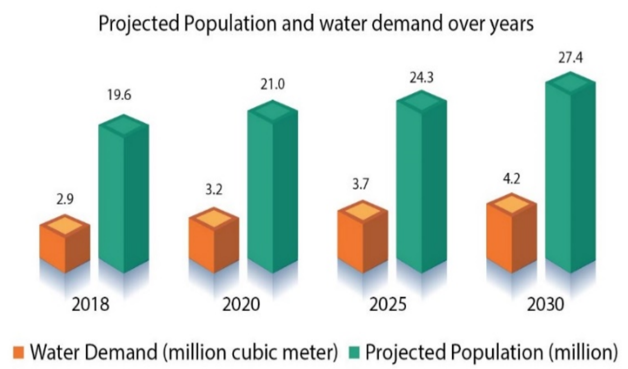

Lithologic Cross Section along Line Y-Y' at Dhaka Division
Y
Y'
Depth in meter (m), MSL
0
-100
-200
Distance in meter (m)
0
5,000
10,000
15,000
Lithology Legend
Clay
Fine Sand
Medium Sand
Coarse Sand

ANNEX 2: GROWTH PROJECTION

POPULATION PROJECTION

The United Nations Population Fund (UNFPA) carried out a population projection for Bangladesh for the period 2011-2061. Based on the assumptions regarding the future course of fertility, three projection scenarios are considered, which are labeled as ‘high’, ‘medium’ and ‘low’ variants. The high scenario assumes that Total Fertility Rate (TFR) remains constant at 2.3 (current level) for the entire projection period. The medium scenario assumes that TFR first drops to 2.1 in the 2011-2016 period, then to 1.9by 2016-21, and remains there until 2061. The low scenario is similar to the medium scenario except that it drops to 2.0 instead of 2.1 in the period 2011-2016, and 1.6 instead of 1.9 in the period 2016-2021. The scenario will be different for Dhaka as high rate of urban migration, which contributes to the population growth of the city significantly. With 36% of the country’s urban population living in greater Dhaka, the capital of Bangladesh has become one of the world’s most densely populated cities. Migration from rural areas to urban, Dhaka is a strong contributor to the population growth. This rural migration accounted for 60% population growth throughout the 1960s and 1970s. While this growth has slowed since that time, Dhaka continues to show steady growth, with estimates placing the 2020 population at almost 21 million, while 2030 may see as many as 27.4 million residents[53]. The fast-growing population has already put tremendous stress on the city, as evidenced by its high rates of poverty, and future concerns include increasing congestion, a higher rate of unemployment and inadequate infrastructure. The growth of population in Dhaka will have an increased demand in water supply as well. At present 2.9 million cubic meter of water is supplied by DWASA abstracted by 760 deep tube-wells, which is expected to be doubled by 2030. Additional 350 bore-wells will be required to install with present abstraction capacity. However, based on the current population growth rate of Greater Dhaka Area (3.6%), the population is projected to be 21.5 million and 27.4 million for the year 2021 and 2030 respectively.

Figure 15: Projected population and water demand (calculated based on UNFPA projection)



INDUSTRIAL EXPANSION

According to the IMF, Bangladesh's economy is the second fastest growing economy in 2016, with a GDP growth rate of 7.1%. It is moving towards record growth figure for the second consecutive year, driven by double-digit growth in manufacturing and construction sectors. In the decade since 2004, Bangladesh averaged a GDP growth of 6.5% that has been largely driven by its export oriented ready-made garments, remittances and the domestic agricultural sector. The textile sector provides the largest single source of growth in Bangladesh's rapidly developing economy. In the financial year 2016-2017 the RMG industry generated US$28.14 billion, which was 80.7% of the total export earnings and 12.36% of the GDP

[53]United Nation Population Fund, 2018

Historic data reveals both an increasing and decreasing scenario in the growth of industrial sector in Bangladesh. Industrial sector marked by notable development in Bangladesh in the mid 1980’s. Since1991 the government successfully followed an enhanced structural adjustment facility and an economic uplift started from around that time. CIA World Factbook reveals that the industrial growth rate in Bangladesh is 8.9% in 2018 (used for BAU scenario analysis), which is expected to be 9.6%, 10.3%, and 11% in the year 2021, 2025 and 2030 respectively (used for BAU plus scenario analysis).

Figure 16: Projected Industrial Growth in greater Dhaka (CIA World Fact book

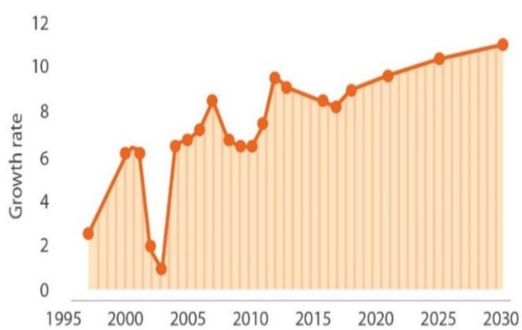
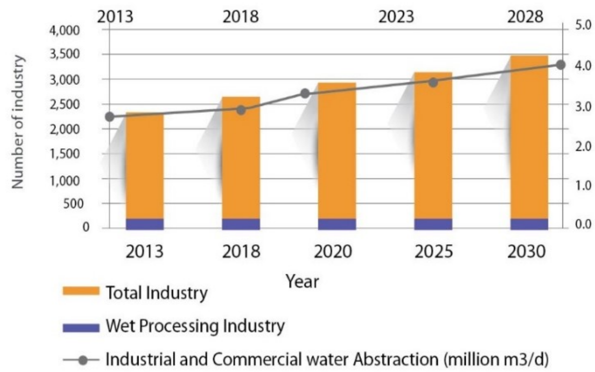


Figure 17: Projected Industrial water demand in Greater Dhaka (Calculated)



IRRIGATION EXPANSION

Land use classification reveals that about 20% of the total land area of Greater Dhaka is agricultural land (table 3 in annex 1). Out of total irrigated area, groundwater covers about 79%[53]. With respect to irrigation technology, minor irrigation contributes to about 86%, whereas 14% is contributed by major canal irrigation. According to a statistic from Bangladesh Rice Research Institute, shallow tube wells (STW) are more popular among small and medium farmers due to their lower capital cost for installation, and simplicity in management. It has occupied 60% of the total minor irrigation and 51% of the total irrigation. The expansion of irrigation for this region is hindered by the falling groundwater tables, power interruption and poor water management the performances of existing STWs, deep tube wells (DTW) and low lift pumps (LLP). On the other hand, a dramatic increase in the number of STWs and a constant decline in command area per STW indicate that the STWs are underutilized. At country scale, it has been observed over several years that both STWs and DTWs, using groundwater and large-scale canal irrigation systems, are operating at lower than 50% of their efficiency level, which can be increased to 75% and 70% respectively[54]. This indicates that there is a room for more water abstraction in the coming years in this sector. Coupled with the increased demand in agricultural production, it is assumed that a 5% growth in irrigation sector annually for BAU plus[55]. At present the irrigation abstraction accounts for 0.88 million cubic meters per day. Considering 5% annual growth, this abstraction may reach to 1.37 million cubic meters per day in 2021 and 1.709 million cubic meters per day in 2030.

[54] *Water management for agricultural development, Irrigation and Water Management Division, Bangladesh Rice Research Institute (BRRI), 2016*
[55] *https://knoema.com/atlas/Bangladesh/topics/Land-Use/Area/Total-area-equipped-for-irrigation*

ANNEX 3: 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, the capital of Bangladesh, is one of the largest of 22 growing megacities in the world, and it depends on mainly groundwater to meet its diverse water demands. A number of studies on groundwater level trend, recharge potential, and aquifer characteristics of Dhaka revealing its vulnerability have been conducted to date. This section describes the relevant findings of these conducted studies for this study.

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[56].

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.[57]

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*[58] 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 m^3/d) in the Dhaka megacity, which has caused regional cones of depression, is balanced by

[56]Hoque, Mohammad A., Hoque, M. Mozzammel, Ahmed, KaziMatin, 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.

[57]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

[58]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

recharge and induced river leakage. The simulated outcome shows the general trend of groundwater flow in the sedimentary Holocene aquifers under a variety of hydro-geological conditions, which will assist in the future development of a rational and sustainable management approach.

Akter and Hossain (2017) constructed a groundwater model for Dhaka city and its surrounding areas and evaluated the effect of artificial recharge to aquifers[59]. The study found, massive withdrawal of water from this aquifer which caused a fall of the 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 show 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 assessment area.

Islam (2017) conducted a research on spatial disparity of groundwater depletion in Dhaka city[60], 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 water level dropped 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, Singairupazila, which are situated in greater Dhaka region and close to Dhaka City, could serve as recharge sites (infiltration galleries). 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 (AR) 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 groundwater is predominantly of Ca-Mg-HCO3 type. Cation exchange and

[59]*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*
[60]*Islam, Dr. Md. Serajul, FarzeenFarhana, 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*

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[61]. 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[62]. Through the vertical hydro-chemical profiles he showed that urban pollution has reached the upper levels of the aquifer within the city. Contaminant transport modeling 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 of 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.[63].

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[64].

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[61] *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.*

[62] *Hasan, M Kamrul, Burgess, William, 1999, The Vulnerability of the DupiTila 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*

[63] *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.*

[64] *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*

Research on Managed Aquifer Recharge (MAR) in Dhaka City conducted by Pervin (2015) analyzed the potential and challenges of MAR and its role on water resources management. In particular, he analyzed the drinking water supply sub sector. 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 Dupi-Tila 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 hydro-geochemical 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[65].

[65] *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 4: METHODOLOGY

The study was 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 was designed to review available research works, articles on groundwater which are published in scientific journals both nationally and internationally. The aim was to generate adequate knowledge and information related to the study. The output of this section has been presented in the literature review section in Annex 3.

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 collected for groundwater level, rainfall, evaporation, and surface water discharge. The aquifer parameters were collected from the scientific journals published on groundwater of Dhaka city and its surroundings.

DATA ANALYSIS

Lithological Model Construction

A number of studies on groundwater system of Dhaka city were done so far and the most of them identified the existence of a multilayer aquifer in and around Dhaka. These studies were done at local level and required information were collected from observation wells constructed by BWDB. Based on the BWDB bore-log information, a lithological model was constructed at the initial stage, the result of which has been given in the Annex 1.

Numerical Modeling- Steady State Condition

Following the lithological model, the study conducted computer aided numerical model to visualize the existing groundwater level 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 were 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 assessment area is the Dupi-Tila sand formation overlain by Madhupur clay. These deposits are of Plio-Pleistocene age. The deeper aquifers under greater Dhaka are yet to be fully explored. The hydro-stratigraphy of this area, up to 350 meters (approx.) depth, was defined based on lithological information. The layered hydro-stratigraphy of the area is mostly irregular and assemblage of sands, silts, and clays. Subsurface sediment formation was classified for different hydro-stratigraphic units based on the lithological characterization. Uniformity of lithological composition, presence of textured sediments and the stratigraphic position were considered for differentiating the Aquifer and Aquitard units including their various depth locations in the assessment area. Accordingly, total 8 hydro-stratigraphic units were defined. It was found from bore-log analysis the aquitard is not continuous, therefore the upper and lower aquifers are connected and they exchange water with each other.

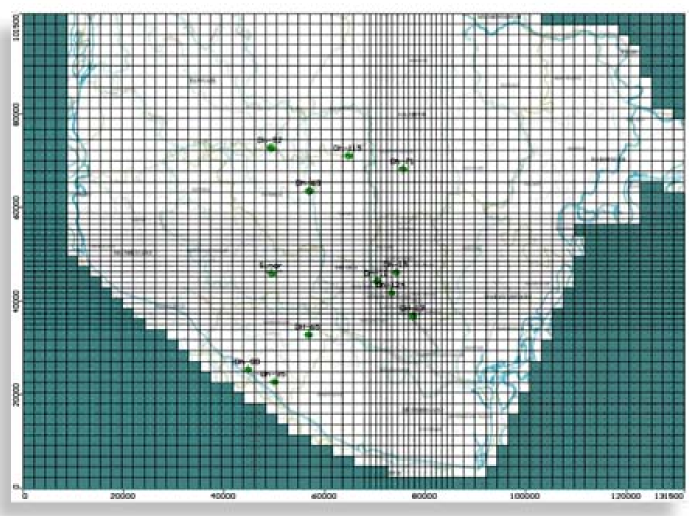
Table 6: Aquifer System of the Assessment Area (Modified after Morris et al. 2003 and Mizanur Rahman et al. 2016, IWM)

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

Selection of Model

Model was constructed by using ASMWin, an environmental simulation version for Microsoft Windows. The simulation methods used in the model was based on the Integrated Finite Difference Method (IFDM). The mathematical approach to model simulation in ASMWin 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 (generated in ASMWin)



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 assessment area defined by UTM coordinated system. Data related to hydro-geological parameters and aquifer geometry were used to build the model grid network. The whole assessment area was represented in grid reference. Data needed to import in the model was prepared according to grid reference. It was based on the repeated subdivision of a regular square mesh. The area of a single square mesh was 2 km^2. For the purpose of simple model, complex geological conditions were approximated by simplified hydraulic equivalents. Seven layers were identified in the aquifer system from the lithological modeling, which are comprised with fine, medium, coarse sand, and clay. Different hydro geological parameters were assigned for each of the modeled layer.

Table 7: Hydro-Geological Parameters as Assigned in Modeled Layer[66]

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	0.0001	0.035	0.5
Aquifer-1	.0002	.0002	4E-5	0.0012	0.15	0.2
Aquitard-2	5.8E-07	5.8E-07	5.8E-7	0.00015	0.05	0.48
Aquifer-2	.0003	.0003	4E-5	0.00107	0.21	0.3
Aquitard-3	1.2E-7	1.2E-7	1.2E-7	0.0002	0.08	0.40
Aquifer-3	.00043	.00043	4.3E-5	0.00109	0.23	0.33
Aquitard-4	1.2E-8	1.2E-8	1.2E-8	0.0002	0.084	0.41

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

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 were considered as external boundaries for modeling purposes. The boundary condition was defined as constant head boundary. Parameters that were incorporated to the model, were mean horizontal and vertical permeability of each layer, storage co-efficient, specific yield and porosity of each layer. Types of aquifers (e.g. confined, unconfined or semi confined) were also declared during the model setup. The aquitards were not continuous throughout the area (based on lithologs) i.e. aquifers were generally connected hydraulically, therefore the aquifer permeability were used on the place of cracks in aquitard layers. It was assumed that the rainfall, river water level and other climatic factors would remain constant in the next 12 years. Groundwater abstraction for irrigation was specified as cluster grid cell and water supply to industry was specified for individual grid cells.

DEVELOPMENT OF NON-STATIC CONDITION

The non-static condition therefore pumping scenarios were developed based on the existing deep tube well locations and their discharge. Location of the pump, operation hour, and pumping rates were used as water abstraction values and the model ran under following assumption:

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

[66] *Akhter, Shireen, Hossain, Md. Sarwar, 2017, Groundwater Modeling 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*