DEVELOPMENT OF ADAPTATION STRATEGIES TO GROUNDWATER LEVEL DECLINATION IN DHAKA CITY

A Thesis by

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CANDIDATE'S DECLARATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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Dedicated to

My Beloved Husband, my source of inspirations

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Abstract

Dhaka city, having a population of more than 15 million, depends on groundwater (GW) as a source of quality water. Recently, the city is encountering GW diminution and the declining scenarios are dissimilar in different parts of the city. This study was carried out to analyze the GW depletion in different parts of Dhaka city from 1970 to 2019. Groundwater level (GWL) data of different locations were collected from Bangladesh Water Development Board (BWDB) and Dhaka Water Supply and Sewerage Authority (DWASA). Trends in annual maximum, minimum and median GWLs were assessed to quantify GW depletion rates by simple linear regression method. Non-parametric tests, namely modified Man-Kendall and Sen‘s slope,wereused to identify and quantify the trends and their significances. Also, contour maps were generated to develop the contemporary GW level scenario of Dhaka city. Spatial analyst tool, Inverse Distance Weighted method, was used to prepare the maps in Arc-GIS. Three contour maps were generated for the trends in maximum, minimum and median GWLs. The contour map of maximum GWL trend exhibits that groundwater flows from all around to central area of Dhaka city. Maximum GWL is found to be decreasing all over Dhaka city. The contour map of minimum GWL trend exhibits that the southwestern part of the city like Khilgaon and Motijheel is facing severe depletion rate. Recharge to upper aquifer to these areas is very low. The contour map of median GWL is similar to that of minimum GWL. From GWL trend analyses and contour maps, vulnerable locations susceptible to severe GW depletion are identified as Khilgaon, Sobujbagh, Motijheel, Dhanmondi, Sutrapur areas and some parts of Cantonment and Mirpur areas.

DWASA is solely responsible for supplying piped water for domestic and commercial purposes. Around 920 deep tubewells (DTWs) of DWASA and 2600 DTWs of private users now extract water from GW sources.DWASA is following some strategies to reduce the pressure on groundwater. Some strategies are focused on supply augmentation like surface water treatment plants, sustainable groundwater plant and installation of new DTWs, and other strategies are focused on demand management like reducing non-revenue water (NRW) by replacing old connection pipes, emergency water supply through water carrier, safe drinking water to consumer by water ATM booth and adopting rainwater harvesting.The effectiveness of these strategies was assessed by SWOT analysis to stand for future adaptabilities. Prior to operation of the Padma (Jashaldia) Water Treatment Plant (Phase-I), water supply ratio from GW to surface water (SW) sources was 78% to 22% in 2019 which had been reduced to 65% to 35% nowadays. DWASA is highly concerned about rapid GW depletion and therefore has prepared a water supply master plan in 2014 with a timeframe up to 2035. DWASA has undertaken some projects to augment supply from SW sources. Construction of two more water treatment plants is ongoing which will add 950 MLD of water from SW sources. A sustainableGW Plant named as Tetulzhora-Bhakurta Well Field Plant Project (Phase-I)is functioning and adding another 150 MLD to the existing water supply. Moreover, two projects focusing on surface water treatment plant and one project

onGW plant with capacity of 1150MLD are planned to be implemented in near future. The aim of DWASA is to change the water supply scenario and to reduce the GW extraction below 20%. Earlier DWASA was facing the problem of high system loss,but at present, it is reducing the system loss by replacing the old connection pipes. After establishment of all District Metered Areas, the NRW would reduce to 15% from 40% and the target is to reduce it to below 5%. Before functioning of all surface water treatment plants, to address supply shortage, the emergency water supply project will add more DTWs including rehabilitation and regeneration of existing DTWs.

Asdemand management strategies, block tariff structure is mentioned in the master plan, though it is yet to be approved. Provision for rainwater harvesting and artificial recharge (AR) is included in the master plan and a prototype design for artificial GW recharge at household level had been done. Yet DWASA could not implement RWH and AR at household level. Dual plumbing system to incorporate RWH and AR as well as greywater reuse should be made compulsory to consumers.Implementation of managed aquifer recharge is stillin planning stage. To develop new adaptation strategies, key informant and semi-structured interviews were performed with DWASA officials, GW experts, researchers and DWASA consumers. Upcoming and current strategies by DWASA were discussed with the professionals. They have emphasized some of the strategies adopted by DWASA and also suggested some new strategies to face upcoming GW depletion scenarios. They also explained how to move forward without causing more depletion. They also addressed some strategies adopted by DWASA which are not praiseworthy.Strategies those are highly emphasized in line with DWASA are adopting more surface water treatment plants, creating alternative sources, providing special attention toRWH, adopting increasing block tariff system, reducing NRW, monitoring family wise consumption by metering, introducing water saving faucets and promoting public awareness.

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Abbreviations and Acronyms

ASR	Aquifer Storage and Recovery
ASTR	Aquifer Storage, Transfer and Recovery
BDP	Bangladesh Delta Plan
BNBC	Bangladesh National Building Code
BWDB	Bangladesh Water Development Board
BMRE	Balancing, Modernization, Rehabilitation and Expansion
DWASA	Dhaka Water Supply and Sewerage Authority
DTW	Deep Tubewell
DPHE	Department of Public Health Engineering
DND	Dhaka-Narayanganj-Demra
DWSNIP	Dhaka Water Supply Network Improvement Project
DESWSP	Dhaka Environmentally Sustainable Water Supply Project
DMA	District Metered Area
DWSSDP	Dhaka Water Supply Sector Development Project
DMP	Dhaka Metropolitan
DoE	Department of Environment
EPWASA	East Pakistan Water Supply and Sewerage Authority
ETP	Effluent Treatment Plant
EWSP	Emergency Water Supply Project
GWL	Groundwater Level
GPS	Global Positioning System
GWH	Ground Water Hydrology
GW	Groundwater
HF-CW	Horizontal Flow Constructed Wetland
HDPE	High-Density Polyethylene
RWH	Rainwater Harvesting
RWCS	Rainwater Catchment System
IWM	Institute of Water Modelling
IRP	Iron Removal Plant
IBT	Increasing Block Tariff
JICA	Japan International Cooperation Agency
KII	Key Informant Interviews
LPCD	Liter per capita per day
MSL	Mean Sea Level
MoP	Ministry of Planning
MoWR	Ministry of Water Resources
MoLGRD	Ministry of Local Government, Rural Development and Co-operatives
MAR	Managed Aquifer Recharge
MLD	Million Liter per Day
MODS	Maintenance Operation Distribution Services
NGO	Non-Governmental Organization
NRW	Non-Revenue Water
OGR	Over Ground Reservoir
PWTP	Padma Water Treatment Plant
PWD	Public Works Department
SWTP	Surface Water Treatment Plant
SWOT	Strengths, Weaknesses, Opportunities and Threats
SCADA	Supervisory Control and Data Acquisition

SWC	Sustainable Water Consumption
USGS	United States Geological Survey
UDA	Upper Dupi Tila Aquifer
UN-HABITAT	United Nations Human Settlements Program
UN/WWAP	United Nations/World Water Assessment Program
VF-CW	Vertical Flow Constructed Wetland
VES	Vertical Electrical Sounding
WRG	Water Resources Group
WTP	Water Treatment Plant
WHO	World Health Organization
WC	Water Closets

Chapter One
Introduction

1.1 Background and Rationale of the Study

Groundwater plays a very significant role in the supply of water for human activities. In most parts of the developing world, rapid expansion in groundwater exploitation occurred between 1970 and 1990 (UN/WWAP, 2003; Villholth, 2006). The alarming news is that in South Asia, the withdrawal rate against available resources is 48 percent (Ariyabandhu,1999). Bangladesh being a riverine country, has been facing dual challenges from water: firstly, unlimited flood water during wet season and secondly, increasing scarcity of fresh water during dry season. Bangladesh is one of the most densely populated countries in the world with a population of over 150 million and has struggled with water supply issues for many years. But it becomes the biggest problem in the nation's capital at Dhaka. Dhaka is the economic and cultural center of Bangladesh and has evolved into one of the largest mega cities in the world over the past decade (Kabir and Parolin, 2013). The rapid growth of the population has caused an immense pressure on the water supply of the city (Hoque et al., 2007). Dhaka Water Supply and Sewerage Authority (DWASA) abstracts up to 78% of the water supply from underground resources (DWASA, 2018). Total estimated abstraction of the entire Dhaka region was about 5.9 million m^3 /d, in which DWASA supplies around 2.75 million m^3 /d of water from approximately 920 deep tube wells (DWASA, 2018). Dhaka pumping, however, has caused groundwater levels to drop more than 60 m over the last half century, and levels are currently declining at a rate of >3 m per year in areas of the city center(Khan et al.,2016). This drawdown of groundwater can eventually lead to drying out the wells (Wada et al., 2010) and a significant increase in pumping costs (Holierhoek, 2016).

The rise in groundwater use over the last 50 years continues apace, from the drilling of the first borehole in 1949 to more than 900 public-supply boreholes abstracting an estimated 1.6 Mm^3 per year against the city's demand of 2.5 Mm^3 per day (DWASA, 2018). New investment in the late 1990's has significantly increased the number of public-supply boreholes operated by the utility, DWASA. Abstraction from private boreholes, whose numbers have also expanded dramatically to more than 2000 (DWASA, 2018), is unquantified but likely to be substantial.

Generally, groundwater table in an area rises due to increase in groundwater storage from sources such as infiltration of rainfall, recharge due to stream seepage, canal irrigation, seepage surface flow, etc. In this perspective, it seems that Dhaka City is rich in groundwater as the city is located adjacent to distributaries of the gigantic Ganges-Brahmaputra-Meghna River system, ensures that induced recharge is possible through the Buriganga River bed (Darling et al., 2002). In fact, the situation is different. The subsurface geology of Dhaka City shows that upper formation is Madhupur clay layer and termed as aquitard and it is 6 to 12 m thick in most parts of the city. This thick clay layer retards vertical recharge of rain water infiltration and horizontal recharge through seepage of streams (Hasan et al., 1999; Ahmed et al., 1999; Morris et al., 2003; Hoque et al., 2007). The Madhupur clay mainly consists of kaolinite (26.79-53.33%) and illite (13.73-33.04%) with very small amount of illite smectite (2.11-12.94%) down to 5 m depth (Zahid et al., 2004). The higher co-efficient of permeability is related to higher amount of illite-smectite mixed layer clay minerals. The vertical permeability of this clay varies from $6.5x10^{-4}$ to $1.5x10^{2}$ m/day that can neither yield to wells nor transmit appreciable water to the aquifer below. However, below the clay layer, medium to coarse grained formation exists. All groundwater has been withdrawn from this aquifer to meet the total water demand of the city dwellers.

At present, DWASA is operating around 920 deep tube wells and five water treatment plants and a groundwater plant on the bank of surrounding rivers. The contribution of four treatment plants in total water supply is only 22% and the rest of water supply comes from exploitation of groundwater(DWASA,2020). The existing facilities of DWASA cannot keep pace with growing demand of safe water supply. Both quantities and distribution facilities are inadequate to serve the inhabitants of the city. So, the city dwellers had already been experienced a scarcity of safe water (Akther and Billah, 2005). The magnitude of the problem becomes severe during the extreme dry and hot season. The reason is that the production of the tube wells decreases and conversely the demand increases. As a result, uncontrolled abstraction of groundwater led to over-exploitation of the resources.

Overall in Bangladesh, the groundwater level in the capital has dropped by six meters in the last seven years. The water table was 51 meters below MSL in 2010 against 46 meters in 2004(Choudhury, 2018). MSL is a measure of the average height of the ocean's surface -- the halfway point between the mean high tide and the mean low tide. In the past, the underground vacuum in the city used to be recharged by the water flowing from the north- from the aquifer of Gazipur district and its adjoining areas. But, at present, these areas too are suffering from severe depletion of groundwater level. Over the past seven years, the water table of Gazipur district has dropped from four meters below MSL to 16 meters.

In contrast, the rechargeable areas are being reduced gradually due to expansion of infrastructures. So, natural water recharge to aquifer cannot keep pace with the water withdrawal since two decades, causing declination of water table which needs closer examination.The strategic importance of the natural high-quality groundwater resource demands a targeted program of aquifer protection. This study was undertaken to determine the trend of groundwater level decline due to over-abstraction, and to propose potential adaptation strategies in managing water supply of Dhaka city.

1.2 Objectives of the Study

The specific objectives of the study are as follows:

a. To assess and map the groundwater level depletion trend in Dhaka City using available time series data;
b. To assess the present DWASA practices to meet the city water demand and to arrest the groundwater depletion; and
c. To propose potential adaptation strategies in managing water supply of Dhaka City.

1.3 Justification of the Study

The Dhaka city is experiencing groundwater depletion over the last few decades due to over abstraction of groundwater and lack of natural recharge.Aquifer dewatering is happening and DTWs are now being establishedin the lower aquifer. A part of this study is conducted on groundwater depletion in Dhaka city. It provides better understanding and updated information on groundwater depletion trend in Dhaka city. Considering the urgent need to alleviate pressure on city groundwater source and to meet the water demand immediately, a number of adaptation actions are being practiced by DWASA. Adaptation practices include surface water treatment plant, pipeline network improvement, well field construction, new deep tube well installation, etc. The expected benefits of these adaptation practices would also meet the Bangladesh Delta Plan (BDP) 2100 goals especially goal #2 (Ensure water security and efficiency of water uses) (MoP, 2018). However, the adaptation practices mostly focus on supply oriented management and the demand oriented management has not received due attention. Moreover, collation and assessment of effectiveness of these practices have not been done yet. This study makes an attempt to fill in these gaps by identifying suitable strategies to manage water supply of Dhaka City.

1.4 Limitations of the Study

This study has a number of limitations. The main limitations of the study are

a. In this study, GWL trend analysis is done with time series data from BWDB. If more stations are installed within study area, result would have been more accurate.
b. Only shallow aquifer data is using in the study. Available deep aquifer data is not adequate for trend analysis.
c. In time series data, dataset was not in continuous interval. For more precise result, daily or hourly interval data should be used.

1.5 Organization of the Thesis

This thesis has been organized in six chapters. The content of each chapter is outlined below:

The first chapter provides with the background and rationale of the study and the specific objectives with which the study was conducted. It also provides the scope and limitation of the study and also the organization of the thesis chapters.

The second chapter reviews relevant literatures on the groundwater declination in Dhaka city, its causes and effects on the aquifer.

The third chapter briefly discusses the geographic location, general information on demography, topography, land use, hydrogeological setting, aquifer recharge process, climate, etc. of the study area.

The fourth chapter provides the methodology of the study, including analysis of groundwater declination, collection of different primary and secondary data to investigate current practices and to suggest potential adaptation strategies.

The fifth chapter presents the detailed analysis on groundwater level declination trends in Dhaka City.

The sixth chapter provides analysis on current practices and potential adaptation options for water management in Dhaka City.

Thefinal chapter provides some conclusions and recommendations of the study.

Chapter Two

Literature Review

2.1 Introduction

Dhaka, the capital city of Bangladesh, has a higher growth rate than the other developing countries. Large abstraction by water-wells has been causing a sharp drop in groundwater level and dewatering of the aquifer. The rate of abstraction has increased drastically which reflects the increased population, rapid expansion of the city and uncontrolled drilling of wells (Alam, 1983). The natural recharge is very negligible in Dhaka city, compared to the abstraction. Overexploitation of groundwater beneath many large cities in the world has resulted environmental hazards including water quality problems.

Large abstraction by water-wells has been causing a linear to exponential drop in groundwater level and substantial aquifer dewatering in Dhaka, Bangladesh. The city is almost entirely dependent on groundwater, which occurs beneath the area in an unconsolidated Plio-Pleistocene sandy aquifer (Hoque et al.,2007).

If the groundwater level declination continues at the present rate, this will create pressure on water storage and may invite subsidence; ecological and environmental hazards in Dhaka City and its surroundings (Akhter and Hossain, 2017).

2.2 History of Water Supply in Dhaka City

The first water supply system was introduced in Dhaka by the British in 1888 atChandnighat. The Chandnighat plant treats water from the Buriganga River and it has acapacity of supplying 39 MLD of water officially (Khan,T.A.,2012). The first deep-water pump wasinstalled in Dhaka in 1949. Till the end of 1960s, the water supply in Dhaka was almostsurface-water system based. Dhaka WASA (Water Supply and Sewerage Authority, Dhaka) was formed in 1963, being separated from the Department of Public Health Engineering(DPHE), with the aim of giving better water service to its city dwellers.In the mid-1990s, DWASA supplied about 428 MLD whereas the demand was estimated at 728 MLD. In 1997, the peak shortage was 490 MLD, which came down to 470 MLD in1999. With the commissioning of the Sayedabad water treatment plant (SWTP), thesituation has improved slightly in recent years. The dependence on groundwater fordomestic, industrial, and commercial water supply in the city area was more than 95 percent prior to the commissioning of SWTP.From so many years since the first operation, the old Chandnighat treatment plant isunable to treat water according to its normal capacity. Moreover, the sources of water for theplant, the city part of the Buriganga River, have become biologically and hydrologicallydead because of ongoing water pollution caused by industrial and domestic sources(Alam, 2003). The conventional treatment plant, which uses only lime and chlorine fortreatment, cannot neutralize the existing pollutants in river water, many of which maycause serious health hazards.DWASA inherited only 33 deep pumps from DPHE (Anwar,2010). But, to meet the steady increasingdemand of the city dwellers, DWASA kept on installing deep-water pumps on a crisis basis without having any long-term vision (Anwar, 2010).

2.3Water Demand and Supply Scenario in Dhaka

To address the need for safe water and sanitation, Dhaka Water Supply and Sewerage Authority (DWASA) was set up in 1963 (before independence it was called EPWASA). Since then, DWASA has grown considerably in size and capacity. DWASA is responsible for operating and maintaining the: (i) water supply services, and (ii) sewerage servicesof Dhakacity. Currently, from a network of some 920 deep tubewells and the three surface water treatment plants at Chandnighat and Sayedabad, DWASA produces 2700 MLD of which 70% of total water supplies are from groundwater (DWASA, 2020). Besides, more than 2600 private deep tube wells (a minimum 2 cusecs discharge) are also discharging water from the Dhaka Aquifer (Geologically, Dupi Tila Formation). The water supply situation during the years 1963 – 2018 is shown in Table 2.1.

DWASA estimates that it serves safe water supply to about 75% of the population in Dhaka. The number of people who receive piped water supply in their homes is estimated to be 5.5 million, of which 75% obtain 24-h supply and 25% an intermittent supply. Another 500,000 have access to piped water via stand posts. An additional 3 million people who live in slums obtain bulk supply of water from DWASA pipe network. The remaining 3 million people receive water from their own supply system. This includes large private apartment complexes and industries, who pay DWASA a fee (DWASA, 2018). The present and future water supply and demand situations are shown in Table 2.1.

Table 2.1:Demand and Supply of Water by Dhaka WASA (Source: DWASA, 2018)

Year	Population (in million)	Water Demand (MLD)	Water Supply Capacity (MLD)	Water Shortage (MLD)	No. of Deep Tube Wells
1963	0.85	150	130	20	30
1970	1.46	260	180	80	47
1980	3.03	550	300	250	87
1990	5.56	1000	510	490	216
1996	7.55	1300	810	490	216
1997	8	1350	870	480	225
1998	8.5	1400	930	470	237
1999	9	1440	1070	370	277

2000	9.5	1500	1130	370	308
2001	10	1600	1220	380	336
2002	10.5	1680	1300	380	379
2003	11.02	1760	1360	400	391
2004	11.56	1850	1400	450	402
2005	12.15	1940	1460	480	418
2006	12.65	1900	1540	460	441
2007	13.15	1980	1660	320	465
2008	13.65	2050	1760	290	490
2009	14.15	2120	1880	240	519
2010	14.5	2180	1990	190	560
2011	15	2240	2150	90	599
2012	15	2240	2180	60	615
2013	15	2250	2420	-	644
2014	15	2250	2420	-	672
2015	15.8	2250-2300	2420	-	702
2016	16	2400	2450	-	795
2017	17	2450	2500	-	827
2018	20	2500	2550	-	887

2.4 Water Resource Availability

2.4.1 Groundwater

The rapid change in land-use pattern in Dhaka Metropolitan area has significantly reduced the area of natural _infiltration galleries' with severe negative impact on groundwater recharge. In the Dhaka Metropolis, the groundwater abstraction rate is about 25% higher than the natural recharge (Islam, 2017). DWASA is responsible for water supply for Dhaka city areas, while in Savar and Gazipur areas, 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 920 deep tube wells (DTWs) with a 3,040 km-long pipeline network, where system loss is assumed to be at around 25% (DWASA, 2017). 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.

Long term monitoring of the groundwater level (GWL) within Dhaka City has shown a significant decrease of the GWL in the central and western regions of Dhaka City since 1983. Between 1985 and the beginning of 2000, the GWL in the Greater Dhaka Area declined significantly from 10 m to 30 m below the ground surface (Islam et.al, 2017). This fall of the GWL resulted in the start of the development of a 'cone of depression‘ (a ‗dried up‘ space beneath the ground surface) 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 m below the ground surface over the last years (WRG, 2019).

Groundwater flow in the Dhaka region is composed of several interconnected and complex groundwater flow systems. Groundwater flow occurs in two aquifers, that are relatively shallow and with localized flow paths that are superimposed on deeper, regional flow paths. Regional groundwater flow is predominantly through the lower Dupi Tila Aquifer and tends to follow the regional topographic gradient; water generally flows towards Shitalakhya River. Most groundwater recharge results from the following: infiltration of precipitation during the late monsoon in the form of widespread flooding (Knappett et al. 2016); river discharge and bank infiltration (Khan et al. 2016; Hoque et al. 2014); leakages from urban water supply (DWASA 2017); and from fluvial drainage as well as sewers and unsewered sanitation (Hoque et al. 2014; Morris et al. 2003)

The resultant value of abstraction computed in theDWASA Resource Assessment study (DWASA, 2014) has some approximation, as reliable data on abstraction volume, particularly for the private wells was hard to obtain. Total subsurface inflow or aquifer recharge has been computed from the total abstraction volume (700 Mm^3) and volume abstracted from aquifer storage (96 Mm^3 or 14%). As such, with the present condition, the annual water volume available from Upper Dupi Tila Aquifer system without causing further depletion is approximately 600 Mm^3. But this volume is the quantity obtained as maximum potential recharge volume. The useable recharge volume should be kept at least 15% below the potential recharge volume.

2.4.2 Surface water

DWASA has a zonal approach of water supply to its consumers by conjunctive use of groundwater and surface water sources. Among the existing 10 zones, only 8 zones have conjunctive sources water, i.e. the supply consists of groundwater and surface water sources. The surface water treatment plants are constructed at Zone-1 and Zone-2, but their service command areas are covered over Zones 1, 2, 3, 5, 6 and 7. Water from the existing 4 surface water treatment plants is mixed with the DTW water in the distribution network and increases both quantity and pressure in the network. **Table 2** shows the service coverage areas of each water treatment plant.

Table 2.2: Surface Water Treatment Plant Details

Sl.	Name SWTP	Capacity (MLD)	Coverage Area
1.	Saidabad Water Treatment Plant (Phase-1 and Phase-2)	450	MODS Zone – 1, 2, 3, 4, 5, 6, 7
2.	Chandnighat (Dhaka) Water Works	39	MODS Zone – 2, 3

Chandnighat Surface Water Treatment Plant (SWTP):

Constructed in 1874, this is the 1st surface water treatment plant in the country. This water treatment plant covers almost all of the old city of Dhaka, and which is one of the most vital business areas having lots of small-scale industries and commercial enterprises. The Buriganga river is the source of raw water for the plant. Rehabilitation works of this treatment plant had been carried out in 1947, 1970 and in the latest in 1996 by Shimizu Corporation of Tokyo under JICA financial cooperation the BMRE (Balancing, Modernization, Rehabilitation and Expansion) of this plant has been implemented. After BMRE, the production capacity of this plant has been raised from 17 MLD to 39 MLD. Water from the Buriganga River is mixed with Aluminium Sulphate to generate flock and is settled out from the water in the flocculation basin. After the flocculation, water is pumped to rapid sand filters for turbidity removal through filtration(DWASA, 2014).

Saidabad Surface Water Treatment Plant (SWTP):

Saidabad water treatment plant (phase-1, capacity 225 MLD) was built in 2002 under 4th DhakaWater Supply Project. The present capacity of the treatment plant is 450 MLD, after the second phase was commissioned in December 2012. Eventually the total plant capacity will be 900 MLD when the third phase is completed. Raw water is drawn from the river Sitalakhya through an intake pumping station constructed in the river at Sarulia point. From the intake, raw water is transmitted through a 40 m wide, 4.6 km long canal known as DND canal. At the tail end of the canal, water is transmitted through gravity to twin 2.0 m × 1.5 m culvert. The culvert itself is 1.6 km long. The culvert extends up to the sump of the pumping station, at the entrance point of the treatment plant. At the beginning, biological pre-treatment aerates the raw water to convert ammonia to insoluble nitrate and nitrite. This ensures, ammonia in raw water is not reacting with chlorine in pre-chlorination and post-chlorination cycles. At the flash mixing chamber, chlorine is added for raw water in pre-chlorination. Aluminium sulphate is added for coagulation and lime for flocculation. In the pre-treatment clarification unit, four pulsator type clarifiers facilitate particle separation mechanism by both flocculation and sedimentation. The sludge blanket removes colloids and planktons. Water from the clarifiers is filtered in a set of 12 dual chamber sand filters. Finally, at the two-chamber clear water reservoir, 30 minute chlorine contact is facilitated to ensure final disinfection of water. Lime is added for pH adjustment and filtered water neutralization(DWASA, 2014).

2.4.3 Rainwater

Dhaka city experiences the Indian Ocean Monsoon. The area experiences four metrological seasons: Pre-monsoon (March to May), Monsoon (June to September), post monsoon (October to November) and Dry (December to February) (DWASA, 2018). More than 80 % of the annual rainfall occurs during the monsoon. Monthly rainfall in Dhaka is shown in Table 2.3.

Table 2.3: Monthly Rainfall of Dhaka City in Recent Years.

Monthly Rainfall (mm)	2010	2011	2012	2013	2014	2015	2016	2017	2018
April	37	123	269	26	80	166	26	230	328
May	177	235	140	390	152	185	215	185	442
June	308	314	189	324	337	366	210	409	316
July	29.3	356	220	297	338	707	406	583	357
August	22.5	406	271	219	392	347	398	549	140
September	54.3	193	82	166	155	346	138	383	74
October	119	112	46	46	49	51	75	381	45
Total	**747.1**	**1739**	**1217**	**1468**	**1503**	**2168**	**1468**	**2720**	**1702**

Although rainfall is abundant (around 2,000 mm annually in Dhaka), there are some practical limitations especially in terms of storage. The international Conference on rainwater Cistern Systems held in Hawaii, June 1982, there are two main types of rainwater catchments system (RWCS). The possibilities for RWCS as well as storage are i) on the roof of buildings or ii) at ground level. Despite these limitations, rainwater harvesting can be an option to increase water supply in the monsoon. Many NGOs are now working with urban communities, where the main source of water supply is street vendors, and looking at ways to harvest rainwater. Computer based models were developed by NGO Forum employing mass curve analysis to calculate the size of the storage tank (Karim et.al.,2015). Monthly average rainfall data, catchment area, roof runoff coefficient, per capita water demand and family size were the input variables for determining the storage volume sufficient to supply water for a period of 8-10 months in a year. Reliability analysis of varying degree of security, 80, 90, or 99%, associated with given roof and tank system was performed to determine appropriate water usage rates.

The possibility of harvesting rainwater in the monsoon season to augment supply has been considered in WSP (1998). For calculation of potential of rainwater for domestic use, roof of building has been assumed as catchment area. In 2002, DWASA collected and utilized 11.5 million liters of rainwater from the rooftop of its main administrative building. Haq (2006) emphasized that use of rainwater be an integral component in the urban water management plan. Chowdhury (2006) estimated potential of rainwater for domestic use in a few residential buildings in Dhaka, mainly for toilet flushing and cloth washing purposes. Rainwater harvesting in urban area of Dhaka city for mitigation of water scarcity and technique of rainwater harvesting has been studied by Sultana (2009). The study estimated that about 15% of total demand of Dhaka city could be met from rainwater from rooftop of building. In 2011, Institute of Water Modelling (IWM) as a consultant of DWASA has studied rainwater harvesting for artificial recharge. If 60% rainfall in monsoon from roof top can be harvested, it will make 89496 ML/year or 245 ML/day (DWASA, 2011). Available rainwater estimated from different percentage of rainfall utilization is shown in Table 2.4.

Table 2.4: Amount of Rainfall for domestic use

Rainfall utilization for domestic use	Unit	Amount
60 % rainfall utilization from rooftop of house,	ML/day	245
45 % rainfall utilization from rooftop of house,	ML/day	183.75
30 % rainfall utilization from rooftop of house,	ML/day	122.5

(Source: DWASA, 2011)

2.4.4 Wastewater

Domestic in-house specific water demand in industrialized countries approximates 100-150 l/c/d (liter/capita/day), of which 60-70% is transformed into grey water, while most of the rest is consumed for toilet flushing and released as black water (Friedler, 2004). Another study shows that the grey water from bathroom sinks, tubs, showers kitchen sinks and dishwashers, include 50-80% of household wastewater (Thakur and Chauhan, 2013). A typical vertical flow constructed wetland (VF-CW) system can remove the BOD_5 up to 96%; the horizontal flow constructed wetland (HF-CW) system can remove only up to 65%(Shrestha, 2008). Grey water reuse for toilet flushing can reduce the in-house net water consumption leading to 10-20% reduction of the urban water consumption, which is significant especially under water scarcity situation (Thakur and Chauhan, 2013). Adding with this, recycled grey water can be used in irrigation, watering golf course, gardening, cleaning and washing and in ground water recharge (Dakua et al., 2016).

The average water consumption for the middle-class families is 200-300 liters per capita per day. The bulk of water in household is used for bathing and cloth washing. Dish washing and toilet flushing account for subsequent major uses of household water. Almost 17-18% of potable water is used for toilet flushing which can be saved by reusing greywater. Excluding kitchen water, about 67% of the generated water is greywater (i.e. about 170 liters per capita per day) which could be reused after treatment (Abedin, et al.,2013). The values of the tested eight parameters (i.e. pH, Color, Turbidity, BOD, COD, TDS, TSS, FC) of the generated greywater exceeded the standard permissible values of water quality. Kitchen water was found to be the most polluted, which indicates its non-reusability. After exclusion of kitchen water, greywater has average pH 6-7.5, color 170-520 Pt-Co, turbidity 65-420 NTU, TDS

120-1570 mg/l, TSS 55-1575 mg/l, BOD 12-320 mg/l, COD 580–1600 mg/l, Fecal coliform 400-42500 CFU/100ml, which exceeds the maximum permissible range of standard quality of irrigation water and potable water (Tamanna et al., 2011). Kitchen wastes are high in suspended solids, fats, oils, and grease, and their generally high organic content encourages the growth of bacteria. Also, high fat and solid content cause problems for filtration and pumping. Due to contamination by oils, greases, and food particles, and its low contribution to the total waste stream for a household, kitchen water is not recommended as a source of greywater (Oteng-Peprah, 2018). A number of key issues of concern need to be taken into attention when intending the reuse of greywater. The system should be as simple and easy to use and maintain as possible, while reducing risk to human health. If storage is required, the greywater must be treated to eliminate biodegradable contaminants; otherwise, the greywater will quickly become septic and may generate toxic odors and create other aesthetic and operational problems (Abedin and Rakib, 2013).

2.5 Tariff Regulation

Municipalities/water utilities can set their own tariff structure for metered and temporary connections with permission from the government. However, the Dhaka WASA Board can increase the tariff to a maximum of 5% to compensate for an increase in electricity rates and inflation (DWASA Act, 1996). It should be noted that DWASA spends approximately 35% of its total expenditure on electricity alone. For any increase above 5% for any reason other than the one mentioned above, prior permission from the government is mandatory. For faulty meters and non-metered connections, the rates can be fixed on the basis of previous three-month average water bill. Under the regulations the utilities have been allowed to disconnect water lines of the customers for non-payment of tariffs. Dhaka WASA collects sewerage tax at a prescribed rate which is equivalent to the water charge. For example, DWASA currently charges Tk 14.46 per m^3 of water for residential users and Tk. 37.04 per m^3 of water for commercial consumers. Holdings with sewer connections have to pay double of water bill.

2.6 Groundwater Depletion Scenario

Groundwater table in the capital has dropped down to 100.80 meters below the surface, 60 meters in the last eighteen years. In 2000 the groundwater table was only 40.0 meters below the surface, declining at the rate of over three meters on average every year. Chowdhury (2018) shows that due to construction of buildings, roads and concrete pavements, natural water recharge to aquifer cannot keep pace with the water withdrawal since more than three decades, causing declination of water table. This study shows that the average declination of GWL per year in Dhaka City is 3.07 m, where maximum declination occurs at zone four and minimum declination occurs at zone two. A previous study shows that due to excessive withdrawal of ground water, an annual decrease in level is about 2 meters (Akhter et al., 2009). If such declination continues and condition of insufficient recharge of ground water sustains, by the year 2050 on an average static water level in Dhaka city will decline by 161 m(Chowdhury, 2018). During the study it is observed that specific capacity of ground water table also decreasing rapidly. The result shows that in Dhaka city loss of specific capacity per year is 0.1 l/s/m, where maximum loss rate found at zone five and minimum loss rate found at zone ten. By the year 2050, average specific capacity will be reduced to 1.80 l/s/m which is 51% less than average specific capacity of ground water table (3.7 l/s/m) of 2018.If this situation continues, in 2050 several deep tube-wells will become inactive. The present water supply in Dhaka city is heavily dependent on groundwater that ensures a future threat with acute water crisis. Though DWASA has already started to shift its present groundwater-based production system to surface water production, the shift demands huge investment and time. Moreover, the status of peripheral rivers of Dhaka city is highly degraded and a major portion is under illegal encroachment. That is why it is highly unlikely to fulfill the future demand just by relying on these sources. Considering the present crisis and future demand, it is high time to seek additional sources. If water table continues to fall then a vacuum will be created in the aquifer which could cause a sudden collapse in the surface. Excessive withdrawal of groundwater to meet the needs of about 15 million city residents and inadequate recharging will result in intrusion of southern saline water into the groundwater reservoir, depriving this mega city of pure drinking water (Chowdhury, 2018).

2.7 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:

2.7.1 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. A study conducted by analyzing data from global positioning system (GPS) at the Earth Observatory Center, Dhaka University found that 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 (Roy, 2012). Due to rapid decline in groundwater levels, this phenomenon may affect all kinds of infrastructure in the Dhaka Metropolitan 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 (Zahid and Hassan, 2017). In the Dhaka Metropolitan area, this may further dry up the surface water bodies and the wetlands in the close proximity of the Turag and Balu rivers.

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: There is a linkage between declining groundwater tables and over-abstraction attributable to increased incidence of earthquakes in certain geological settings similar to California and Spain (Amos et al., 2014). In Dhaka and its surrounding areas, due to its unique geological settings, the probability of earthquakes is minimal.

2.7.2 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 (U.S. Geological Survey Fact Sheet 103-03), 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.

2.7.3 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 (WRG, 2019). Table 2.5 summarizes the vulnerability and risk due to groundwater depletion.

Table 2.5: Impacts of Groundwater Depletion in Dhaka (Adopted from USGS Sustainability of Ground-Water Resources-- Circular 1186)

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
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

2.8 Practices from Other Countries in Minimizing GW Declination

Sustaining a reliable supply of drinking water to urban areas is essential for the well-being of the majority of the planet‘s people. Not only does good health depend on clean drinking water, but so too does the economic health of these communities. Climate change impacts, increasingly jeopardize cities that depend on surface water catchments.India has started practicing Managed Aquifer Recharge (MAR) in many areas for irrigation and recharge of groundwater. Underground Transfer of Floods for Irrigation (UTFI) method is practiced in Uttar Pradesh, India which achieved much higher recharge rates (2–9 times) than what would have beenachieved from village ponds alone through infiltration (Alam et al.,2018).MAR concept is also applied on other parts of India like Andhra Pradesh, Tamil Nadu etc.(Richard et al, 2018 and Massuel et al., 2014).Australia provides a salutary example. In the mid-1970s inflows into the city of Perth‘s water storages began a series of ‗step changes‘ such that a decline in the order of 70 % of the previous long-term average was experienced (Petrone et al., 2010). During the 2002–2010 Millennium Drought, another five cities in southern Australia also saw their water storages reduced to perilously low levels. A common response of the impacted states was to diversify the supplies of water for these cities by adding reuse, groundwater, and desalination sources. In particular, Adelaide, Perth and Sydney each drew on new groundwater resources, applied managed aquifer recharge, or set aside aquifers as drought reserves.

This Australian example highlights the potential of aquifers to grow in importance as existing urban water storage as source becomes more sensitive to increasingly variable climatic and surface hydrological conditions. These same storage characteristics will also make aquifers more attractive as a source of water for food production.

Additionally, an important buffering role of groundwater can be provided by individual on-site water wells. Private wells can reduce demand pressures on larger aquifers. In the US over 40 million people are supplied with their water needs from 15 million private wells (US

Census Bureau, 2007). In most instances homeowner wells (often in bedrock fractures) are accessing small discrete aquifer systems that are economically unusable for any major supply. Provided there is limited outside lawn watering, virtually all the pumped water is treated and returned to the sub-surface via septic systems and leach-fields. The key to continuing this harmonious use of groundwater is to ensure through zoning regulations that well density does not exceed renewability and that the rights of private well owners sharing access to aquifers with major pumpers are protected. ―Deepest well wins" is not a good basis for groundwater management (Pittock et al., 2016). Shrestha et al. (2018) suggests some adaptations strategies, such as, estimation of safe yields and potential groundwater critical zones as well as potential groundwater recharge zones for adoption and protection in groundwater planning and regulations need to be addressed. Conjunctive use of surface and groundwater sources should be introduced. Integration of the recharge agenda with the flood control agenda and vice-versa and groundwater monitoring networks should be strengthened.Regulatory provision for groundwater abstraction should be exercised.

Direct recharge using recharge wells (same as the abstraction wells) fed by rainwater harvesting as well as regulating groundwater abstraction from groundwater depression zones and combining with rainwater harvesting techniques and conjunctive water use or reuse of water should be made mandatory (Shrestha et al.,2018).

Establishing a groundwater level monitoring mechanism for both networks and institutions is important. On the other hand, safe yield complying with existing regulations and areas experiencing greater groundwater depletion for current and future conditions should be kept in mind. Overall increasing stakeholder awareness on rising groundwater levels at the post regulation stage have to be given much concern.

Foster,2020 analyses both the benefits to water users and the broader community of groundwater use, and the associated risks in terms of (a) compromising resource sustainability, (b) impacting the built infrastructure, (c) public-health hazards arising from widespread groundwater pollution and (d) the economic distortion of water-sector investments. He analyzed on ten cities around the world with existing situation with management approach. Conserving groundwater to water security, incorporating groundwater in sanitation and drainage planning, decentralization of groundwater use has come out to the solution of existing depleted groundwater situation. He also added that government needs to find the political will and practical means to constrain groundwater demand and limit abstraction by socio-economic and regulatory measures, so as to avoid excessive aquifer depletion and degradation, plan urban sanitation better and regulate the storage of industrial chemicals and handling of industrial effluents in the interest of much improved groundwater quality protection.

DWASA has taken more projects to decrease the dependency on groundwater but there is a gap between projects' output and people's perception. So, it can be concluded that in order to develop best adaptation strategies for future, help and knowledge of root level people, community and organizations should be taken into consideration besides government initiatives.

Chapter Three

Description of the Study Area

3.1 Location

The geographical area of this study includes the Dhaka Metropolitan City and DND area. The target area is located between 22°35′ to 23°54′ North Latitude and 90°20′ to 90°33′ East Longitude. The target area is surrounded by the Tongi Khal on the north, the Turag - Buriganga river system on the west, the Balu River on the east and the Sitalakhya River on the south (Figure 3.1).

3.2 Climate

Dhaka City experiences the climatic condition of the Indian Monsoon. The area experiences four meteorological seasons: Pre - monsoon (March to May), Monsoon (June to September), Post - monsoon (October to November) and Winter (December to February). Average annual rainfall is in the range of 1700 to 2200 mm. About 71% of the rainfall occurs during the period from June to September. Average temperature ranges between 25°C and 31°C. Maximum temperature may rise up to 40°C and minimum temperature may go down to 6°C. Average humidity remains at 80% to 90%.

3.3 Topography

The northern and central parts of the Greater Dhaka are occupied by the southern part of the Madhupur Tract. The rest of the area is covered by the floodplain of the major rivers. A remarkable difference in the ground elevation can be observed throughout the Dhaka City, which is reflected in distinct landforms: high lands, low lands, abandoned channels and depressions.

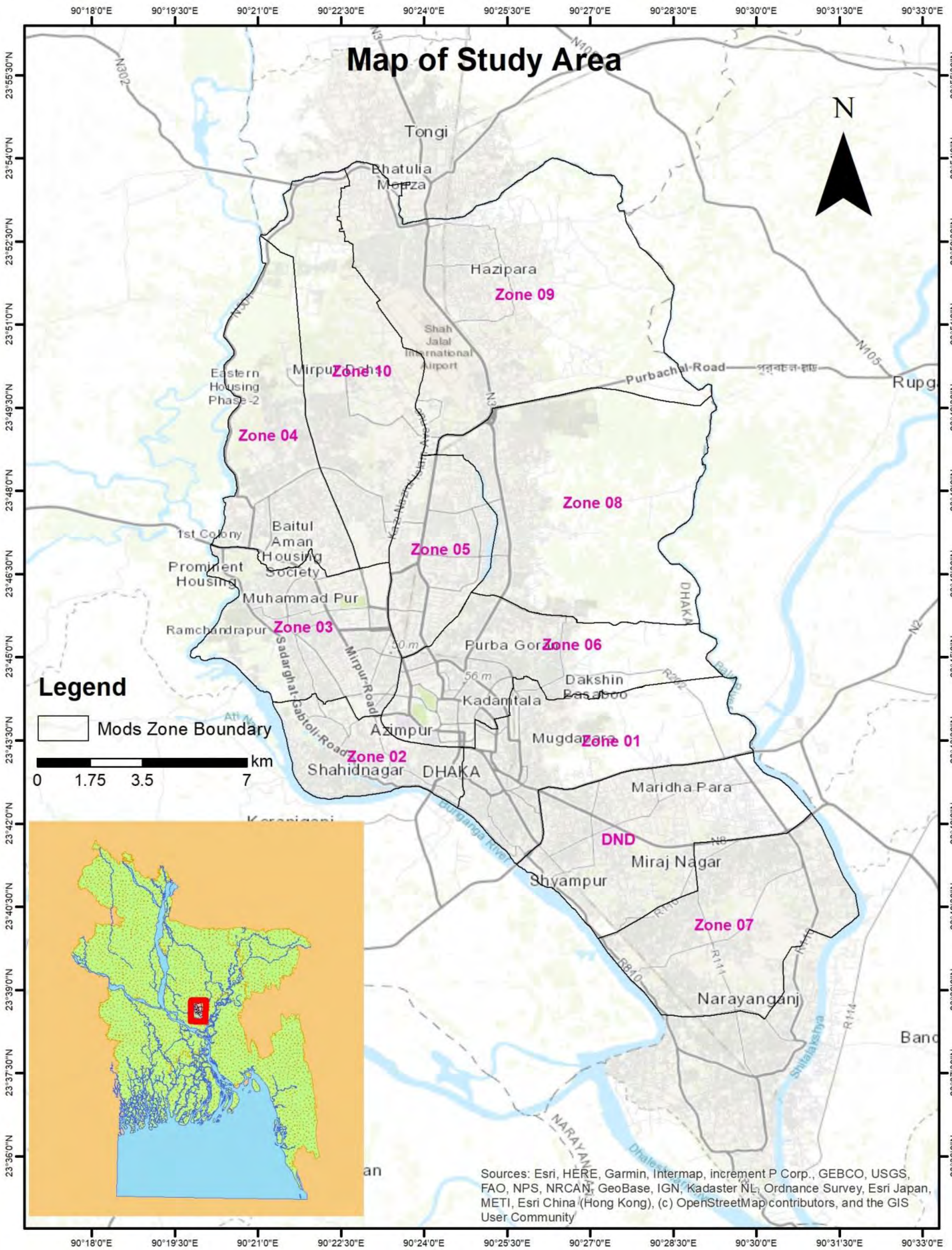

Figure 3.1: Map of the Study Area

Ground elevation of the city varies from 0.5 to 12 mPWD. About 60% to 70%of the city area includes low lands, abandoned channels and depressions, and these areas vary from 0.5 to 5 mPWD (Hoque, 2004).

3.4 Land Use

Dhaka started to develop in a more planned way after 1947 when it gained regional and political importance (Chowdhury, 1998). Previously, commercial and residential areas were situated side by side, mostly concentrated beside the narrow roads. The Old Dhaka still presents this situation with a mixture of commercial, residential and small industries. After preparation of the Master Plan of the city in 1958, the commercial centers of the city was moved to Motijheel and a high residential area was developed at Dhanmondi (Islam and Adnan, 2011). Detailed land use for Dhaka metropolitan development area has been surveyed by GBL in 2008 and it is presented in Figure 3.2. Housing colonies for government employees, universities, parks, commercial and industrial zones, lakes and other public facilities were developed gradually to meet the demands of the expanding city. With the development of the city, wide roads and other paved areas replaced the unpaved areas, natural depressions and agricultural land. In many cases, natural drainage canals and open water bodies were filled up for development works. Unequal urbanization in the country and concentration of urban services,employment and business opportunities in Dhaka has transformed it into a megacity (Rahman, 2004). Absence of adequate parks, open water bodies and drainage system has degraded the quality of living in the city in many ways. Moreover, in the metropolitan city area, the percentage of the agricultural land is much lower.

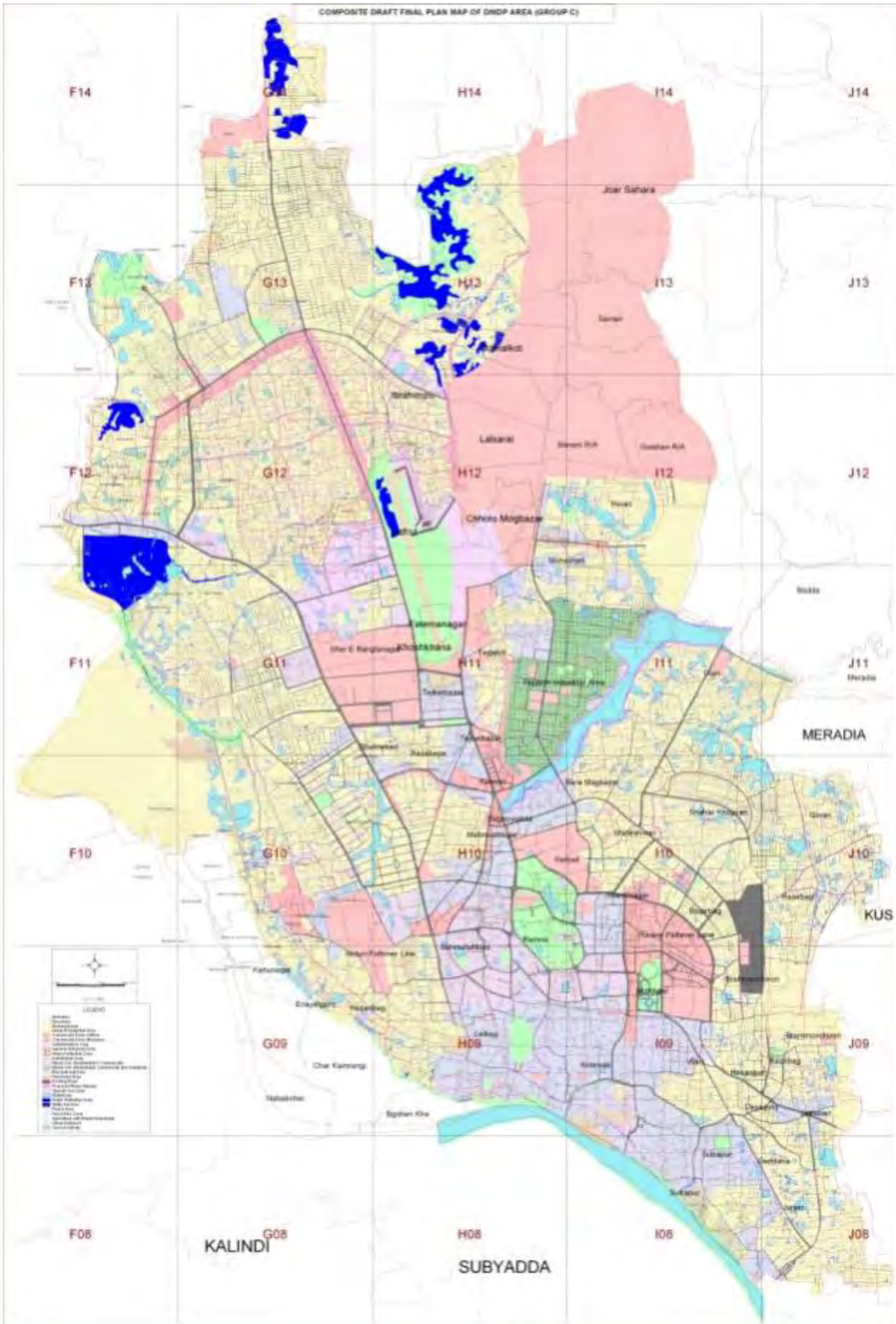

Figure 3.2: Land use in Dhaka city
(Source: RAJUK and GBL, 2008)

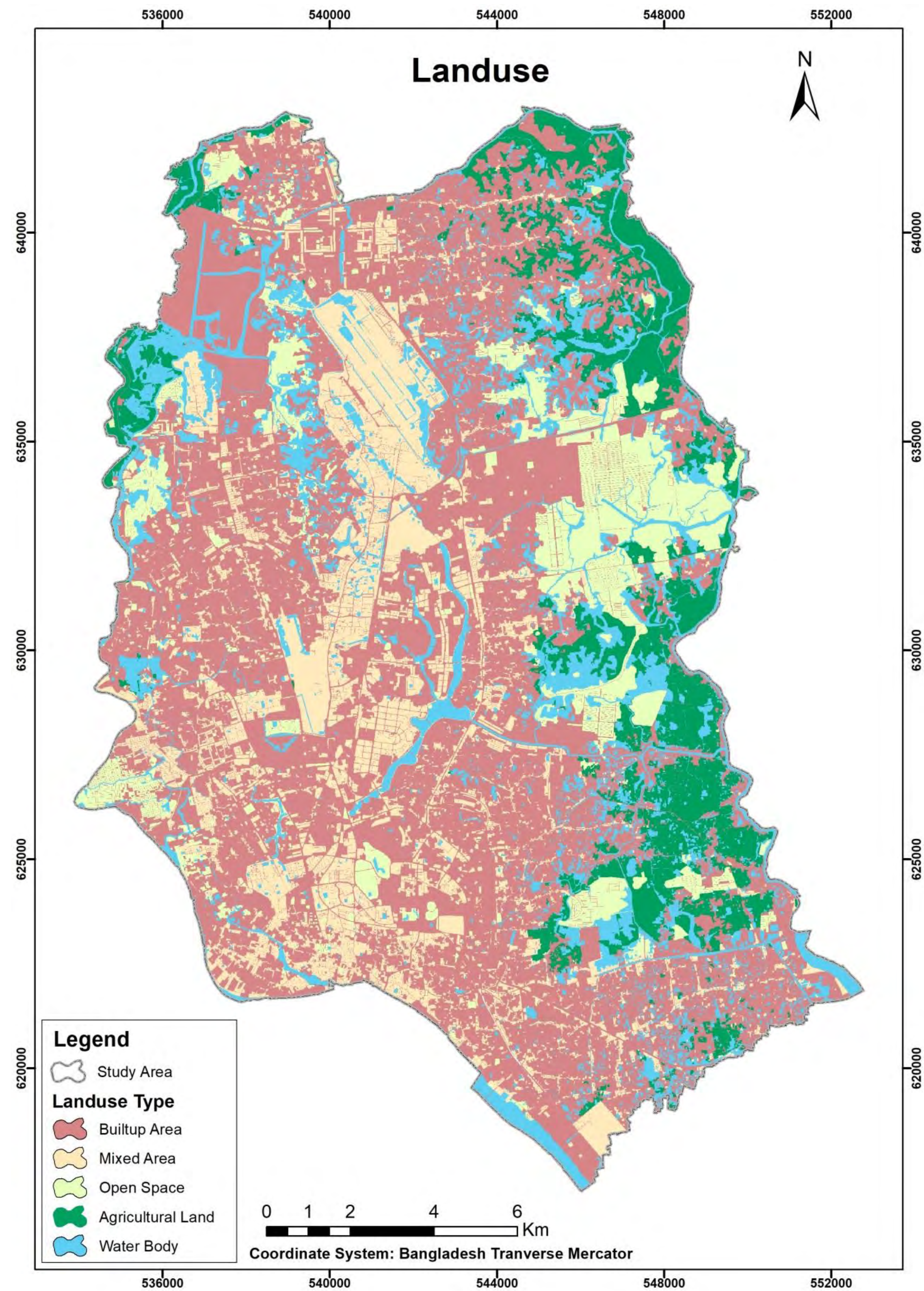

Figure 3.3: Land use map in Dhaka city
(Source: Islam and Imran, 2019)

3.5 Hydrogeological Setting

Source aquifer system in the Dhaka City area is Pilo-Pleistocene Dupi Tila formation. This unconsolidated sediment has four aquifer layers from surface to 364m depth level with variable thickness, viz. Upper Dupi Tila Aquifer – 1, Upper Dupi Tila Aquifer – 2, Lower Dupi Tila Aquifer - 1 and Lower Dupi Tila Aquifer - 2.

Table 3.1: Hydrostratigraphic Units of Dhaka Aquifer System (Source: DWASA, 2018)

Aquifer System	Hydrostratigraphic Unit	Average Thickness (m)	Average Bottom Depth (m)
Upper Dupi Tila Aquifer - 1	Top soil/ Clay	9	9
	Aquitard – 1	41	50
	Aquifer - 1	69	118
	Aquitard / Aquiclude - 1	16	134
Upper Dupi Tila Aquifer - 2	Aquifer - 2	32	166
	Aquitard / Aquiclude - 2	26	192
Lower Dupi Tila Aquifer - 1	Aquifer - 3	93	285
	Aquitard / Aquiclude - 3	16	301
Lower Dupi Tila Aquifer - 2	Aquifer - 4	36	337

Existing information on aquifer formation obtained from various exploration data gives a good idea about the depth and variable thickness of the aquifer in the study area. This information confirms that the local geology is representative of the regional geological unit. Hydrogeological parameters of this area are governed by the lithostratigraphyand prevailing tectonic activities, which is also part of regional hydrogeological setting and tectonic features.

The geology of the study area can be attributed to Quaternary alluvial sequence, which is a part of the Ganges - Jamuna flood plain (Figure 3.3). According to Davies (1989, 1995), Davies and Exley (1992), Monsur (1995) and Umitsu (1993), the study area lies in the Faridpur trough of Bengal Foredeep considering the tectonic setting.

The Quaternary sequence provides good aquifers, which have been extensively exploited in Bangladesh. The aquifers are generally thick multilayered with high transmissivities and storage coefficients. The aquifer systems underlying Dhaka city is the Dupi Tila sand formation overlain by the Madhupur clay. These deposits are of Pilo-Pleistocene age with its ground surface between 3m and 10m above sea level. Upper Dupi Tila Aquifer or shallow aquifer system beneath Dhaka city is being explored from the inception of the DWASA. The deeper aquifers under Dhaka city and its adjoining areas are yet to be fully explored and studied. Recent exploration by installing production wells in the city has provided positive results so far (DWASA, 2018).

The hydrostartigraphy of the city area up to 364 m depth has been defined based on lithological information. The layered hydrostratigraphy of the area is mostly homogeneous and assemblage of sands, silts and clays. Subsurface sediment formation has been classified for different hydrostratigraphic units based on the borelog probability, geophysical profiles, application of Vertical Electrical Sounding (VES) method and lithological characterization (Meshram and Khadse, 2015)

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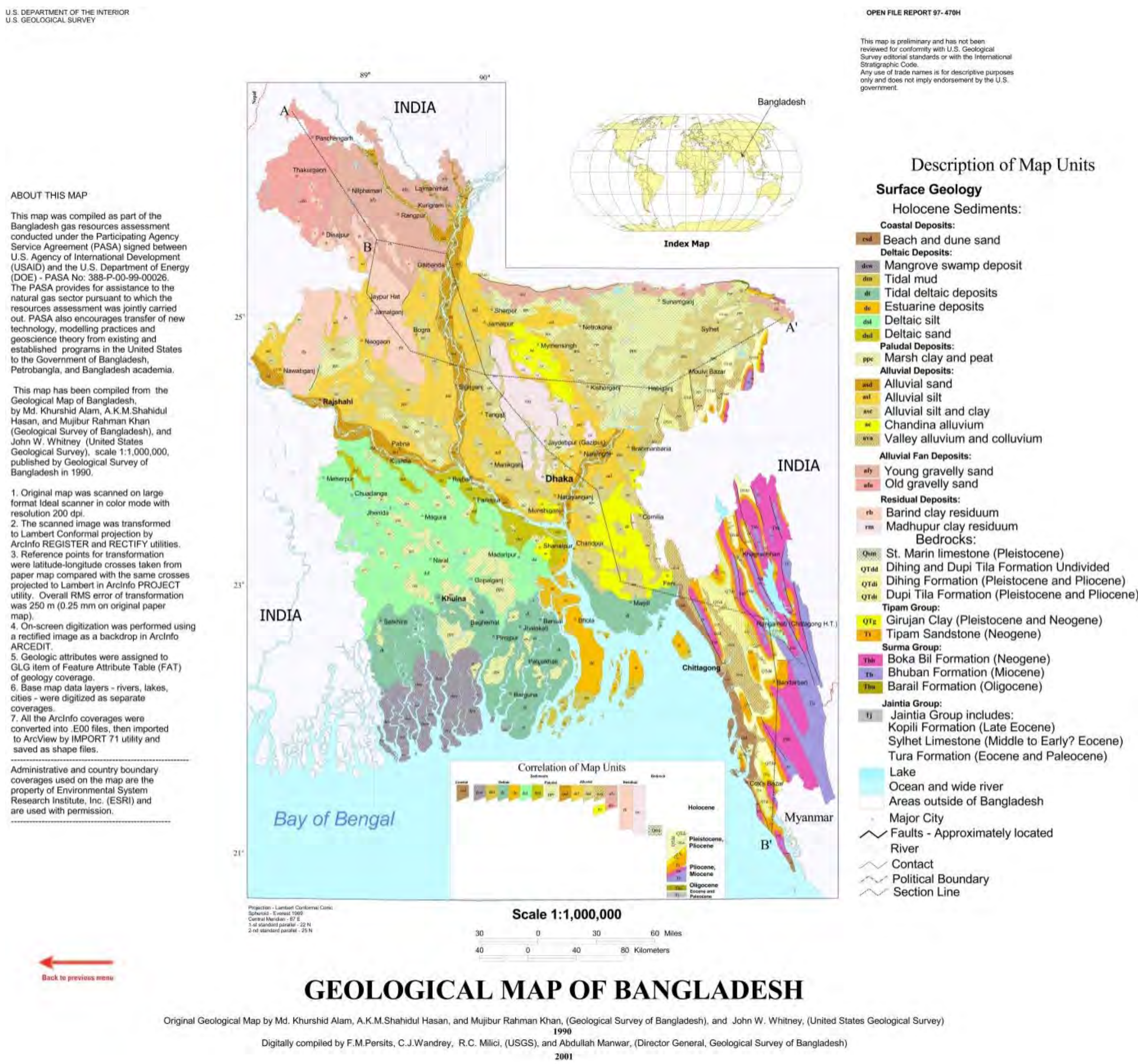

Figure 3.4: Geological Map of Bangladesh (Source: Alam et al., 1990)

Uniformity of lithological composition, presence of textured sediments and the stratigraphic position have been considered for differentiating the aquifer and aquitard units including their various depth locations in the study area. Accordingly, up to the studied depth, a total of 9 hydrostartigraphic unis were defined (Table 3.1). Chronologically, near surface unit is named as top soil/clay and remaining six are alternate of aquitard/aquiclude and aquifer units. Near surface first aquifer layer is composed of medium sand with admixture of occasional coarse and fine sand flatly lie below the topsoil and composite aquitard formation.

At the base, low permeable silty-clay layers beyond the layer, where as it is hydraulically continuous with the middle layer but at some places discontinuous due to intermittent clay layers between them. The second coarse sand and occasional gravel layer extends for a considerable thickness. Another aquifer layer exists as the third or lower aquifer separated by a layer of aquiclude from the second aquifer layer. This aquifer is confined in nature and water quality is different from other two layers. The second and third aquifer layers are composed of coarse sand and occasional gravel making it an excellent aquifer with high hydraulic conductivity and storage coefficient.

There is another aquifer layer beneath the Lower Dupi Tila Aquifer. Locations of the deeper drill holes of DWASA production wells are mostly in the western part of the city. Hydrostratigraphic cross section evidenced the existence of the fourth aquifer in the wide area of the city. In the explored boreholes, the maximum thickness of this fourth aquifer layer is 70m (Rahman et al., 2013). Static piezometric head is minimum 17.53 m and maximum 25.46 m. Analyses of so far gathered data reveal that the fourth aquifer is a prolific aquifer and merits for further detail study without constructing production wells in an indiscriminate manner. Otherwise, it may lead to an imbalanced groundwater withdrawal and ultimately cause aquifer mining (Arefin, 2020).

Abstraction is the main discharge from the Dhaka Aquifer system. Stratigraphically the upper aquifer is in direct hydraulic connection with the surrounding rivers, particularly the Buriganga River (Rahman et al., 2013). These rivers could have a significant role in the aquifer recharge but not in reality, because of human activities like river encroachment, water pollution etc. DWASA has been abstracting most supply water from the different horizons of both the first and second aquifer units of the upper Dupi Tila Aquifer system. But due to the increasing drawdown of groundwater level, piezometric surface of shallow aquifer systems has fallen more than 50 m which compelled to avoid first aquifer layer in most of the areas. Presently, DWASA is abstracting groundwater from the 3rd and 4th aquifer layers of the Dupi Tila Aquifer system (DWASA, 2018).

3.6 Aquifer Recharge Process

Groundwater recharge condition of Dhaka city is not similar to that of other parts of the country. During wet season in other parts, the unconfined to semi-confined types of aquifer layers gain most recharge through vertical percolation from precipitation and surface runoff. However, in Dhaka, the aquifer layers are covered by a thick Pleistocene clay layer and the top surface area is also covered with impervious surfaces, such as roads and buildings, which are man-made in general. The clay layer and impervious surface completely restrict or retard any form of vertical percolation. Therefore, the Dhaka aquifer gains most of its recharge volume through underground horizontal inflow (Islam et al., 2017). However, this horizontal inflow is not sufficient to maintain groundwater balance considering the current rate of abstraction.

Declining groundwater table makes pumping of groundwater more costly and technically difficult. This results in lower water security. Furthermore, such abstraction activity causes groundwater quality hazard due to intrusion from nearby polluted river water. In this regard, the surrounding rivers of Dhaka are severely polluted from discharge of industrial effluent, domestic sewage, untreated drainage runoff, etc. The situation demands recharging of freshwater zones in declining water table areas with artificial means to maintain the groundwater table at optimum levels (Zahid, 2015).

From all operational data and monitoring studies (DWASA, 2014), it is evident that the Deep Tube Well (DTW) pumping volume is much higher than the recharge volume and safe yield. This leads to over-abstraction. The volume of groundwater that is extracted is from aquifer storage and constitutes aquifer mining. However, such mining compromises sustainability of the aquifer and in turn, long-term future of Dhaka.

Dependence on groundwater has increased many folds and natural recharge of groundwater has decreased due to urbanization and subsequent extraction to meet the incident need, construction of buildings and paved area, etc. Such over-development of groundwater is resulting in declining of groundwater level (DWASA, 2014).

Chapter Four

Methodology and Data Collection

4.1 General

This study investigates the declination trends in GWL in Dhaka city. Over exploitation for a rapid growth of population is causing the depletion. Due to continuous pumping from aquifer, there is not enough time to replenish and recharge. This study targets to determine the trends in GWL from the secondary data collected from BWDB and DWASA. This study also visualizes the severely depleted zone by plotting trend of GWL contour map. Primary data is collected from Semi Structured Interviews and Key Informant Interviews to arrest the declining situation and to provide some adaptation strategies to overcome the situation.

In the second section of this chapter, methodology for the declination of groundwater level (GWL) and trend analysis of GWL is discussed. After that, methodology to assess the DWASA‘s practices to meet the city water supply and to arrest the GW depletion is described elaborately. In the last section, the methodology to propose future adaptation options is discussed. The study was conducted by followingtechnical as well as socio-economic analysis. A framework showing different steps ofthe methodology adopted in the study is given in Figure 4.1.

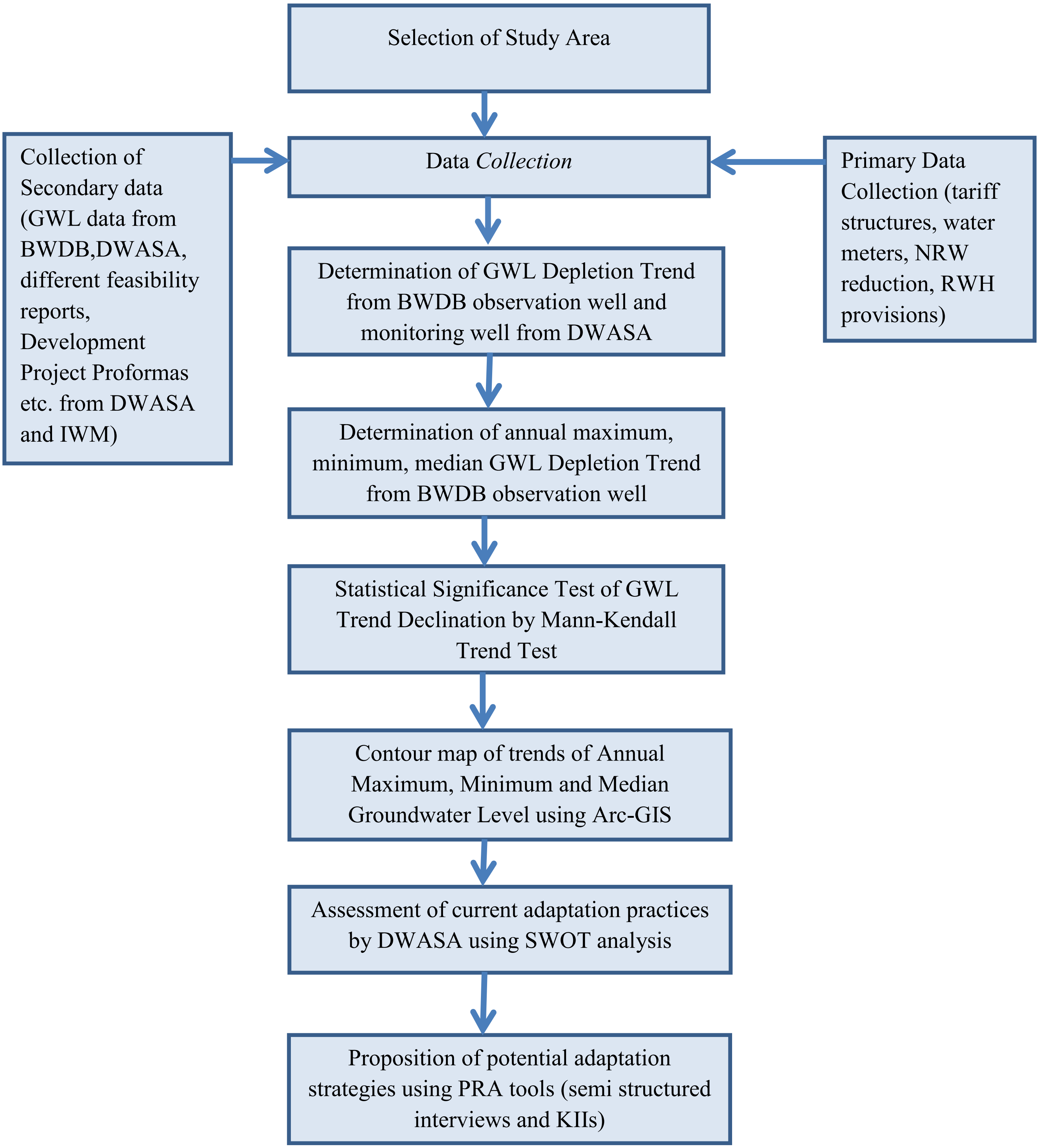

Figure 4.1: Methodological Framework of the Study

Groundwater is of course a valuable natural resource for the people of Dhaka City as surface water such as lake, river, reservoir etc. are not accessible to them sufficiently. People of Dhaka City depend on groundwater specially to meet their urgent daily needs. But the present conditions of groundwater in the city are not favorable for its population. In many parts of the city there is scarcity of pure water. This study shows that the groundwater in Dhaka city is declining at an alarming rate. The continuous over withdrawal of ground water and irregular and insufficient recharge causes depletion of groundwater. Rapid growing urbanization in the past 30 years also contributed to the present condition of Dhaka City. Moreover, the demand is increasing day by day and a few chances of improving the situation are there. The volume of groundwater in storage is decreasing in many areas of the Dhaka City due to permanent over pumping. Thus it has become obligatory to find out solutions for improvement. Therefore, scientific research on groundwater depletion in Dhaka City is very crucial to bring out fruitful solutions.

4.2 Data Collection

Primary data has been collected for assessing adaptation options to reduce groundwater level declination and for better water management in Dhaka city. Secondary data was collected for assessing groundwater level declination trend and mapping of groundwater level trend with the available time series data. Other secondary information such as various study reports, water production, tubewell nos. etc. has been collected from various government and non-government organizations.

4.2.1 Primary data collection

Key Informant Interview (KII) was used to consult about the justification of current practices by DWASA. Also future potential adaptation strategies are discussed for better water supply management (Photo 4.1 - 4.2). KII is an important method for collecting information on the overall aspects of the study basedon observation and experience. KIIs were conducted to gatherboth qualitative and quantitative information on groundwater depletion and how DWASA and their consumers cope up with water shortage over time. A list of interviews conducted isshown in Table 4.1 and views of key informant interviews with Director (Technical) and Deputy Project Director of Saidabad Surface Water Treatment Plant (Phase – III) are shown in Photo 4.1 and Photo 4.2, respectively.

Semi Structured Interview with consumers of DWASA from different MODS Zones (Table 4.2) has been conducted to compare the overall water supply scenario from severe groundwater depleted areas (Photo 4.3).

Table 4.1: List of Interviews with the Key Informants

Date	Location	Respondents
2 March,2020	Ground Water Hydrology, Bangladesh Water Development Board	Dr. Anwar Zahid Director, Ground Water Hydrology, Bangladesh Water Development Board
10 March, 2020	Department of Geology, University of Dhaka.	Dr. Kazi Matin Uddin Ahmed, Professor, Department of Geology, University of Dhaka
22 December, 2020	DWASA Bhaban, Karwan Bazar, Dhaka	Mr. A.K.M Shahid Uddin, Director (Technical), DWASA
23 December, 2020	DWASA Bhaban, Karwan Bazar, Dhaka	Mr. Md. Nurul Islam, Project Director, Emergency Water Supply Project, DWASA

23 December, 2020	DWASA Bhaban, Karwan Bazar, Dhaka	Mr. S.M. Mostafa Kamal Mozumder, Deputy Project Director, Saidabad Surface Water Treatment Plant (Phase – III), DWASA
30 December, 2020	Virtual platform	Dr. Sabbir Mostafa Khan Professor, Department of Water Resources Engineering, BUET
8 January, 2021	Virtual platform	Mr. Md. Zahid Hossain, Program Specialist Engineer, WaterAid Bangladesh

Photo 4.1: View of a KII with Director (Technical), Dhaka WASA (Photo taken on 22.12.2020)

Photo 4.2: View of a KII with Deputy Project Director, Saidabad Surface Water Treatment Plant (Phase – III), DWASA (Photo taken on 23.12.2020)

Table 4.2: List of Semi Structured Interviews at Different Zones

Date	Location	Respondents
6 Dec, 2020	Maniknagar (Zone – 01)	Nasrin Akter Deputy Director Department of Women Affairs
8 Dec, 2020	Lalbagh (Zone -02)	Monzurul Hasan M.Sc Student, BUET.
19 Dec, 2020	Lalmatia (Zone – 03)	Md. Ashraful Millat Businessman

28 Dec, 2020	Technical, Mirpur -01 (Zone -04)	Mohammad Golam Baki Ibn Hafiz Sub- Division Engineer Public Works Department
19 Dec, 2020	Tejkunipara (Zone-05)	Md. Mehedi Hasan Manager,Bkash Limited
2 Jan, 2021	Iskaton Garden (Zone – 06)	Sathi Sikhdar Housewife
8 Dec, 2020	Jatrabari (Zone - 07)	Md. Obaidul Hoque Electrician, Nova Electronics
21 Dec, 2020	Aftafnagar (Zone -08)	Abdur Rahim Sub-Divisional Engineer Power Grid Company Bangladesh
21 Dec, 2020	Kaolar (Zone -09)	Shahnaz Akter Housewife
28 Dec, 2020	Mirpur -10 (Zone -10)	Anwar Hossain Assistant Engineer, Dhaka WASA

Photo 4.3: Views of semi structured interviewwith the Consumers of DWASA (Photo taken on 02.01.2021, Zone - 06 and 19.12.2020, Zone - 03)

4.2.2 Secondary data collection

Groundwater Level Data

Ground Water Hydrology (GWH) of Bangladesh Water Development Board (BWDB) has water level monitoring network of 1250 piezometers throughout the country. 21 nos. of such piezometric observation wells within Dhaka city is considered to assess the declining trend of groundwater level. Detailed information of these piezometers is given in Table 4.3.

Table 4.3: Detailed Information on Observation Wells Used in This Study (Source: BWDB)

Well ID	Location	Thana	Latitude	Longitude	Data Available
2614004	Shaha Balishwa	Dhamrai	23.97	90.19	6/6/1977- 13/06/2016
2672018	Subandi	Savar	23.92	90.31	1/1/1979- 16/09/2019
2614002	Bannal	Dhamrai	23.87	90.22	1/5/1970- 28/10/2019
2672017	Savar	Savar	23.87	90.31	17/02/1975- 11/11/2019
2638008	Bamonsur	Keraniganj	23.69	90.34	7/6/1976- 5/8/2019
2662016	Paragram	Nawabganj	23.68	90.13	7/6/1976- 20/08/2007
2662015	Nawabganj School	Nawabganj	23.66	90.21	16/06/1975- 20/11/2017
2618006	Dayagajaria	Dohar	23.58	90.14	21/11/1977- 3/09/2018
2608001	Joar Shahara	Cantonment	23.83	90.42	1/7/1991- 24/09/2018
2616005	Green road	Dhanmondi	23.74	90.37	1/1/1990 -28/10/2019
2650012	Sultangonj	Mohammadpur	23.76	90.36	20/2/1978- 19/03/2012
2618007	Sundaripara	Dohar	23.60	90.10	2/1/1978-27/06/2016
2614003	Dhamrai	Dhamrai	23.91	90.22	6/1/1975-25/4/2016
2654013	Maniknagar	Motijheel	23.73	90.42	13/02/1978- 30/12/1991
2642009	Baksibazer	Lalbagh	23.72	90.41	19/05/1980- 27/08/2012
2648010	New Sewrapara	Mirpur	23.79	90.37	5/1/1970-26/08/2019
2650011	Mohammadpur	Mohammadpur	23.75	90.37	05/12/1977- 14/10/2019
2654014	South Khilgaon	Motijheel	23.75	90.42	25/12/1989-7/2/1979
2668019	Khilgaon	Sabujbagh	23.75	90.43	20/03/1978-25/11/2019
2668020	South Bashabo	Sabujbagh	23.73	90.44	29/06/2009- 7/2/1979
2688021	Jaganath University	Sutrapur	23.70	90.42	5/1/1970-23/08/2010

DWASA has installed 19 groundwater level monitoring wells to observe groundwater level from 2016 to 2017. These groundwater level data from monitoring wells have been collected from Planning and Development (Water & Hydrology) Division, DWASA. Detail description of monitoring well is given in Table 4.4.

Table 4.4: Detailed Information on Observation Wells Used in This Study (Source: DWASA)

Well_ID	Latitude	Longitude	Location	Data Available From	Data Available To
GMW-01	23.89	90.45	Moinertek, Uttar khan	1-Oct-16	26-Apr-19
GMW-02	23.88	90.37	Dia Bari, Uttara	12-Mar-16	26-Apr-19
GMW-03	23.83	90.42	Kha-84/Tanpara, Nikunja	19-Mar-16	26-Apr-19
GMW-04	23.83	90.48	Mastul, Khilkhet	22-Mar-16	26-Apr-19
GMW-05	23.80	90.47	Beraid, Vatara	1-Oct-16	26-Apr-19
GMW-06	23.78	90.35	Bangla Collage, Mirpur	8-Mar-16	25-Apr-19
GMW-07	23.79	90.41	BWDB Officers Qtrs, Banani	8-Mar-16	26-Apr-19
GMW-08	23.76	90.36	Ashraful Madrasa Mohammadpur	22-Mar-16	25-Apr-19
GMW-09	23.75	90.42	Khilgaon H/School	1-Mar-16	26-Apr-19
GMW-10	23.70	90.42	WASA Staff Qtrs, Gandaria	19-Mar-17	27/Apr/19
GMW-11	23.72	90.50	Sarulia Intake	8-Mar-17	27-Apr-19
GMW-12	23.67	90.48	DWASA Staff quarter, Pagla	14-Mar-17	27-Apr-19
GMW-13	23.67	90.52	Adamjinagar, Siddirgonj	29-Mar-16	27-Apr-19
GMW-14	23.65	90.51	Godenail, Siddirgonj	29-Mar-16	27-Apr-19
GMW-15	23.63	90.51	Twin OHT Khanpur	14-Sep-17	27-Apr-19
GMW-16	23.88	90.42	Atipara, Dakkhinkhan	1-Jul-16	26-Apr-19
GMW-17	23.76	90.47	Nasirabad High School, Khilgaon	15-Aug-16	26-Apr-19
GMW-18	23.84	90.34	Goranchatbari Pump House, Rupnagar	26-Oct-16	30-Apr-19
GMW-19	23.71	90.38	Matbor Bari Mosque, Kamrangirchar	4-Dec-16	25-Apr-19

Other Secondary Data

Other information has been gathered from government and non-government organizations. Water production by DTWs, present tariff structure, depth of DTWs etc. has been collected from DWASA. Various study reports, Development Project Proformas, feasibility reports etc. have also been collected from IWM and DWASA.

4.3 Assessment of Groundwater Level Depletion Trend

4.3.1 Simple linear regression method

Simple linear regression analysis is a common and major parametric method applied for observing the monotonic trend in data series. It is often carried out to develop an association between two variables (independent and dependent) by fitting a linear equation to the observed data, which shows the average periodic variation of the measured parameter. Positive gradient indicates rising trend, whereas negative gradient indicates falling trend.

It is an equation of the form Y = a + bX, where X is the explanatory variable and Y is the dependent variable.

4.3.2 Statistical method for trend analysis

Mann Kendall Test

The Mann–Kendall (MK) test (Kendall, 1955; Mann, 1945) is a non-parametric test, which does not require the data to be distributed normally. The second advantage of the test is its low sensitivity to abrupt breaks due to in homogeneous time series (Tabari et al., 2011). The MK test has been widely used by various researchers for detecting the trends in rainfall (Kumar et al., 2010; Mann, 1955; Partal and Kahy, 2006). The test has also been popularly used to assess the significance of the trend in hydrological time series (Yue and Wang, 2004). The test requires sample data to be serially arranged.

The MK statistic, S, is defined as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(X_j - X_i) \quad \text{.......................................(4.1)}$$

where, X_1, X_2, X_3…………., Xn represents n data points where Xj represents the data point at the time j of data (time series); and Xj - Xi = θ

$$\text{sgn}\,\theta = \begin{Bmatrix} 1\ if\ \theta > 0 \\ 0\ if\ \theta = 0 \\ -1\ if\ \theta < 0 \end{Bmatrix} \quad \text{.......................................(4.2)}$$

Under the assumption that the data are independent and identically distributed, the mean and variance of the S statistic in Eq. (4.2) are given by Kendall (1975) as (Dinpashoh et al., 2011):

E = [S] = 0

$$Var\ (S) = \frac{n\ (n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \quad \text{……………………………………………} (4.3)$$

where m is the number of groups of tied ranks, each with t_i tied observations. The original MK statistic, designated by Z and the corresponding P-value (p) of the one-tailed test was computed as:

$$Z = \begin{Bmatrix} \frac{S-1}{\sqrt{Var\ (S)}} & If\ S > 0 \\ 0 & If\ S = 0 \\ \frac{S+1}{\sqrt{Var\ (S)}} & If\ S < 0 \end{Bmatrix} \quad \text{…………………………………………………………} (4.4)$$

$$p = 0.5 - \emptyset(|Z|)$$

$$\emptyset(|Z|) = \frac{1}{\sqrt{2\pi}} \int_0^{|Z|} e^{\frac{-t^2}{2}}\ dt \quad \text{……………………………………………….. } (4.5)$$

If the p-value is small enough, the trend is quite unlikely to be caused by random sampling. The Z values are approximately normally distributed, and a positive Z value larger than 1.96 (based on normal probability tables) denotes a significant increasing trend at the significance level of 0.05, whereas a negative Z value lower than -1.96 shows a significant decreasing trend.

Modified Mann Kendal Test

The proposed modification of the Mann Kendall trend test is based on the assumption that data are autocorrelated and therefore the autocorrelation is estimated from the data. When the data are actually independent, the assumption of autocorrelation may lead, in some cases, to failure to identify true trends, thus reducing the power of the test. This is due to the uncertainties in evaluating the autocorrelation in the data, especially with small samples. A theoretical relationship is derived for evaluating the variance of the Mann-Kendall statistic S for data with autocorrelation. A modified trend test, which is robust in the presence of autocorrelation in the data is proposed based on the modified variance of S.In Modified Mann-Kendall test, the effect of all significant autocorrelation coefficients is removed from a data set (Hamed and Rao, 1998). For this purpose, a modified variance of S, designated as Var(S)*, was used as follows:

$$Var\ (S)^{*} = V\ (S)\frac{n}{n^{*}} \quad \ldots\ldots (4.6)$$

where, n*= effective sample size. The n/n* ratio was computed directly from the equation proposed by Hamed and Rao (1998) as:

$$\frac{n}{n^{*}} = 1 + \frac{2}{n(n-1)(n-2)}\sum_{i=1}^{n=1}(n-1)(n-i-1)(n-i-2)ri \quad \ldots\ldots (4.7)$$

Where, n= actual number of observations: and ri=lag-1 significant autocorrelation coefficient of rank i of time series. Once Var(S)* was computed from Eq. (4.6), then it is substituted for Var(S) in Eq. (4.4). Finally, the Mann-Kendall Z was tested for significance of trend comparing it with threshold level at 5% level of significance which is about 1.96.

Sen's Slope Estimator

If a linear trend is present in a time series, then the true slope (change per unit time) can be estimated using a simple nonparametric procedure developed by Sen (1968). It has been widely used for determining the magnitude of the trend in hydro-meteorological time series

(Tabari et al., 2011; Tabari et al., 2015). In this method, the slope estimates of N pairs of data are first calculated using the following expression as:

$$Q_i = \frac{X_j - X_k}{j-k} \quad for\ i = 1,2,3, \dots \dots, n \qquad \dots \dots (4.8)$$

where, Xj and Xk are data values at time j and k (j>k) respectively. The median of these N values of Qi is Sen‘s estimator of slope which is calculated as:

$$\beta = \begin{Bmatrix} Q_{\left[\frac{N+1\left[\frac{N}{2}\right]}{2}\right]} & N\ is\ odd \\ \frac{1}{2}\ (Q + Q_{\frac{(N+2)}{2}} & N\ is\ even \end{Bmatrix} \qquad \dots \dots (4.9)$$

A positive value of β indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series data.

In this study, significance of groundwater level trend has been computed using Normalized Test Statistics Z, Var(S) and Man Kendall Statistics (S). Furthermore, MK is used to detect the trend of groundwater level with Sen's slope estimator. Entire time series is segregated into two parts, e.g., dry and monsoon seasons during 1970 to 2019 (available data). Further, general statistical parameters, i.e., mean, standard deviation, Kendall‘s tau, Normalized Test Statistic Z have been calculated for each station for both dry and monsoon periods. Further, each time series has been treated as a separate set for the MMK test and for estimating Sen‘s slope.

Data analysis is undertaken using statistical software XLSTAT on excel spreadsheet. The following steps were followed in data analysis:

- Data sorting is done by averaging the groundwater level according to dry season (November to May) and monsoon season (Juneto October).

- Mann – Kendall Trend test is conducted at 5 % significance level.
- If P value <0.05, that means the test is acceptable for that particular observation well and trend exits.
- Nature of the trend (increasing/decreasing) has been estimated by M-K Statistics S, Normalized Test Statistics Z and Sen's slope.
- M- K Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

If the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha. The risk to reject the null hypothesis H0 while it is true is lower than 0.01%. Views of data analysis in XLSTAT are given in Figures 4.4 and 4.5.

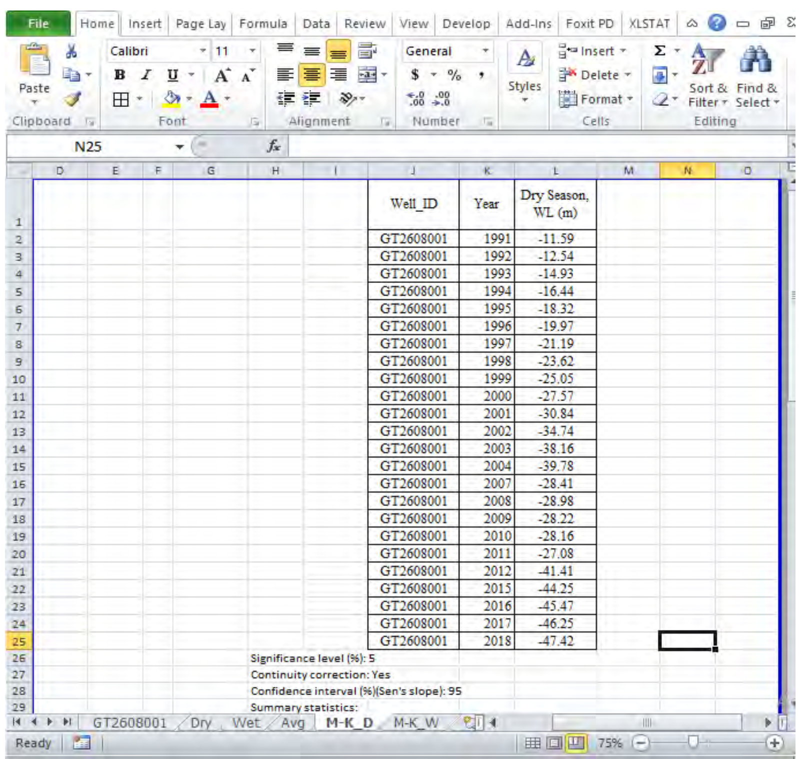

Photo 4.4: A View in XLSTAT after the Input of GWL Data

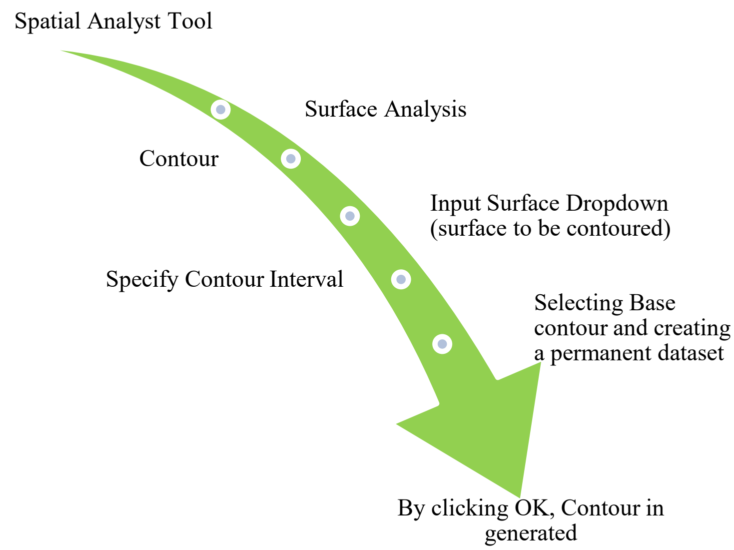

Figure 4.2: Steps followed in Generation of Contour Map with ARC-GIS

4.4 Identification and Assessment of Current Practices by DWASA

By interviewing the key experts and studying the relevant reports on various projects, the current practices adopted by DWASA have been identified. Later by using SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis, each practice is assessed to stand for future adaptabilities.

SWOT Analysis is a decision making method that has been widely used in business management. SWOT analysis also has successfully been applied in identifying and solving problems related with water resource management which often involve interdisciplinary issues that are difficult to quantify (Kallioras et al. 2010; Mainali et al. 2011). In a similar manner, SWOT analysis will be applied to evaluate each water solution. This method is selected because it has the capacity to incorporate not only the present conditions (through strengths and weaknesses) but also the future conditions (through opportunities and threats) which are very important for Asian and African countries that are undergoing rapid changes especially in terms of population and economic development. The present research adopts an expert interview approach to gather information. Knowledge and information collected through interviews with relevant experts are used as the main input for the SWOT analysis.

Expert interviews have been a popular method of gathering information in various fields of sciences as it can provide insight and valuable knowledge in the relevant field and it is also considered as an efficient and concentrated method of gathering data especially in exploratory phase (Bogner et al. 2009). Selecting the relevant experts is essential to gather usable information and successfully construct framework for analyzing different water solutions. The experts interviewed for this research compose of people that work closely in the area of water and environmental sciences.

4.5 Identification of Potential Adaptation Options

Severe water stressed areas in respect to groundwater depletion are identified from regression analysis and contour map. After that, a number of KIIs, and semi structured interviewsare conducted with key officials, groundwater experts, academicians of various universities, etc. This provided information about future potential adaptation options. These options are ranked according to the emphasis put by the respondents. From these a number of potential adaptation options are proposed for better water supply management with a view to reduce groundwater depletion by DWASA.

Chapter Five

Groundwater Level Declination Trends in Dhaka City

5.1 Present Situation of Groundwater Deep Tube Wells

Over the years the number of DTWs in Dhaka city has been increased enormously. At present 68% of the total supplied water is provided from around 920 wells which were more than 88% before the introduction of Saidabad Phase - IISWTP. Every year more numbers of new DTWs are installed to meet the increasing demand of thecity. Over the years, the increasing trend of DTW in Dhaka city is shown in Figure 5.1.

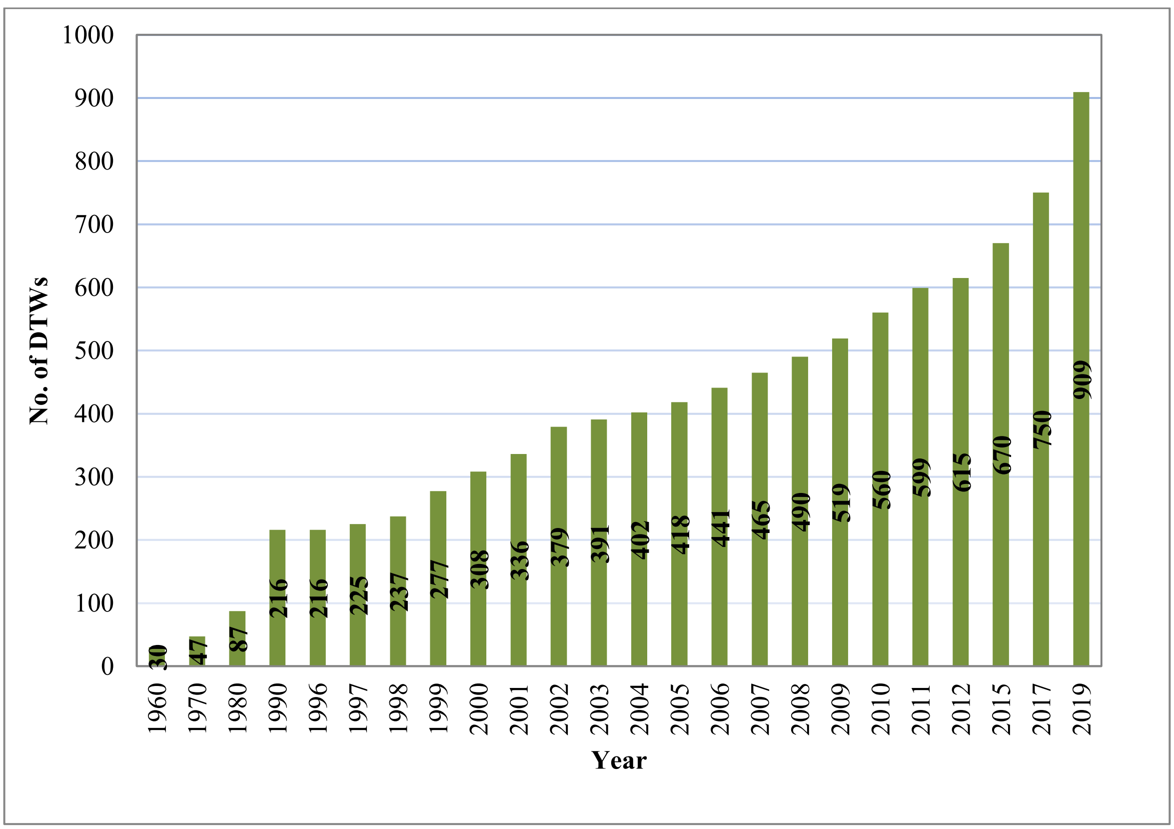

Figure 5.1: Increasing Number of DTWs in Dhaka City over the Years

The gradual mining depth of DTWs for water extraction is shown in Figure 5.2.It is seen thatmining depth for DTW has an increasing trend. The depth of DTW indicates at which level groundwater is extracted from ground level. The depth is taken as an average value of extracted groundwater level for each year. For instance, in 1960 the depth from ground level was 60 m and in 2019the depth has reached to 375 m. Some DTWs are used to extract water from a depth of 375 meterswhich is an alarming situation.

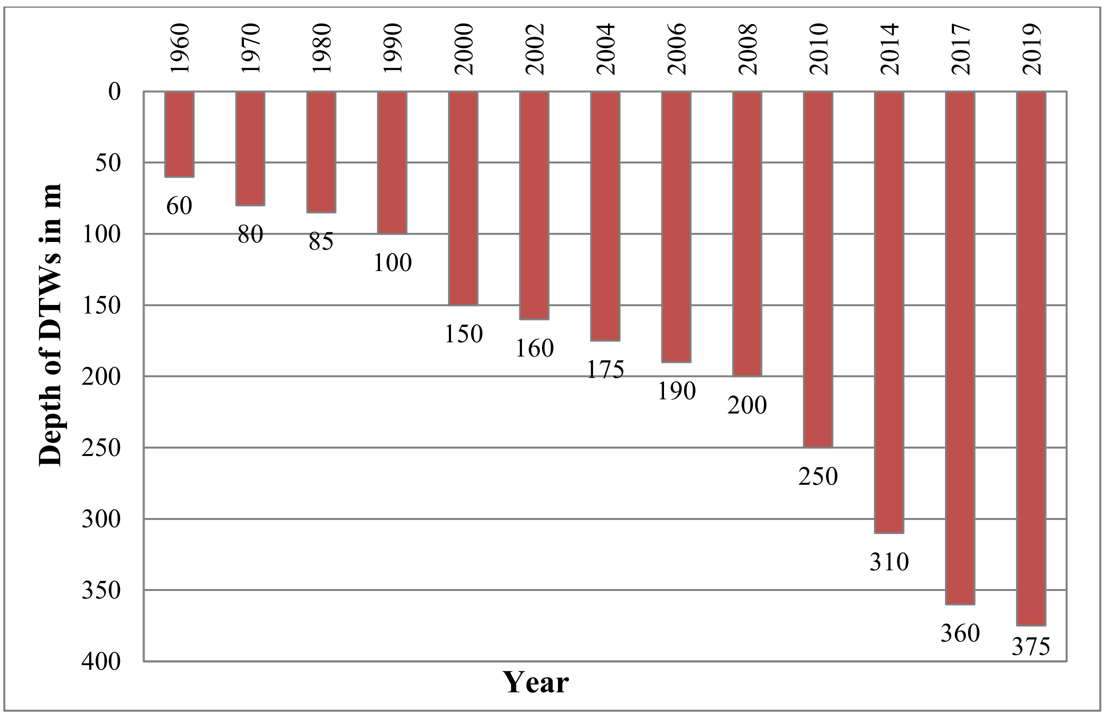

Figure 5.2: Gradual Increase in Mining Depth of DTWs

To determine the depletion rate, trends of groundwater hydrograph has been analyzed and contour map of groundwater level has been plotted to spot the severely depleted area.

5.2 Long Term Groundwater Level Hydrograph of Upper Dupi Tila Aquifer (Observation Wells from BWDB)

Groundwater level hydrographs of observation wells have been constructed by plotting depth to groundwater level against time for the shallow aquifer. A typical hydrograph is shown in Figure 5.3. All the hydrographs are given in Appendix A.

Linear regression model is developed for groundwater level for observation well of the available data showing the R squared value and the rate of change in groundwater level which is indicated by the slope of the regression line. Summary of the groundwater level from the available observation wells is presented in Table 5.1.

Depending on the frequency of water level measurement and period of hydrologic record, water level hydrographs has been constructed to illustrate the historical water levels, compare the recent and historical water level data and to present of the descriptive statistics for water level measurements.

Table 5.1: Trends in Groundwater Levels from Observation Wells of BWDB

Well ID	Location		Number of Data Points	Minimum Value	Maximum Value	Mean	Standard Deviation	Rate of Depletion/ Augmentation m/yr	R^2 Value
2614004	Shaha Balishwa	Dhamrai	24	-47.42	-11.59	-29.18	10.97	-0.03	0.06
2672018	Subandi	Savar	47	1.42	7.31	4.46	1.76	-0.66	0.63
2614002	Bannal	Dhamrai	40	-1.86	3.31	0.64	1.16	-0.07	0.2
2672017	Savar	Savar	38	3.23	6.1	4.73	0.61	-0.26	0.48
2638008	Bamonsur	Keraniganj	24	-69.6	-4.7	-42.4	18.2	-0.47	0.48
2662016	Paragram	Nawabganj	40	-0.54	5.17	1.54	1.02	0.02	0.01
2662015	Nawabganj School	Nawabganj	37	1.14	2.45	1.93	0.31	-0.07	0.23
2618006	Dayagajaria	Dohar	39	-28.46	6.4	1.35	9.24	0	0
2608001	Joar Shahara	Cantonment	27	-37.42	5.87	-15.02	14.12	-1.13	0.76
2616005	Green Road	Dhanmondi	44	-68.07	0.36	-25.13	26.04	-1.79	0.74
2650012	Sultangonj	Mohammadpur	38	-60.57	-0.96	-18.52	16.28	-0.8	0.96

2618007	Sundaripara	Dohar	32	-22.6	0.28	-11.71	7.78	-0.01	0
2614003	Dhamrai	Dhamrai	14	-8.22	-1.42	-4.84	2.15	0.03	0.03
2654013	Maniknagar	Motijheel	11	-14.96	5.19	-2.74	9.11	-0.22	0.14
2642009	Baksibazer	Lalbagh	36	-6.04	3.23	1.2	1.53	-1.68	0.94
2648010	New Sewrapara	Mirpur	27	-1.78	0.81	0.27	0.51	-1.68	0.88
2650011	Mohammadpur	Mohammadpur	41	-13.92	5.47	1.55	4.58	-0.99	0.89
2654014	South Khilgaon	Motijheel	36	-27.38	7.19	-1.82	9.03	-2.63	0.89
2668019	Khilgaon	Sobujbag	31	-45.44	5.64	-14.95	15.12	-0.73	0.42
2668020	South Bashabo	Sobujbag	28	-55.28	5.44	-19.66	19.83	-2.15	0.97
2688021	Jaganath College	Sutrapur	40	-13.88	3.69	-5.08	6.14	-0.51	0.94

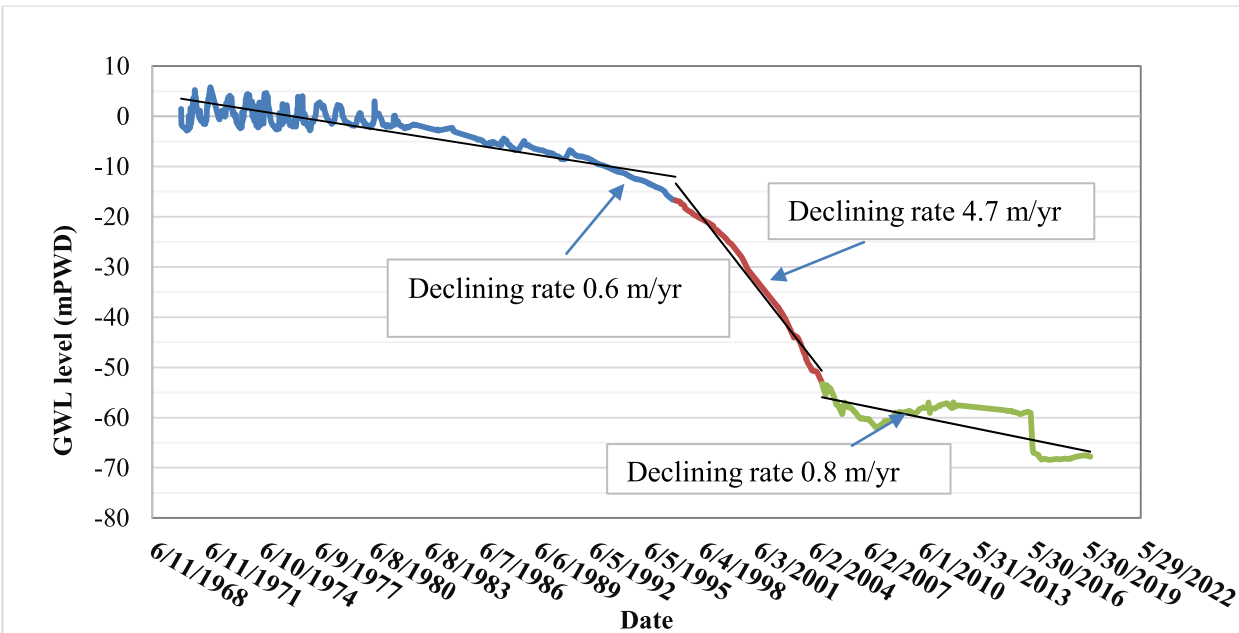

Figure 5.3: Hydrograph Showing Long Term Groundwater Declining Trend at New Shewrapra, Mirpur BWDB Well

Graphical plots showing changes in water levels over time using data collected from monitoring wells provide a visual representation of the range in water level fluctuations, seasonal water level variations and cumulative effects of short-term and long-term hydrologic stresses. To prepare a hydrograph, date of records is plotted along X-axis and groundwater table data in mPWD along Y-axis. Groundwater level data of Upper Dupi Tila Aquifer (UDA) system in Dhaka city demonstrates a steady downward trend. The gradual declining situation of groundwater level implies that the groundwater over-abstraction situation had started in the city area long before. In fact, the depletion started in early eighties. At present the depletion rate of the Upper Dupi Tila Aquifer in the city is about 2.5m to 4.5m per year (Figure 5.3). The over-abstraction situation causes the changes of upper aquifer characteristics from semi-confined to unconfined nature with increased vulnerability, risk and mining situation. In recent time groundwater level rise has been observed from the middle of 2007 to 2012. The rise in groundwater level in UDA happened due to the increase of abstraction from the deeper aquifer. Groundwater level in Mirpur area started declining gradually again from 2012. This situation may be attributed to the increased trend of private well abstraction.

5.3 Annual Maximum, Minimum and Median Groundwater Levels

Annual maximum, annual minimum and annual median groundwater levels for observation wells have been constructed by plotting the depth to groundwater level data against time for the shallow aquifer. Typical variations of such groundwater levels with time are shown in Figure 5.4 - Figure 5.6.All the variations are given in Appendix B.

Linear regression model is fitted to the groundwater level for each observation well with the available data showing the R squared value and the rate of change in groundwater level which is indicated by the slope of the regression line. Summary of the groundwater level from the available observation wells is presented in Table 5.2.

Annual maximum groundwater level of each year from an observation well at Green Road, Dhanmondi is plotted against year in Figure 5.4. The maximum groundwater level of the well represents a steady downward trend. The depletion rate is about 1.75 m per year. From the figure, it is seen that the groundwater level after 2010 increased slightly. It can have happened due to extraction of water from the deeper aquifer instead of the upper aquifer.

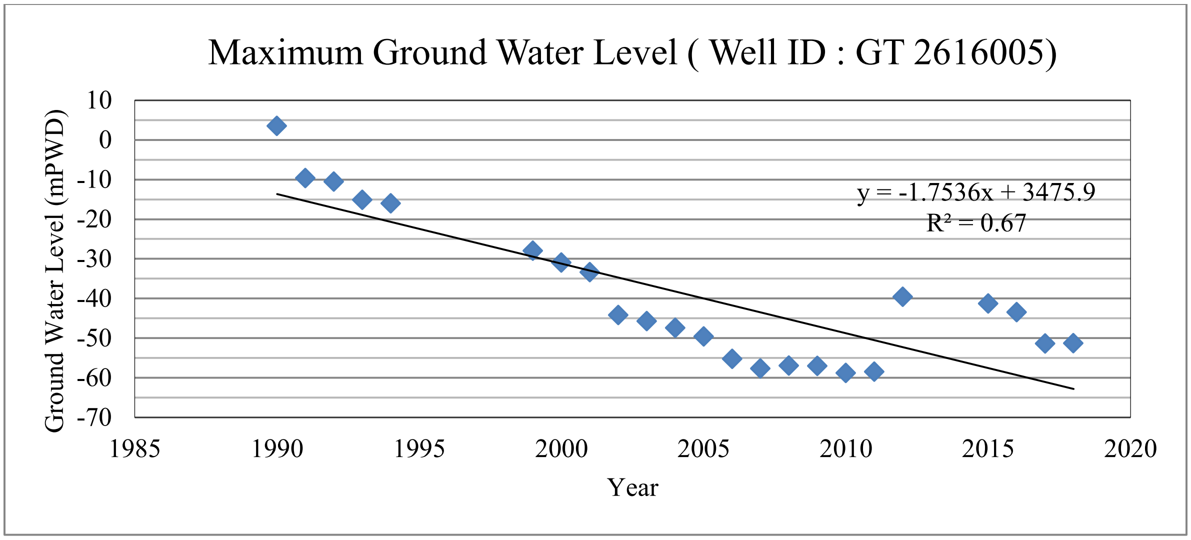

Figure 5.4: Trend in Annual Maximum Groundwater Level (Location: Well ID GT 2616005,Green Road, Dhanmondi)

Annual minimum and median groundwater levels from the same observation well at Green Road, Dhanmondi also represent a steady downward trend. The depletion rate is about 1.90 m per year for the minimum water level and 1.50 m per year for the median water level.

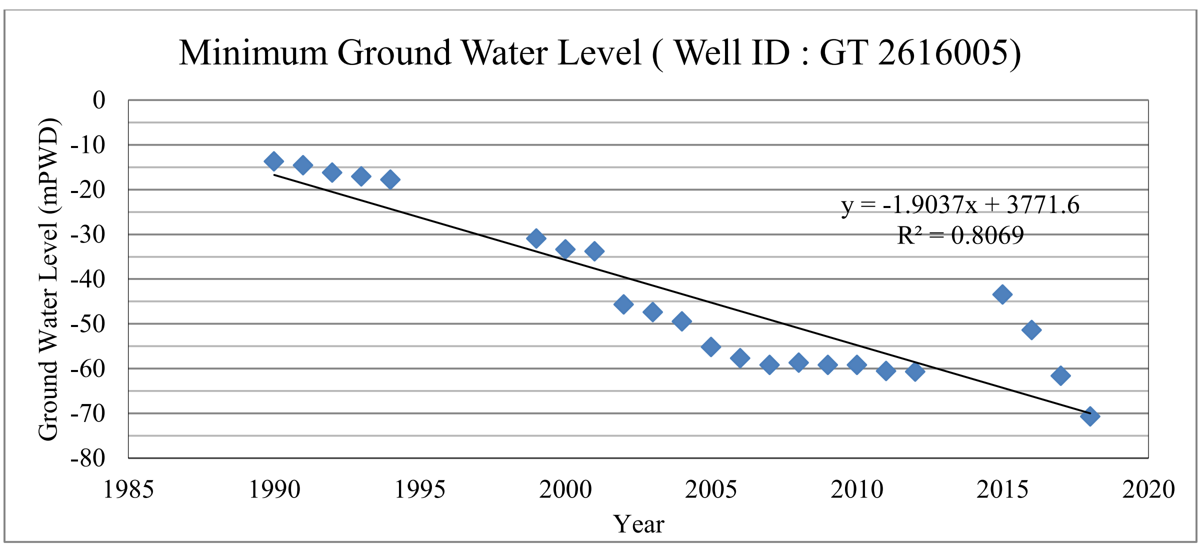

Figure 5.5: Trend in Annual Minimum Groundwater Level (Location: Well ID GT 2616005, Green Road, Dhanmondi)

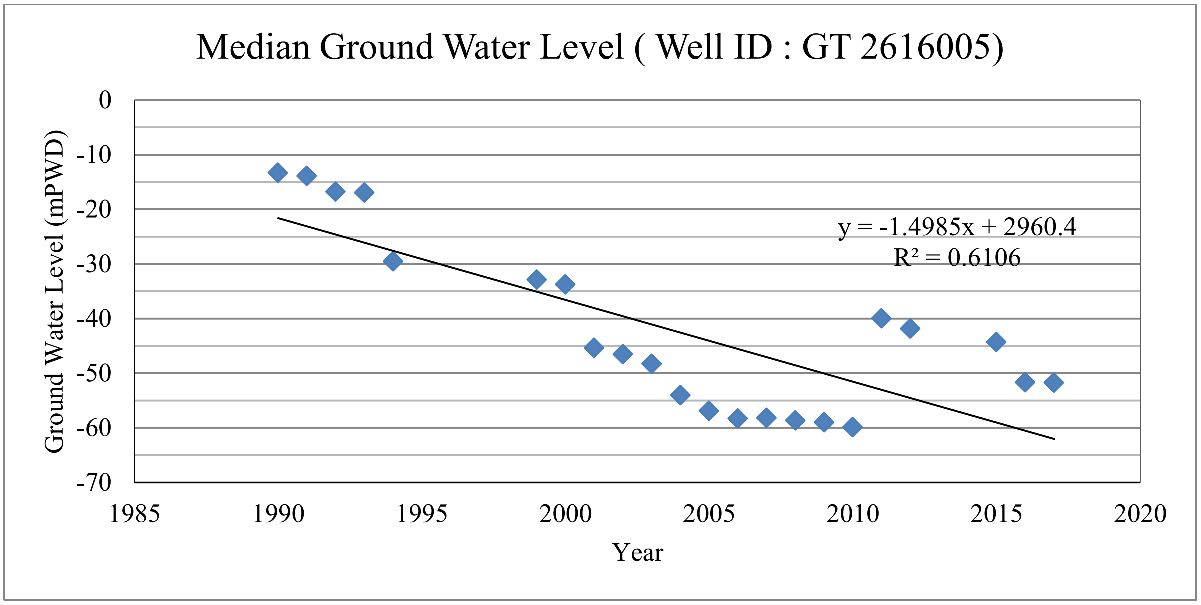

Figure 5.6: Trend in Annual Median Groundwater Level (Location: Well ID GT 2616005,Green Road, Dhanmondi)

Table 5.2: Trends in Annual Maximum, Minimum and Median Groundwater Levels for Available Observation Wells

Well ID	Location		Maximum GWL		Minimum GWL		Median GWL	
			Rate of Depletion/ Augmentation	R^2 Value	Rate of Depletion/ Augmentation	R^2 Value	Rate of Depletion/ Augmentation	R^2 Value
2614004	Shaha Balishwa	Dhamrai	-0.043	0.263	-0.050	0.431	-0.036	0.309
2672018	Subandi	Savar	-0.639	0.651	-0.577	0.624	-0.604	0.677
2614002	Bannal	Dhamrai	-0.043	0.178	-0.108	0.437	-0.083	0.457
2672017	Savar	Savar	-0.229	0.488	-0.221	0.465	-0.246	0.579
2638008	Bamonsur	Keraniganj	-0.406	0.489	-0.376	0.419	-0.389	0.431
2662016	Paragram	Nawabganj	0.027	0.052	0.058	0.202	0.014	0.029
2662015	Nawabganj School	Nawabganj	-0.106	0.437	-0.088	0.373	-0.074	0.304
2618006	Dayagajaria	Dohar	-0.002	0.001	-0.031	0.091	0.000	0.000
2608001	Joar Shahara	Cantonment	-1.192	0.780	-1.094	0.756	-1.136	0.763
2616005	Green Road	Dhanmondi	-1.754	0.670	-1.904	0.807	-1.499	0.611
2650012	Sultangonj	Mohammadpur	-0.822	0.973	-0.822	0.973	-0.822	0.973
2618007	Sundaripara	Dohar	-0.0203	0.0487	-0.0304	0.6859	-0.0133	0.0894
2614003	Dhamrai	Dhamrai	-0.027	0.041	-0.0647	0.3	0.04	0.13
2654013	Maniknagar	Motijheel	-0.137	0.054	-0.290	0.269	-0.241	0.171

2642009	Baksibazar	Lalbagh	-1.55	0.922	-1.57	0.92	-1.56	0.923
2648010	New Sewra Para	Mirpur	-1.696	0.881	-1.615	0.839	-1.619	0.851
2650011	Mohammadpur	Mohammadpur	-1.054	0.875	-0.992	0.918	-0.993	0.915
2654014	South Khilgaon	Motijheel	-2.486	0.836	-2.488	0.841	-2.562	0.833
2668019	Khilgaon	Sobujbag	-0.869	0.358	-0.909	0.403	-0.904	0.393
2668020	South Bashabo	Sobujbag	-2.133	0.974	-2.131	0.964	-2.123	0.972
2688021	Jagannath College	Sutrapur	-0.598	0.964	-0.449	0.928	-0.533	0.963

5.4 Short Term Groundwater Level Hydrographs (Monitoring Wells Installed by DWASA)

Groundwater (GW) table situation in and around Dhaka city and its seasonal fluctuation is an important parameter for groundwater resource budgeting, protection of GW quality from degradation and future planning for GW use. Piezometric head distribution in the aquifer system also provides valuable information on long term changes in pattern of GW fluctuations and reflects the availability of GW resource that could prove to be sustainable resource.
DWASA, with the help of IWM, has installed 19 twin monitoring wells in Dhaka. Most of the hydrographs of these wells show an overall declining trend due to over extraction than annual replenishment for both shallow and deeper aquifer systems.

Groundwater level declining situation has been observed almost in every monitoring well location. Rate of groundwater level declination varies from place to place ranging from cm to m. Though 1-1.5 years of data is not sufficient to get actual rate of declination, however presently recorded groundwater level data vividly shows the continuous declining situation of groundwater level of Dhaka city aquifer.

For example, groundwater level fluctuation data of monitoring wells of Khilgaon area has been plotted against time to draw groundwater level hydrograph (Figure 5.7). All the hydrographs are given in Appendix C. The hydrographs of Khilgaon area monitoring wells demonstrate that the shallow aquifer is under a hugely stressed condition due to excessive withdrawal of groundwater from that layer. There is a sharp difference in water level depth among the shallow and deep wells. Like monitoring wells of other areas, the deeper aquifer follows the regional condition of pressurized aquifer (condition of artesian aquifer). In both aquifers, water level follows a declining situation.

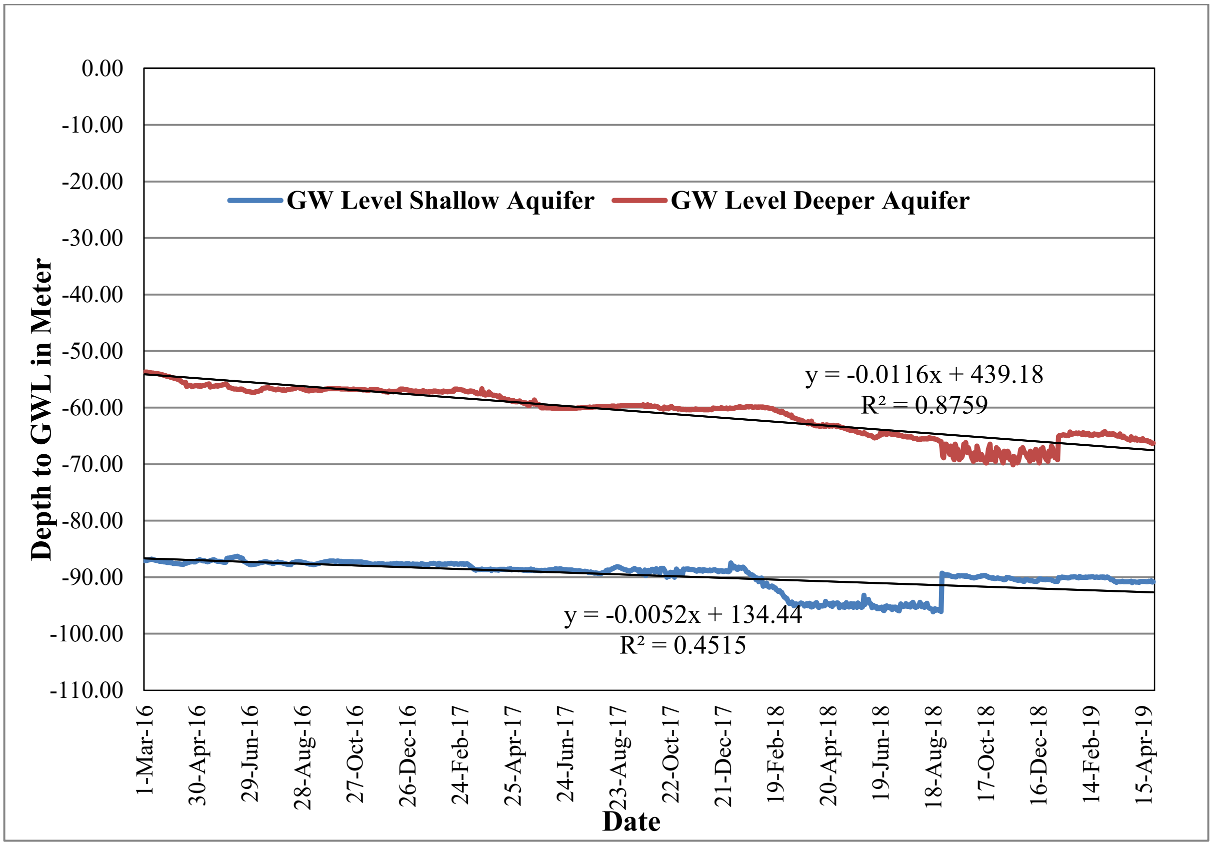

Figure 5.7: Hydrographs of Twin Monitoring Wells of Khilgaon High School Area

Groundwater level in shallow aquifer was at 87.3m depth from ground level on 1st March 2016 and the level was at 90.79 m on 26th April 2019 which is the highest. Around 1.50 m depletion is observed within eighteen months. So, linear depletion of 1.0 m per year is observed in shallow aquifer in the Khilgaon area. Maximum depth to groundwater level of this aquifer was 96.15 m from ground surface on 18th August 2018 and the minimum depth was 87.37 m on 9th March 2016 during this period.

Deeper aquifer on the other hand, is experiencing also declining situation with fluctuation started from 54.31 m on 1st March 2016 to 66.30 m on 26th April 2019. So, water level has declined by 11.99 m during this period and is following a 4.02 m per year declining situation. Maximum depth to groundwater level of this aquifer was at 70.12 m from ground surface and minimum depth was at 54.29 m.

All of the monitoring wells except GMW - 19 (KamrangirChar) show groundwater depletion. Summary of groundwater level depletion of all monitoring wells installed by DWASA is presented in Table 5.3. This table is prepared based on data availability of March 2016 to April 2019.

Table 5.3: Trends in Groundwater Levels from Monitoring Wells Installed by DWASA

Well ID	Location	Trend in GWL (m/year)		R^2 Value	
		GW Level of Shallow Aquifer	GW Level of Deeper Aquifer	GW Level of Shallow Aquifer	GW Level of Deeper Aquifer
GMW-01	Moinertek, Uttar Khan	-1.57	-2.45	0.95	0.95
GMW-02	Dia Bari, Uttara	-3.07	-2.74	0.97	0.89
GMW-03	Kha-84/Tanpara, Nikunja	-2.34	-3.14	0.91	0.92
GMW-04	Mastul, Khilkhet	-1.61	-2.19	0.82	0.86
GMW-05	Beraid, Vatara	-1.06	-2.12	0.78	0.83
GMW-06	Bangla College, Mirpur	-2.45	-2.30	0.55	0.40
GMW-07	BWDB Officers Qtrs, Banani	-1.28	-3.39	0.87	0.88
GMW-08	Ashraful Madrasa Mohammadpur	0.00	-2.34		0.63
GMW-09	Khilgaon H/School	-1.90	-4.23	0.45	0.88
GMW-10	WASA Staff Qtrs, Gandaria	-0.95	-1.50	0.38	0.73
GMW-11	Sarulia Intake	-2.01	-2.04	0.98	0.87
GMW-13	Adamjinagar, Siddirgonj	-2.26	-2.12	0.87	0.87

GMW-14	Godenail, Siddirgonj	-0.69	-3.25	0.18	0.67
GMW-15	Twin OHT Khanpur	-0.95	-1.79	0.30	0.61
GMW-16	Atipara, Dakkhinkhan	-2.92	-3.76	0.97	0.89
GMW-17	Nasirabad High School, Khilgaon	-1.61	-1.64	0.98	0.98
GMW-18	Goranchatbari Pump House, Rupnagar	-2.37	-2.48	0.73	0.75
GMW-19	Matbor Bari Mosque, Kamrangirchar	1.97	0.40	0.21	0.01

5.5 Statistical Significance of Groundwater Level Trends

5.5.1 Results from Modified Mann Kendall Test

In the present study, results are estimated by two parts – dry season and monsoon season. In dry season out of 21 stations, 19 stations are showing negative and remaining 2 are positive trends. The magnitude of trend from Sen‘s Slope method varies from -2.36 m/yr (Well ID:GT2654014, South Khilgaon) to 0.06 m/yr (Well ID:2614003, Dhamrai). Whereas, in monsoon season out of 21 stations, 17 stations are showing negative and remaining 4 are showing no trend. The magnitude of trend varies from -2.34 m/yr (Well ID:GT2654014, South Khilgaon) to 0.04 m/yr (Well ID:2614003, Dhamrai). The values obtained from Sen‘s Slope method is compared with rate of depletion obtained from Median GWL from linear regression method.The trend condition is same for both parametric and non-parametric method.

Table 5.4: Trend in Groundwater Level Using Mann-Kendall Trend Test and Sen's Slope Method (Dry Season)

Well ID	Kendall's tau	Mann Kendall Statistic (S)	Variance of S	Normalized Test Statistic (Z)	p- value	Sen's Slope (m)	Rate of depletion/ Augmentation Median GWL in m	Trend
GT2608001	-0.78	-216	1625.33	-5.33	< 0.0001	-1.57	-1.136	Decreasing Trend
GT2614002	-0.32	-343	11891	-3.14	0.0017	-0.07	-0.083	Decreasing Trend
GT2614003	0.32	252	7366.67	2.92	0.0035	0.06	0.04	Increasing Trend
GT2614004	-0.56	-391	6327	-4.9	< 0.0001	-0.04	-0.036	Decreasing Trend
GT2616005	-0.7	-194	1625.33	-4.79	< 0.0001	-2.22	-1.499	Decreasing Trend
GT2618006	-0.36	-280	7366.67	-3.25	0.0012	-0.03	0	Decreasing Trend
GT2618007	-0.4	-264	5846	-3.44	0.0006	-0.02	-0.0133	Decreasing Trend
GT2638008	-0.65	-485	6833.67	-5.85	< 0.0001	-0.18	-0.389	Decreasing Trend
GT2642009	-0.95	-333	2301	-6.92	< 0.0001	-1.67	-1.56	Decreasing Trend
GT2648010	-0.91	-864	9775.33	-8.73	< 0.0001	-1.73	-1.619	Decreasing Trend
GT2650011	-0.95	-665	6327	-8.35	< 0.0001	-1.01	-0.993	Decreasing Trend
GT2650012	-0.97	-480	3802.67	-7.77	< 0.0001	-0.8	-0.822	Decreasing Trend
GT2654013	-0.43	-39	333.67	-2.08	0.04	-0.57	-0.241	Decreasing Trend
GT2654014	-0.85	-47	165	-3.58	0.00034	-2.36	-2.562	Decreasing Trend
GT2662015	-0.46	-288	5390	-3.91	< 0.0001	-0.05	-0.074	Decreasing Trend
GT2662016	0.21	73	2301	1.5	0.13	0.02	0.014	No Trend
GT2672017	-0.71	-582	7926.67	-6.53	< 0.0001	-0.14	-0.246	Decreasing Trend
GT2672018	-0.87	-548	5390	-7.45	< 0.0001	-0.4	-0.604	Decreasing Trend
GT2668019	-0.71	-331	3461.67	-5.61	< 0.0001	-1.54	-0.904	Decreasing Trend
GT2668020	-0.96	-364	2562	-7.17	< 0.0001	-2.14	-2.123	Decreasing Trend
GT2688021	-0.92	-716	7366.67	-8.33	< 0.0001	-0.51	-0.533	Decreasing Trend

Z-statistics of entire 21 locations during dry season varies from -8.73 to 2.92. In dry season, 19 locations are showing declining trend, 1 is showing rising trend and 1 is showing no trend. However, out of them the Well ID:2648010, New Sewra Para, Mirpur and the Well ID:2650011, Mohammadpur are showing significant declining trend and the Well ID:2614003, Dhamrai is showing significant rising trend at 5% level of significance.

Z-statistics of entire 21 locations during monsoon season varies from -8.79 to 0.20. In monsoon season, 17 locations are showing declining and remaining 4 are showing no trend. However, out of them the Well ID:2648010, New Sewra Para, Mirpur and the Well ID:2650011, Mohammadpur are showing significant declining trend at 5% level of significance. The overall results of MMK test and Sen‘s slope are summarized in Table 5.4 and Table 5.5.

Dry season and monsoon season mean groundwater level fluctuations varied from -42.40 m to 4.73 m and -42.85 m to 6.75 m, respectively. Well ID:2616005, Green Road, Dhanmondi and Well ID:2608001, Joar Shahara, Cantonment had maximum groundwater extraction in both dry and monsoon periods. As compared to all the stations, the middle part of the city (Dhanmondi, Mohammadpur, Khilgaon and Motijheel area) is identified as groundwater depletion zone. The decreasing trend indicates an increasing depth of water level from the ground surface and the increasing trend indicates a decreasing depth of water level from the ground surface. Hence, almost all of the wells are showing the significant decreasing trend(s) that means the groundwater table is declining in these locations due to over-extraction of groundwater.

Table 5.5: Trend in Groundwater Level using Mann-Kendall Trend Test and Sen's Slope Method (Monsoon season)

Well ID	Kendall's tau	Mann Kendall Statistic (S)	Variance of S	Normalized Test Statistic (Z)	p- value	Sen's Slope (m)	Rate of depletion/ Augmentation Median GWL in m	Trend
GT2608001	-0.77	-177	1257.67	-4.96	< 0.0001	-1.741	-1.136	Decreasing Trend
GT2614002	-0.57	-595	11155	-5.62	< 0.0001	-0.092	-0.083	Decreasing Trend
GT2614003	0.02	17	6327	0.2	0.84	0.004	0.04	No Trend
GT2614004	-0.26	-170	5846	-2.21	0.03	-0.023	-0.036	Decreasing Trend
GT2616005	-0.75	-189	1433.67	-4.97	< 0.0001	-2.246	-1.499	Decreasing Trend
GT2618006	-0.21	-145	6327	-1.81	0.07	-0.018	0	No Trend
GT2618007	-0.05	-34	5390	-0.45	0.65	-0.006	-0.0133	No Trend
GT2638008	-0.65	-485	6833.67	-5.85	< 0.0001	-0.181	-0.389	Decreasing Trend
GT2642009	-0.92	-254	1625.33	-6.28	< 0.0001	-1.844	-1.56	Decreasing Trend
GT2648010	-0.92	-870	9775.33	-8.79	< 0.0001	-1.82	-1.619	Decreasing Trend
GT2650011	-0.9	-568	5390	-7.72	< 0.0001	-1.1	-0.993	Decreasing Trend
GT2650012	-0.97	-451	3461.67	-7.65	< 0.0001	-0.855	-0.822	Decreasing Trend
GT2654013	-0.47	-43	333.67	-2.3	0.02	-0.701	-0.241	Decreasing Trend
GT2654014	-0.82	-45	165	-3.43	0.0006	-2.339	-2.562	Decreasing Trend
GT2662015	-0.43	-257	4958.33	-3.64	0.0003	-0.082	-0.074	Decreasing Trend
GT2662016	0	1	2301	0	1	0	0.014	No Trend
GT2672017	-0.74	-574	7366.67	-6.68	< 0.0001	-0.181	-0.246	Decreasing Trend
GT2672018	-0.8	-475	4958.33	-6.73	< 0.0001	-0.632	-0.604	Decreasing Trend
GT2668019	-0.68	-278	2842	-5.2	< 0.0001	-1.7	-0.904	Decreasing Trend
GT2668020	-0.96	-362	2562	-7.13	< 0.0001	-2.184	-2.123	Decreasing Trend
GT2688021	-0.95	-669	6327	-8.4	< 0.0001	-0.614	-0.533	Decreasing Trend

Long term groundwater fluctuation trends indicate the effect of groundwater withdrawal and recharge on changes in water stored in aquifer, which is required for assessing the groundwater potential available for utilization. Hence, the best management strategies are needed to conserve the groundwater storage at particular places. The study reveals that the MMK test is an appropriate tool to identify the historical trends of groundwater level changes. The results from the study can be useful for planning and managing the water resources, and sustainable development of the city. Also, such findings are important for any strategic planning for future.

5.6 Contours of Annual Maximum, Minimum and Median Groundwater Level Depletion Trends

From contour maps of maximum groundwater level trend (Figure 5.8) of the study area, it is seen that the cone of depression with a maximum declination rate of 2.4 m/yr is in the vicinity of Motijheel area and 2.2 m/yr in the Khilgaon area. A moderate declination rate of about 1.6 – 2.0 m/yr is found near Dhanmondi and Mohammadpur areas. The lateral extent and magnitude of Motijheel and Khilgaon areas‘ declination are larger than that of Dhanmondi and Mohammadpur areas. All other areas of Dhaka city are also undergoing a total groundwater level declining condition varying from 0.6 – 2.0 m/yr.

From the contour map of the minimum groundwater level trend (Figure 5.9) of the study area, it is seen that the cone of depression with a maximum declination of 2.4 m/yr is in the vicinity of Motijheel area and 2.2 m/yr in the Khilgaon and Sobujbag areas. Moderate declination of about 1.6 – 2.0 m/yr is found near Dhanmondi and Mohammadpur areas. The lateral extent and magnitude of Motijheel, Khilgaon and Sabujbag areas are larger than that of Dhanmondi and Mohammadpur areas. Cantonment and Mirpur areas are undergoing a gradual declination of 1.4 m/yr. The extent of depression is increasing laterally. All other areas of Dhaka city are also undergoing a total groundwater level declining condition varying from 0.6 – 2.0 m/yr.

Contour map of the median groundwater level trend (Figure 5.10) of the study area exhibits a similar situation like the minimum groundwater level contour map. Groundwater level is declining at a rate of 0.4 – 2.4 m/yr.

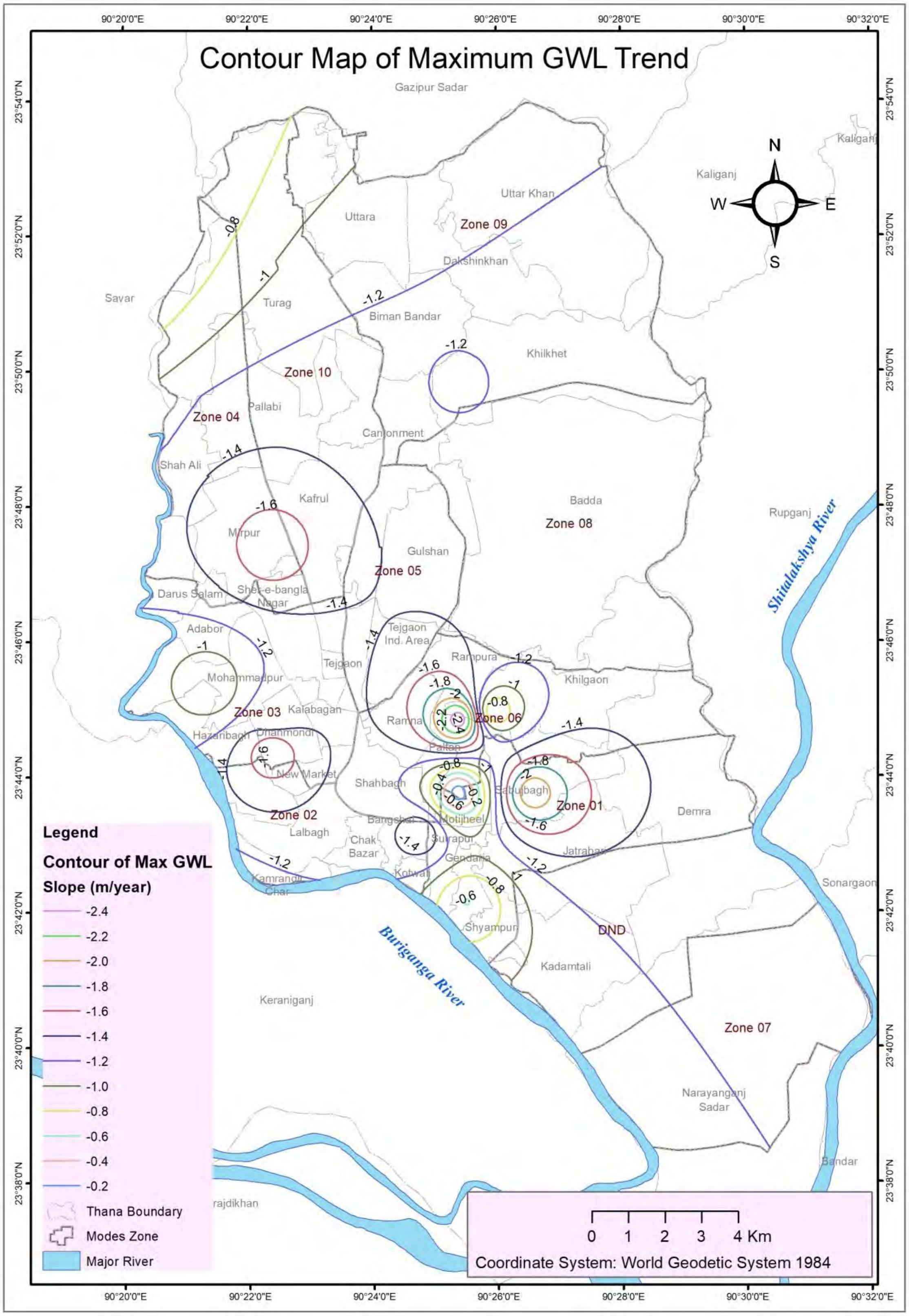

Figure 5.8: Contour Map Using the Maximum GWL Trend for the Study Area

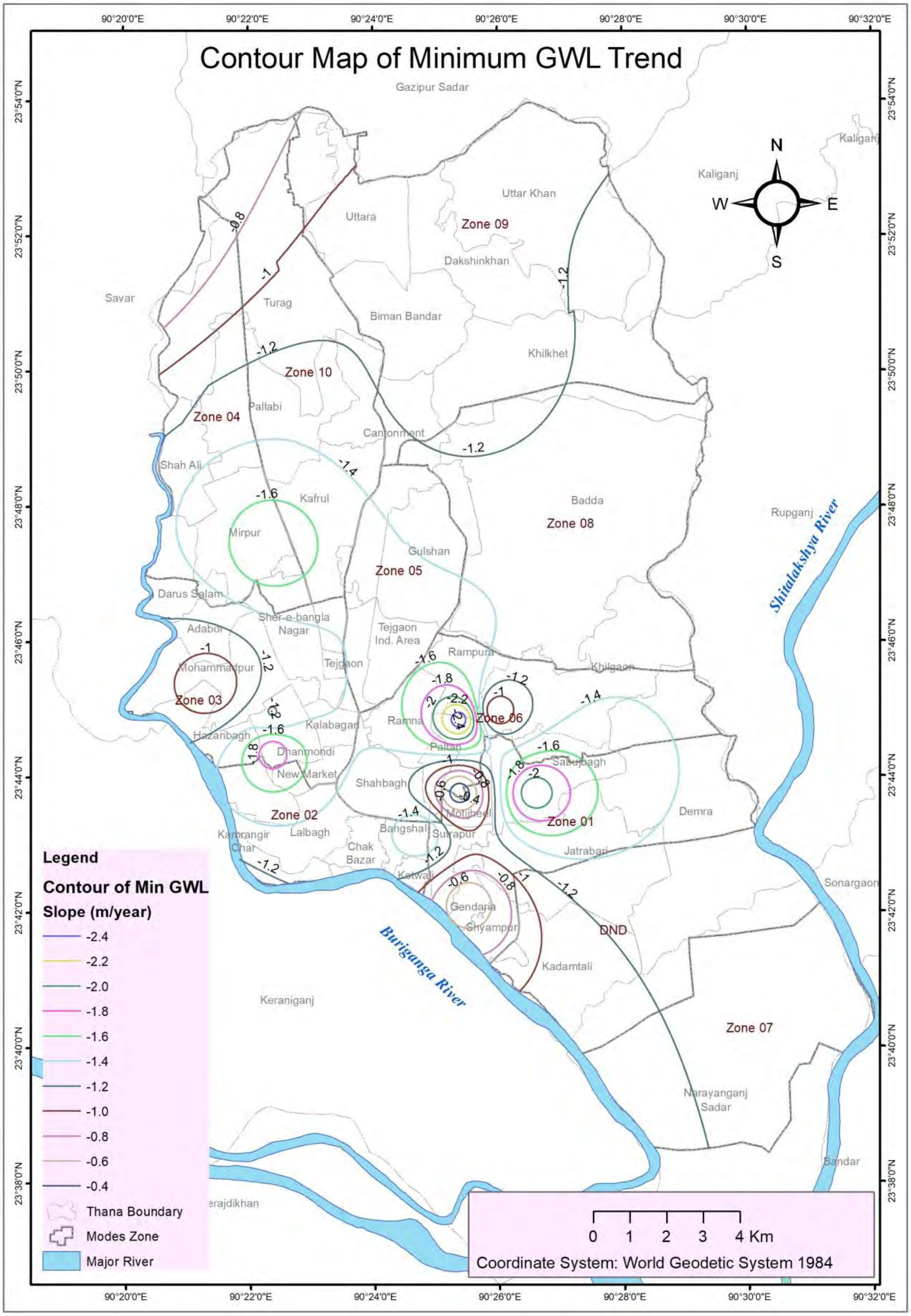

Figure 5.9: Contour Map Using the Minimum GWL Trend for The Study Area

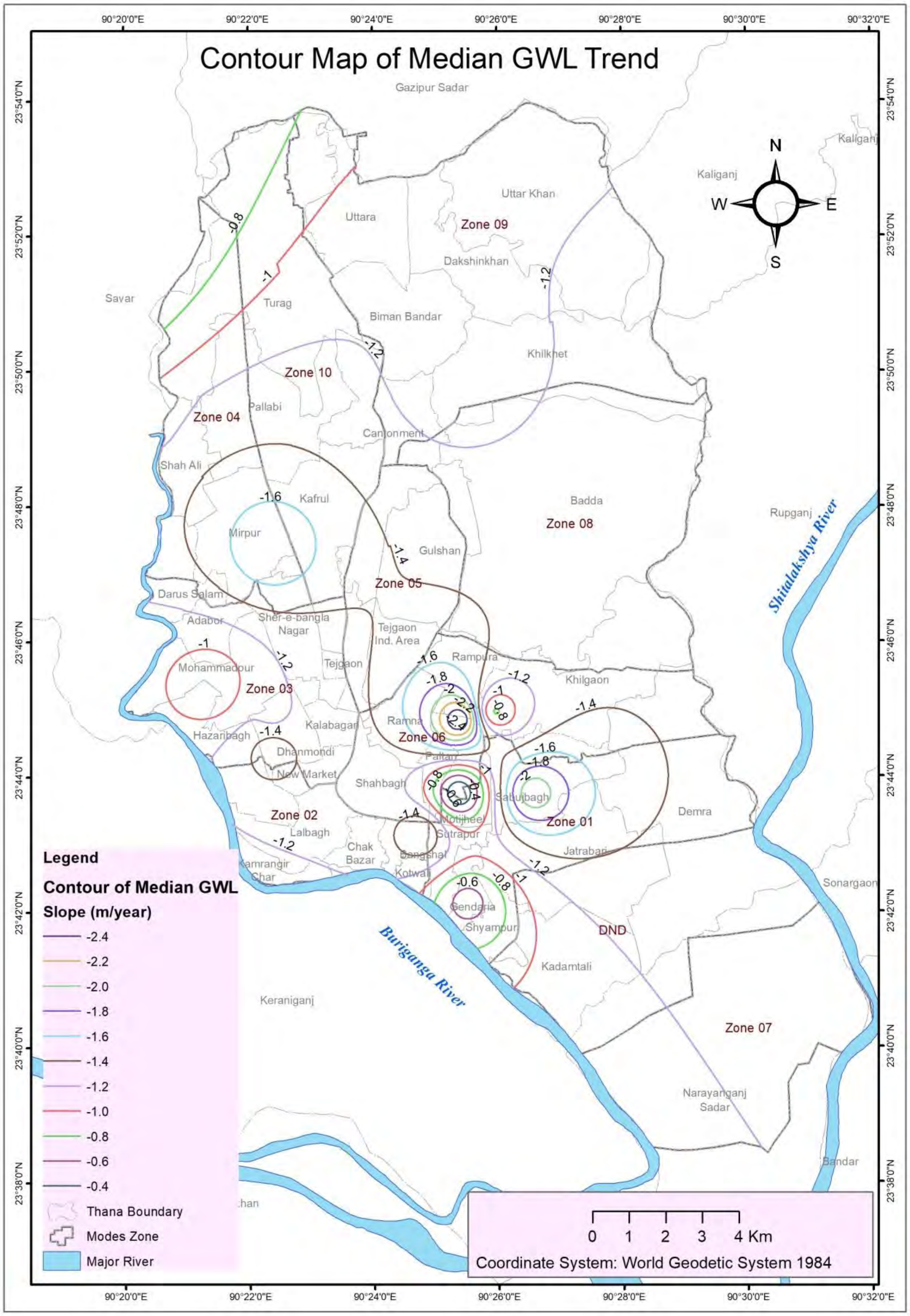

Figure 5.10: Contour Map Using the Median GWL Trend for the Study Area

All of the contour maps illustrate that water is flowing from all around Dhaka city to central area, mostly southern central area. As the rate of declination is almost the same for the maximum and minimum groundwater level trend contour maps, there is little or almost no impact of rain during the rainy reason. The abstraction rate is drastically higher than the recharge rate. Permanent drawdown is occurring due to unsustainable abstraction.

A deep cone of depression may have caused the additional resistance to natural recharge in the center of Dhaka region. The Dupi Tila Aquifer is confined by the leaky silty clay of Madhupur formation. As the groundwater level fell from a few meters in the late 1990s, the aquitard has been drained and the upper part of the Dupi Tila became dewatered. The resulting unsaturated conditions have reduced the vertical hydraulic conductivity, especially in the uppermost finer grained strata where narrow pore spaces became filled with air which obstructed the water passage, and thus hydraulic resistance increased (Morris et al. 2003).

Hoque et al. (2007) presented piezometric surfaces of 1988, 1993, 1998 and 2002 of Dhaka city. This shows that the declination rate from the present study is quite similar to the previous study. That means the declination trend is increasing with time and the cone of depression is increasing laterally and also deepening.

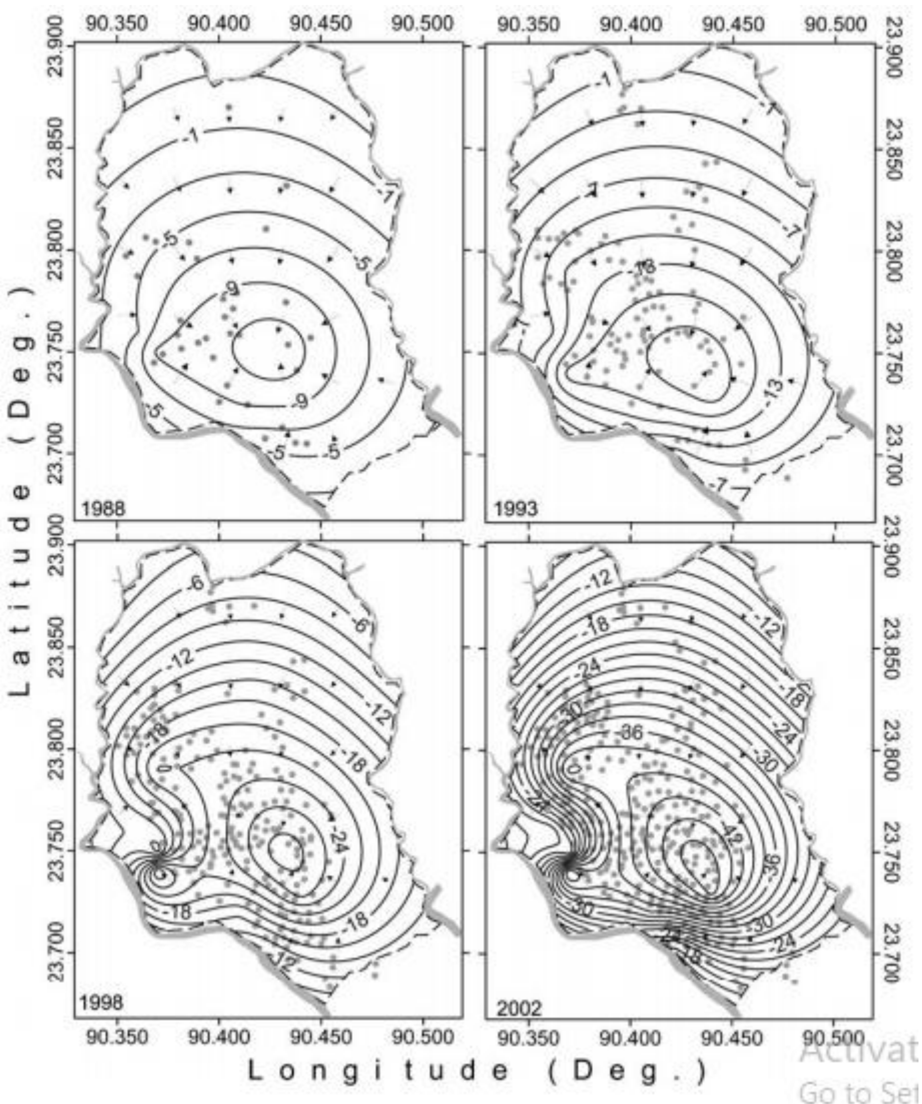

Figure 5.11: Water Level Contour (with 2-m interval) Surfaces Showing the Development and Deepening of Cones of Depression in the City of Dhaka During the Years 1988 to 2002 (Source: Hoque et al., 2007).

5.7 Contour of Maximum and Minimum Groundwater Depths of Shallow and Deep Aquifer for the Year 2018

Contour map of maximum groundwater depth of shallow aquifer for the year 2018 has been plotted by using the maximum depth of water level of each monitoring well installed by

DWASA (Figure 5.12). Groundwater depletion is severe mainly at GMW-05 and GMW-09, which means at the central Dhaka groundwater is depleted quickly than the peripheral area of Dhaka. At the peripheral area, depletion is less than the central part.

Contour map of minimum groundwater depth of shallow aquifer for the year 2018 (Figure 5.13) has been plotted by using the minimum depth of water level of each monitoring well. Groundwater depletion is severe mainly at GMW-05 and GMW-09, which means at the central Dhaka groundwater is depleted quickly than the peripheral area of Dhaka. At the peripheral area, depletion is less than the central part.

Contour map of maximum groundwater depth of deep aquifer for the year 2018 (Figure 5.14) has been plotted by using the maximum depth of water level of each monitoring well. Groundwater depletion is severe mainly at GMW-09, which means at the central Dhaka groundwater is depleted quickly than the peripheral area of Dhaka. Cone of depression is the highest at central Dhaka near Khilgaon and Motijheel areas. At the peripheral area, depletion is less than the central part.

Contour map of minimum groundwater depth of deep aquifer for the year 2018 (Figure 5.15) has been plotted by using the minimum depth of water level of each monitoring well. Groundwater depletion is severe mainly at GMW-05 and GMW-09, which means at the central Dhaka groundwater is depleted quickly than the peripheral area of Dhaka. At the peripheral area, depletion is less than the central part.

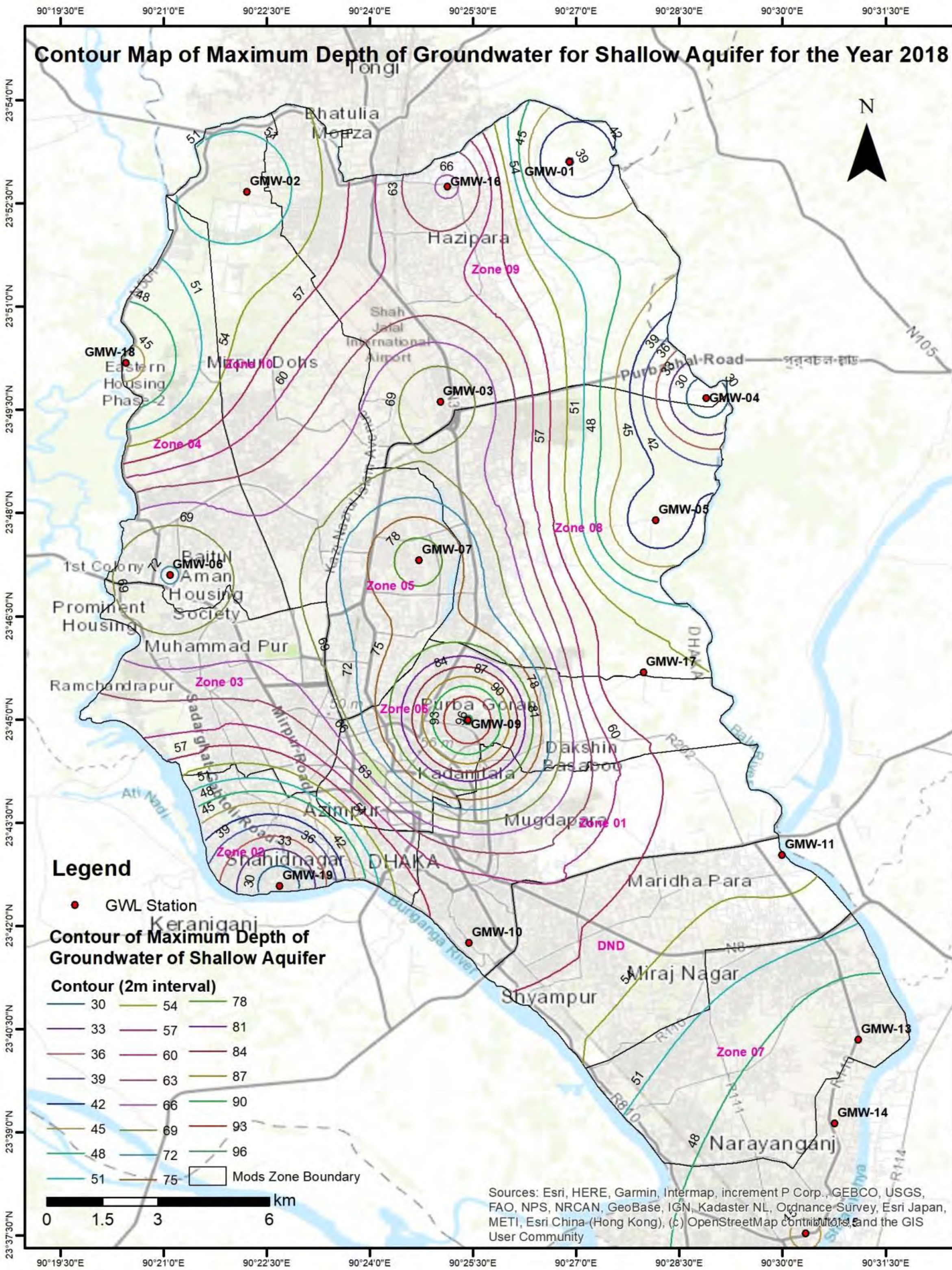

Figure 5.12: Contour Map of Maximum Groundwater Depth of Shallow Aquifer (Year 2018)

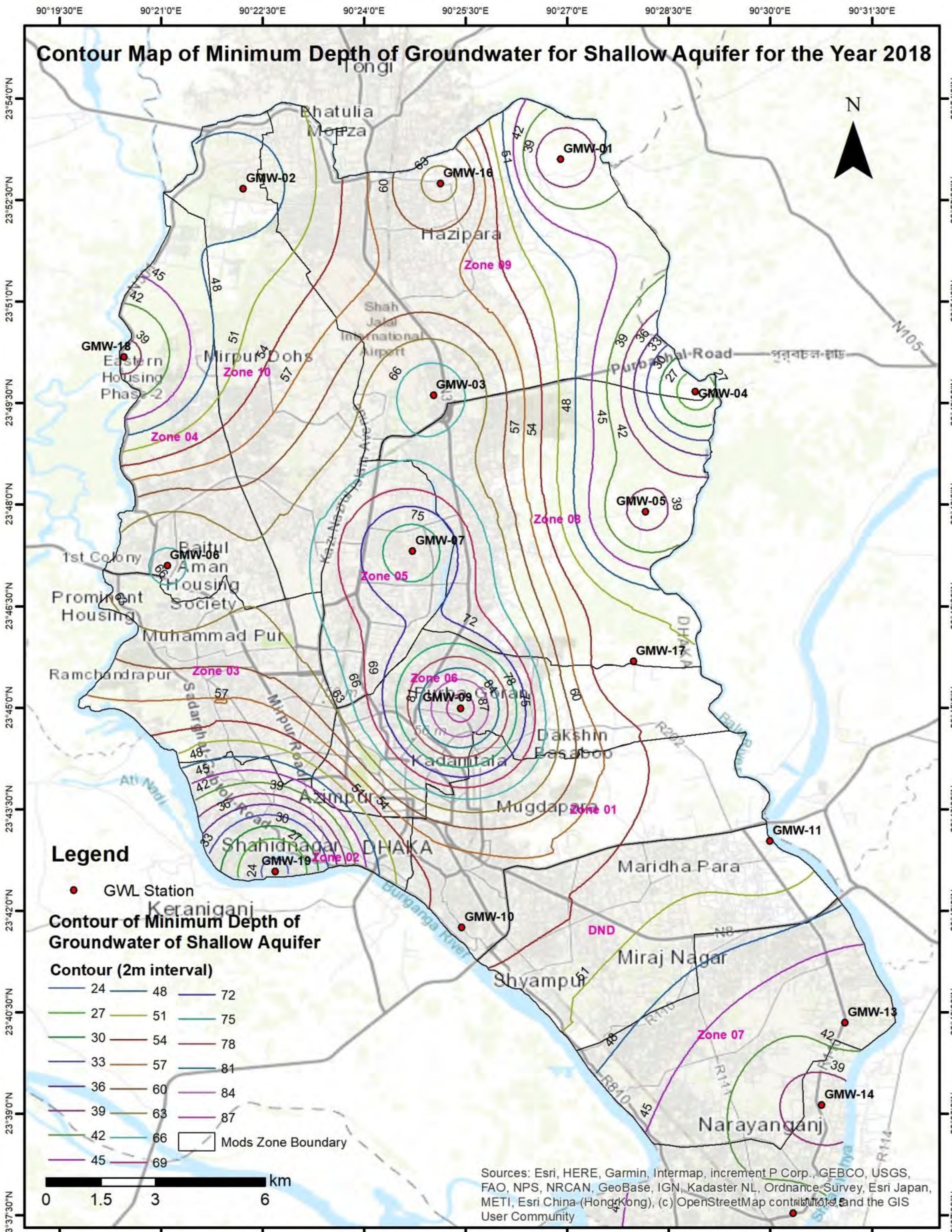

Figure 5.13: Contour Map of Minimum Groundwater Depth of Shallow Aquifer (Year 2018)

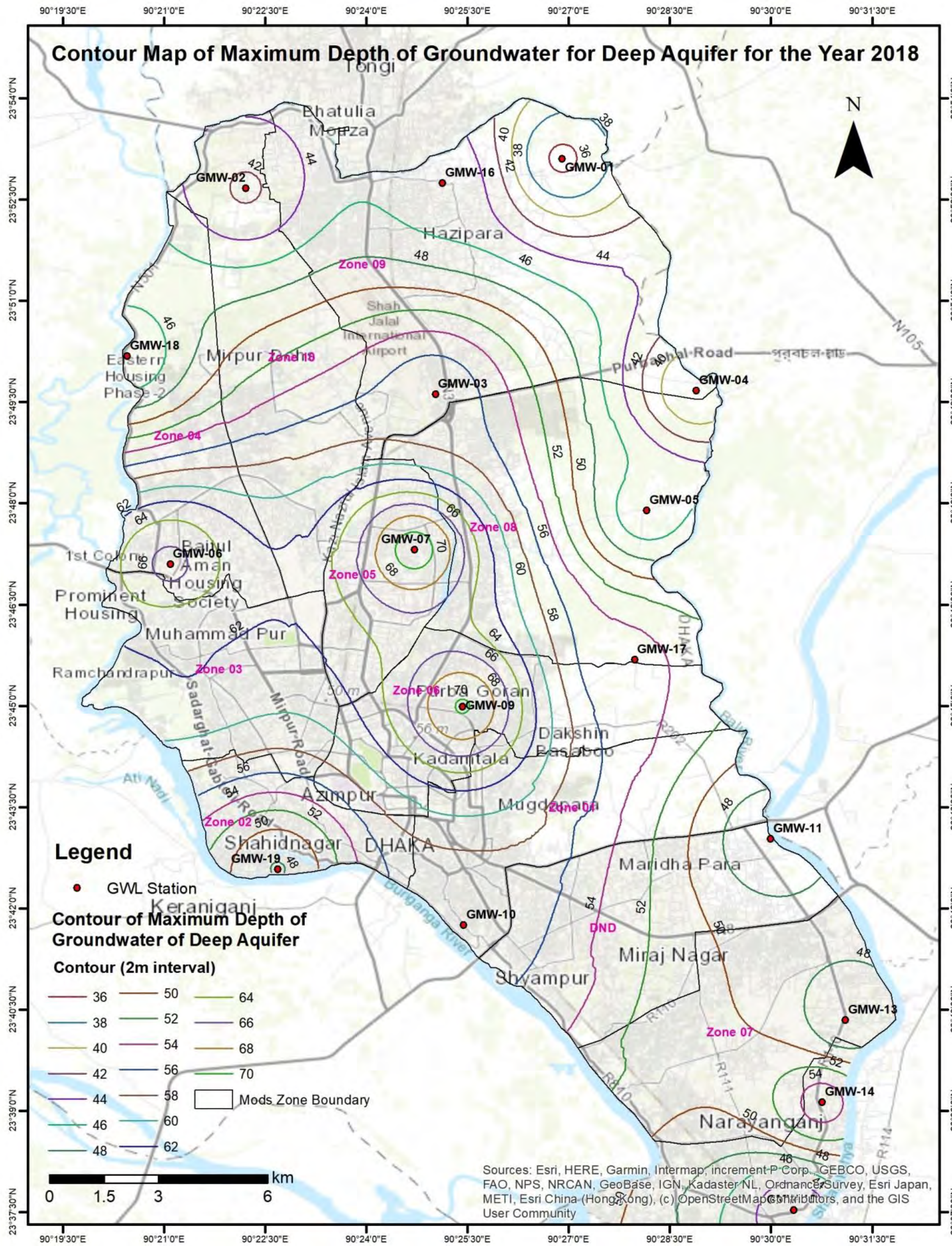

Figure 5.14: Contour Map of Maximum Groundwater Depth of Deep Aquifer (Year 2018)

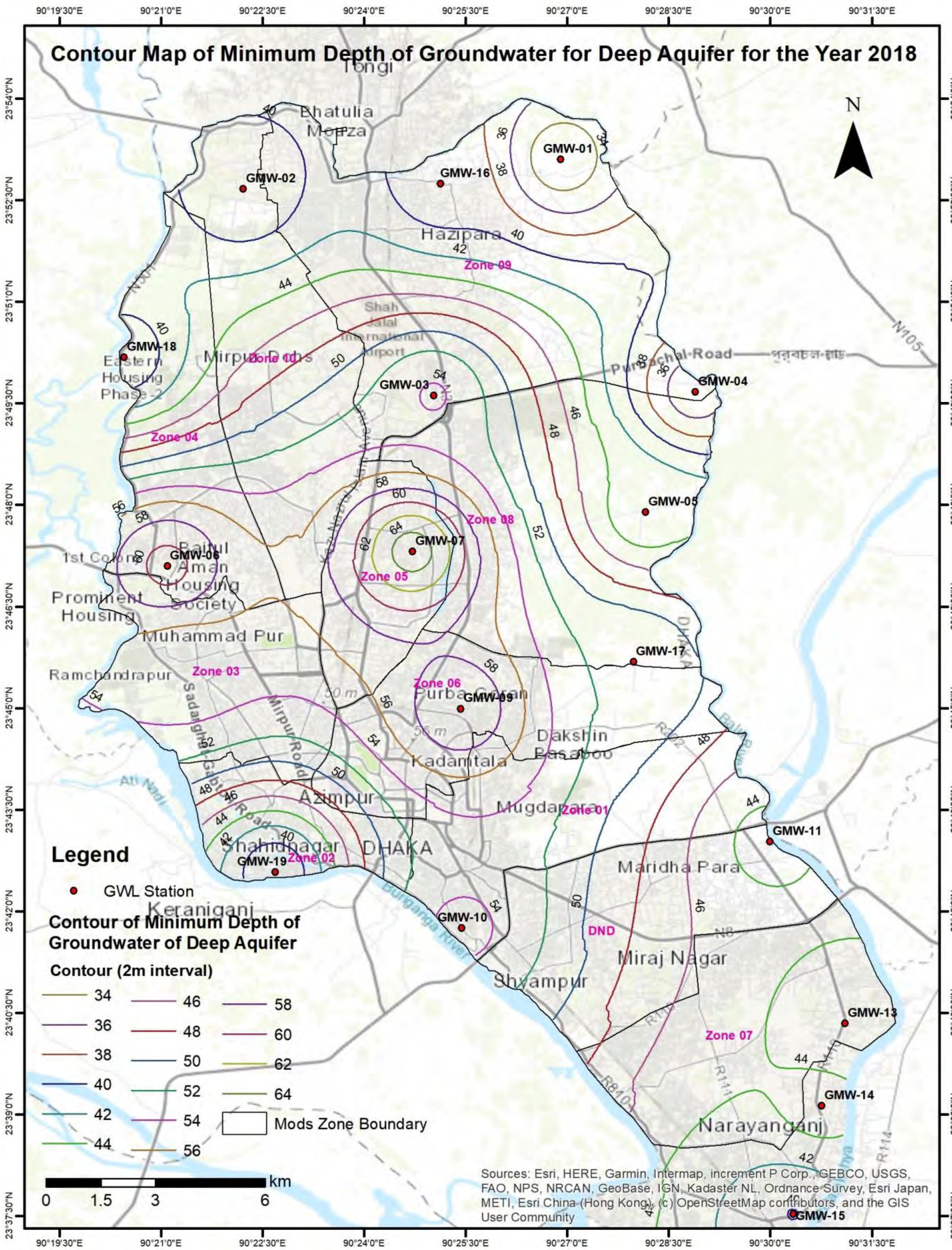

Figure 5.15: Contour Map of Minimum Groundwater Depth of Deep Aquifer (Year 2018)

Chapter Six

Current Practices and Potential Adaptation Options for Water Management in Dhaka City

6.1 Assessment of Current Practices of DWASA

DWASA is solely responsible for supplying water to the consumer of Dhaka city. To reduce pressure on groundwater resource and for sustainable water supply management in Dhaka city, DWASA is currently practicing some strategies. These strategies are discussed below with their potentialities.

6.1.1 Supply augmentation through surface water

DWASA is trying to shift the source of water from groundwater source to surface water source as groundwater level is declining significantly. In this regard, DWASA has completed some projects in the recent past and some are ongoing. All of these projects are discussed in two types: Completed and Ongoing.

6.1.1.1 Completed surface water treatment plants

Padma Water Treatment Plant (PWTP) – Phase -Iis operating from January 2019. The plant is located at Jashaldia under Lauhajang Upazila of Munshiganj District (Figure 5.1). It is now improving the water supply to the southern and eastern parts of Dhaka. Water from the Padma River is getting treated at the plant and then passing through 33-km-long pipeline to the distribution lines near Mitford Hospital before it is supplied to the Dhaka city. The treatment plant is designed to supply 450 MLD of treated water. But upon completion of the first phase, the proposed Padma water treatment plant is supplying 150 MLD to the city due to poor network system at the delivery point. The network system is being replaced by another ongoing project, Dhaka Water Supply Network Improvement Project (DWSNIP). The areas to be covered by the plant are Old Dhaka, Mohammadpur, Dhanmondi and Kawran Bazar. Conventional surface water treatment procedure is followed to treat the raw water.

Figure 6.1: Aerial view of the Padma (Jashaldia) Water Treatment Plant – Phase – I (Source: Google Earth, accessed on 21 January,2021).

This project is being implemented as part of moving towards the environment-friendly, sustainable and pro-people water supply system. After full functioning of the project, it will increase the ratio of surface water to 35% from 22%.

6.1.1.2 Ongoing surface water treatment plants

DWASA has taken a number of projects at present to augment water supply using surface water. These projects include:

- Padma (Jashaldia) Water Treatment Plant Project – Phase II
- Dhaka Environmentally Sustainable Water Supply Project (includes SWTP in char Gandharbpur)

- Saidabad Surface Water Treatment Plant Project – Phase III

Padma (Jashaldia) Water Treatment Plant Project (PWTP) – Phase II is at its planning stage. Another 450 MLD capacity water treatment plant will be constructed beside the existing plant.

Dhaka Environmentally Sustainable Water Supply Project (DESWSP) (includes surface water treatment plant at Gandharbpur, Phase- I) will provide more reliable and improved water supply in Dhaka by developing a new surface water supply scheme for supply augmentation, which includes the development of a water intake at the Meghna River, a raw water transmission pipeline, a water treatment plant (WTP) at Gandharbpur with capacity of 500 MLD, a treated water transmission pipeline to the existing water supply network and distribution reinforcements. The project will also include distribution network improvements to reduce non-revenue water (NRW) and will improve the quality of water supply services, including support to low-income communities. The WTP will serve the population of about 3 million in Badda, Gulshan, Mirpur, and Uttara (whole of zones 5, 8, and 9; and part of zones 4 and 10). Distribution network will be strengthened in zone 6 of DWASA‘s service areas.

Photo 6.1: Construction Site of Gandharbpur Surface Water Treatment Plant Phase- I (Photo taken on 2 February, 2021).

Saidabad Water Treatment Plant Project (SWTP) - Phase – III consists of construction of a 450 MLD WTP with Sludge Treatment Plant for Saidabad phase - I, II & III and distribution of treated water to different parts of the city to cope with the increasing need of water of the growing population and reduce the ground water dependency. It also includes construction of intake pumping station (total 900 MLD) with raw water transmission line to ensure treatable raw water source for Saidabad WTP phase-I & II and proposed phase III.

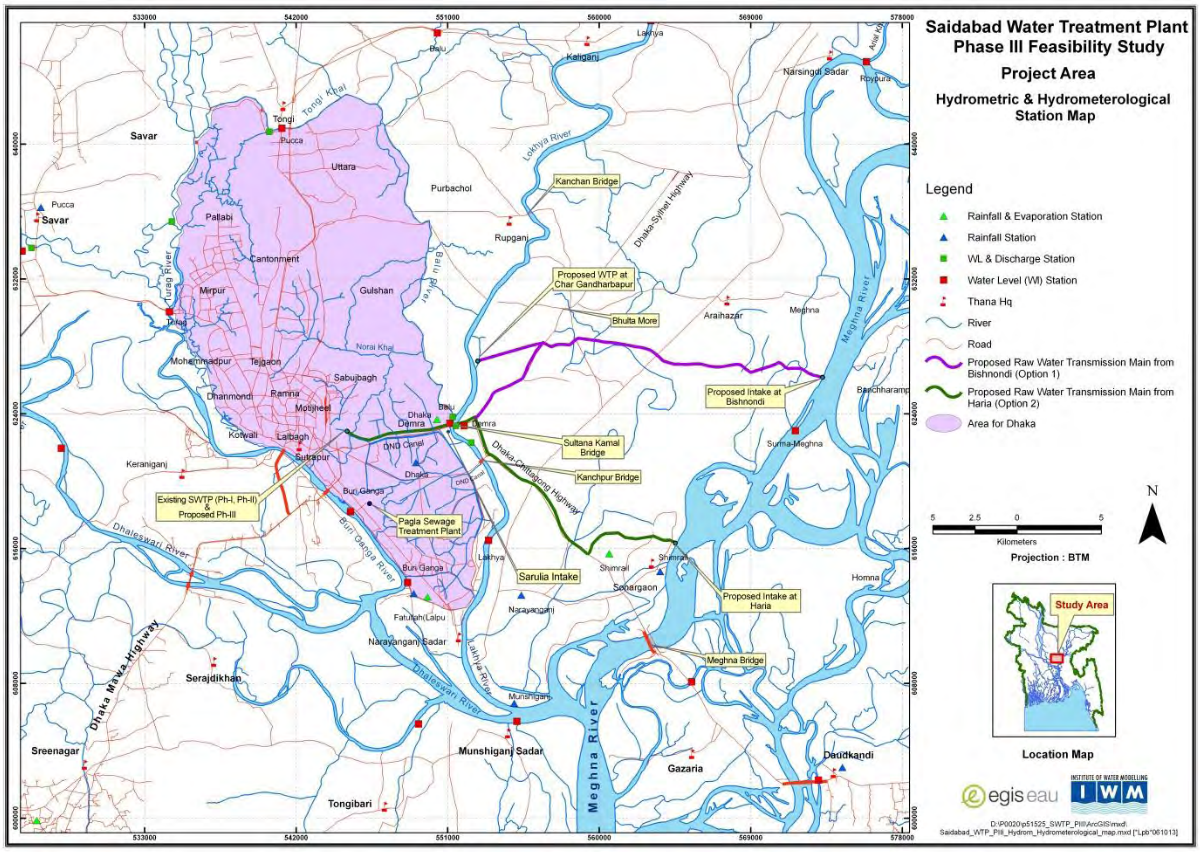

Figure 6.2: Location of the Saidabad Surface Water Treatment Plant Phase – III with Intake Location (Source: Ashraf and Ahmed, 2014)

A SWOT analysis for surface water treatment plants is presented below:

Table 6.1: SWOT Analysis for Surface Water Treatment Plants

Strengths:	Weaknesses:
1. Potential for incremental development. 2. Selective withdrawal of source water. 3. Mitigation of environmental disruption. 4. Multipurpose use. 5. Environment friendly. 6. Reduction of dependency on groundwater. 7. Supply augmentation to the existing system.	1. Water purification requires regular maintenance. 2. High operation and maintenance expenses. 3. High initial capital and energy costs. 4. Reservation on quality of intake. 5. Requirement of trained operation and maintenance unit.
Opportunities: Learning from operation and maintenance of SWTP can be used for other small and large scale SWTP projects.	Threats: Surface waters can be contaminated by pollution from "nonpoint sources," sometimes called "polluted runoff," or "point sources," usually permitted discharges from sewage treatment or industrial waste treatment plants.

6.1.2 Supply augmentation through groundwater

The main source of water supply is still from groundwater source. DWASA is now supplying water from around 920 tubewells. In this regard, DWASA has completed some projects in the recent past and some are ongoing. All of these projects can be discussed in two types: Completed and Ongoing.

6.1.2.1 Completed groundwater plants

Tetulzhora Bhakurta Well Field Construction project started operating from June 2019 and is extracting about 176 MLD. Considering possible loss at the well field and during transmission, 150 MLD water is available at Gabtoli/Mirpur point for injecting to city water supply network. The project included construction of 46 numbers of production wells including pumping stations, 02 Iron Removal Plant (IRP) of capacity 75000 m^3/day each and related works. The plant is fullySupervisory Control and Data Acquisition (SCADA) operated. Chlorine is dozed for disinfection of water in the inlet pipes of Over Ground Reservoir (OGR) tank in order to maintain the required residual chlorine level. This chemical dozing is controlled with flow meter by Flow Proportional Control.

 

Photo 6.2: Tetuljhora - Bhakurta Well Field with Iron Removal Plant (Photo taken on 13 February,2021)

6.1.2.2 Ongoing groundwater plants

Well Field Construction Project at Singair Upazilla - Part – II is at its planning stage. Another 150 MLD capacity groundwater plant will be constructed beside the existing plant.

The **Emergency Water Supply Project(EWSP)** has been undertaken as an interim measure to meet water demand of Dhaka city until water supply from surface water sources is implemented. According to the water supply master plan, the projected water demand of 2020 is 3152 MLD against a planned water supply of 3306 MLD. Out of 3306 MLD, around 950 MLD water supply was planned to be supplied from Saidabad Phase – III (450 MLD) and Gandharbpur– I (500 MLD). Considering the present situation, commissioning of those surface water treatment plants would be delayed by 4-5 years. However, with additional supply from the Emergency Water Supply Project, commissioning of the Padma (Jashaldia) WTP and Tetuljhora – Bhakurta well field projects, an additional 747 MLD could be added to the system. Still there would be water supply deficit of around 488 MLD in 2024. As a result, more than three million people will severely suffer from scarcity of safe drinking water. For minimizing this supply shortage, the ongoing EWSP proposes additional production tube wells including rehabilitation and regeneration of existing ones in phases over four years. This project will serve the growing water demand for Dhaka city dwellers.

This project will add an extra 447 MLD of water. About 1.60 crore people of Dhaka city will be benefited and it will improve their standard of living. The project includes construction of 95 new tubewells, replacement of 285 tubewells, regeneration of 190 tubewells and rehabilitation of 95 tubewells. About 200 DTWs will be operated under SCADA system. This project will also install 50 rainwater harvesting zones.

Photo 6.3: View of Boring for Installation of a New Deep Tubewell (Photo taken on 8 March, 2021)

A SWOT analysis for groundwater plants is presented below:

Table 6.2: SWOT Analysis for Groundwater Plants

Strengths: 1. Present in many locations around the world like Columbia, USA and Brazil. 2. Practical choice for most locations since it requires relatively simple technology. 3. Produces moderate to high quality water with low energy and cost. 4. Offers reduced exposure to pathogenic microbes compared to surface water sources. 5. Offers higher efficiency since groundwater has less water loss to evaporation compared to surface water resource.	Weaknesses: 1. Groundwater aquifers and sources can be easily depleted and costs of extraction rises rapidly as the water table falls. 2. Costs of clean-ups for groundwater contamination are tremendous. 3. Requires constant monitoring to maintain water quality of sources. 4. Over exploitation of groundwater may lead to land subsidence, earth quake and other major hazards.
Opportunities: 1. Can be useful in environmental management aspect such as in terms of flood control. 2. Acts as a useful back up in water supply gaps during long dry seasons and droughts. 3. Technological innovation has led to cheaper and better tube wells and mechanical pump technology.	Threats: 1. Contamination from surface sanitation facilities or surface activities can affect groundwater aquifers. 2. Inorganic chemical such as arsenic is the main concern of groundwater contamination. 3. Overall supply of water resources may be affected if there are numerous wells in one watershed. 4. Degradation of freshwater

	ecosystem such as wetlands can affect the groundwater replenishment.

6.1.3 Improved network system to reduce contamination and non-revenue water

In the early 1990s, Dhaka WASA was struggling to meet water demand, a struggle that stemmed in part from rising unaccounted-for water losses and poor performance in revenue collection. In Dhaka, there is substantial portion of non-revenue water (NRW) and system loss which is not billed and this is due to leakage and illegal connections. Also, the bacteriological quality of WASA source water is superior to pipeline and house tap water, so contamination of water takes place in distribution system and/or domestic tanks or reservoirs (Mahbub et al., 2011). To reduce NRW, DWASA is rehabilitating and replacing the existing distribution network and introducing a new asset management concept, ‗District Metered Area' (DMA). DMA is designed to be a 24-hour pressurized system that sources water from local DTWs and SWTPs, i.e. conjunctive usage.Each DMA distribution network is sufficiently metered to monitor and account water flow. Any anomaly in the system due to leakage, pilferage, etc. is quickly identified and remedied. In this context, Dhaka WASA has undertaken a project titled ‗Dhaka Water Supply Network Improvement Project' (DWSNIP) to rehabilitate and optimize water distribution network to minimize loss and contamination at the same time.

The ongoing **DWSNIP** would cover rehabilitation of distribution networks of 7 zone areas. These include (i) zone 9 covering 13 DMAs and replacement of 475km of old pipelines, (ii) zone 2 covering 15 DMAs and replacement of 180km of old pipelines, (iii) zone 1 covering 19 DMAs and replacement of 300km of old pipelines, (iv) zones 3, 4 and 10 covering 16

DMAs and replacement of 453km of old pipelines, and (v) zone 7 covering 19 DMAs and replacement of 192km of old pipelines. The network rehabilitation and extension of existing distribution network are done by using mostly trenchless technology and by establishment of DMA. Total 145 DMA is required in Dhaka city. Already 47 DMAs has been completed through DWSSDP. A **High-density polyethylene** (**HDPE**) pipe would be used to strengthen the distribution network.

Photo 6.4: Construction of a New DMA by Replacing the Old Pipes with the HDPE Pipes

(Photo taken on 8 March, 2021)

A SWOT analysis in relation to strengthening of distribution network and DMA management is presented below:

Table 6.3: SWOT Analysis for Strengthening of Distribution Network

Strengths:	Weaknesses:
1. The volume of NRW (the difference between DMA inflow and billed volume) can be calculated on a monthly basis. 2. Improved burst detection and leakage identification. 3. Advantaged sub-area management and reduced NRW 4. Improved sub-area pressure control. 5. Improved protection against contamination. 6. Reduced maintenance and repair costs. 7. Characterized demand curve, especially at night.	1. The size of DMAs has an impact on the cost of creating them. The smaller the DMA, the higher the cost. This is because more valves and flow meters are required and maintenance is costlier. 2. Exact calculation of pipe sizes is not possible due to provision of valves on all branches. 3. Reduced resilience to failures. 4. Reduced operational flexibility. 5. Potential negative impact on water quality. 6. Security issues in peripheral areas and emergency cases. 7. High initial investment cost. 8. Reduced hydraulic redundancy.
Opportunities: 1. Can be useful in environmental management aspect. 2. Legalization of illegal connections. 3. Promoting legalconnections in low	Threats: 1. Decrease in produced volumes by DTWs is directly reflected in a negative NRW. 2. Certain risk of inaccuracy in the

income community areas. 4. Encourage lower consumer water consumption.	billed volume of individual months and cause systematically over-billing of consumption to customers. 3. Non-functional water meter reading is estimated and there is high probability of inaccuracy in reading.

6.1.4 Water ATM booth for purchasing safe water

DWASA has recently established 86 water-ATMs out of 300 booths in different areas of the city, from where people can collect fresh drinking water by using water-ATM card (Photo 5.1). One can get different quantities of water, starting from 1.0 liter. Such booths are now available in areas like Siddheswari, Fakirapool, Basabo, Mugda, Banasree, Matuail and Rampura. DWASA has installed these water stations to supply pure water. All the water clients have to do is buy a prepaid card at Taka 50. They can collect the water in their own containers by using the card. At the booths one liter water cost Taka 0.40 only. For the same quantity of water filled and sealed in bottles and sold at shops, one has to pay Taka 20. Most of the people buy large quantities of ATM water at a time, which they told will keep them free from water-borne diseases.

Photo 6.5: Water ATM Booth at Fakirapool, Dhaka (Source: https://drinkwellsystem.com/)

A SWOT analysis for water ATM booth is presented below:

Table 6.4: SWOT Analysis for Water ATM Booth

Strengths: 1. Instant source for fresh drinking water. 2. Cheaper price. 3. Public acceptability. 4. Illegal vandalism of water is reduced. 5. Protect the locality from water-borne diseases.	Weaknesses: 1. Unwillingness to issue prepaid ATM card.
Opportunities: 1. No. of water ATM can be	Threats: 1. If the production of respective

increased according to public demand. 2. Economic efficiency of DWASA water supply can be increased.	deep tubewell decreases to the minimum level, proper functioning of the ATM booth may be hampered. 2. Sudden breakdown of respective pump may cause temporary shutdown of the booth.

6.1.5 Tariff regulation

Municipalities/water utilities can set their own tariff structure for metered and temporary connections with permission from the government. However, the Dhaka WASA Board according to DWASA Act, 1996 under section 22 (subsection -3) can increase the tariff to a maximum of 5% to compensate for an increase in electricity rate. It should be noted that DWASA spends approximately 35% of its total expenditure on electricity alone. For any increase above 5% for any reason other than the one mentioned above, prior permission from the government is mandatory. For faulty meters and non-metered connections, rates can be fixed on the basis of previous three months' average water bills. Under the regulations, the utilities have been allowed to disconnect water lines of the customers for non-payment of tariffs. Dhaka WASA collects sewerage tax at a prescribed rate which is equivalent to the water charge. For example, DWASA currently charges Taka 14.46 per m^3 of water for residential users and Taka 37.04 per m^3 of water for commercial consumers. Holdings with sewer connections have to pay double of water bill.

A SWOT analysis for tariff regulation is presented below:

Table 6.5: SWOT Analysis for Tariff Regulation

Strengths:	Weaknesses:
1. Present tariff system is cheaper for all categories if consumers can afford it. 2. 5% rate increase per year is still quite cheaper in comparison with yearly economic inflation rate.	1. With the present tariff system, misuse of water cannot be identified. 2. Household level exact consumption cannot be calculated.
Opportunities:	**Threats:**
1. Increasing Block Tariff structure can be introduced. 2. Area wise tariff structure can be introduced. 3. Individual household metering can be introduced to calculate exact consumption.	1. Constraint to water conservation. 2. Sustainability of water management is also hindered.

6.1.6 Water carrier

DWASA also supplies water through water carriers (lorry, trolley and tank). Water carrier contains water ranges from 4000 liters to 6000 liters and price varies from Taka 400-600. For various national and religious functions/festivals, DWASA provides on spot water using its trolleys and tanks. For emergency pocket water crisis, DWASA provides supports to consumers through these water carriers.

Photo 6.6: View of a Water Carrier (Capacity: 6000 liters) (Photo taken on 28 February, 2021)

Table 6.6: SWOT Analysis for Water Carrier

Strengths: 1. Trucks can bring the water to almost every area. 2. Delivers fresh drinking water to households without an access to a piped water system or during natural disasters and emergencies.	Weaknesses: 1. Higher costs compared to a piped water system. 2. Continuous operation and maintenance is required for smooth transportation. 3. High risk of contamination.
Opportunities: 1. Water stored from rainwater harvesting can be used occasionally as source water to fill water carriers after proper disinfections	Threats: 1. Appropriate in all kinds of areas but generally only sustainable as a short-term solution.

2. Can be profitable and preferable options of utility service if managed properly with constructive feedback from customers.	

6.1.7 Rainwater harvesting

Rainwater harvesting is a common and good option as an alternative water source for city water supply. There are two different ways to use harvested water: (a) direct use and (b) through artificial recharge to groundwater. Household level direct use of harvested rainwater is very common practice in Bangladesh, particularly in saline prone coastal area. But, direct use is not commonly practiced in Dhaka city because of limited facility for household level rainwater harvesting and reluctance to incur the extra cost for installing the required plumbing, pumps, etc. (DWASA, 2014). Considering the limited scope of rainwater harvesting for direct use in household level, use of harvested rainwater through artificial recharge is the best option for Dhaka city area (DWASA, 2014). Moreover, such artificial recharge would also increase recharge volume to Dhaka aquifer, which would help keep groundwater balance in respect to huge abstraction in groundwater depleting area.

Study on Artificial Recharge to Aquifer by Rainwater Harvesting from Building Roof - Tops in Dhaka City has been conducted to identify the potentiality of artificial recharge in Dhaka Metropolitan city area (Sultana et al., 2010). In order to solve the problem of declining groundwater and to restore the balance between recharge and discharge, groundwater abstraction is required to be reduced on one hand and recharge is to be increased on the other. The situation demands recharging of freshwater in groundwater level declining areas through artificial means. Artificial recharge is an important approach towards aquifer augmentation and groundwater management as it provides storage space free of cost avoiding evaporation losses and allows the use of stored water in dry season for water supply.

BNBC 2020 [S.R.O. No. 55 – Law/2020 under section 18A of the Building Construction Act,1952 (Act No. II of 1953)] has formulated the code mentioning that every building proposed for construction on a plot having extent of 300 m^2 or above shall have facilities for conserving and harvesting rainwater. Arrangement should be made for artificial recharge to aquifer through a single percolation well. When roof top size exceeds 1000 m^2, an additional percolation well is to be constructed for the remaining space or for every 1000 m^2 space. Specification and licensed plumber should be engaged in this work. After 20 minutes for flushing out of initial rainwater for DMP area, rainwater has to be collected with separate collection pipe and after proper treatment it can be used for household cleaning, gardening purposes. For artificial recharge, provision for recharge pit is to be kept.

According to a study conducted by DWASA (2018), artificial recharge well arrangement using rainwater harvesting on the roof top of city buildings was developed. Artificial recharge structures have been constructed in 8 different DWASA MODS Zone office compounds, otherwise at residential compounds of DWASA officials or staff. In addition, two existing structures in MODS Zones 3 and 6 are renovated. Rainfall data of the catchment is measured to quantify the rainfall injected to the aquifer. Out of nine rainwater recharge units, rainfall data was collected in six locations for the year 2017 and in eight locations for the year 2018. Considering the annual rainfall measurement, total volume of rainwater available for recharge was about 4028 m^3 during 2017 (in six units) and about 4645 m^3 during 2018 (in eight units) without any loss. With 90% efficiency (10% loss), the volume of water available for recharge was about 3626 m^3 and 4180 m^3 respectively.

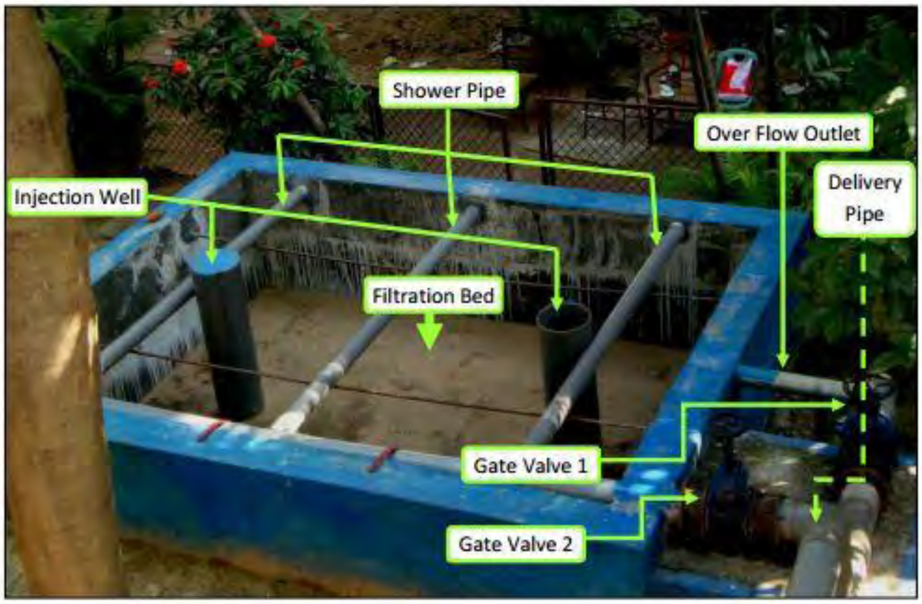

Figure 6.3: Recharge Pit with Part of Collection Network (Source: DWASA, 2018)

Figure 6.4: Release of Rainwater through Shower Pipe (Source: DWASA, 2018)

A SWOT analysis for rainwater harvesting and artificial recharge to groundwater is presented below:

Table 6.7: SWOT Analysis for Rainwater Harvesting and Artificial Recharge

Strengths: 1. Low cost local technology. 2. Not affected by local geology or topography.	Weaknesses: 1. Low awareness of local people. 2. Low community involvement. 3. Limited research and data. 4. Limited institutional coordination. 5. Low skilled people in rainwater harvesting system. 6. Limited finance / funds.
Opportunities: 1. Huge annual rainfall in Bangladesh. 2. Integration with donor agencies. 3. All time alternative source of drinking water. 4. Political will (well set policies, legal and institutional frameworks). 5. Available best practices at national level especially at coastal region. 6. Attraction of the climate change trust fund of Bangladesh.	Threats: 1. Vulnerability to climate change. 2. Proper operation and regular maintenance is a very important factor that is often neglected. 3. Rainwater quality may be affected by air pollution, animal or bird droppings, insects, dirts and organic matters.

7. Availability of media for communication.	

6.2 Potential Adaptation Strategies

The adaptation strategies to reduce GW declination were obtained from interviews and discussions with experts from relevant field and from previous studies.

The proposed adaptation strategies are divided into two groups:

- Supply Augmentation Strategies
- Demand Management Strategies

6.2.1 Supply augmentation strategies

6.2.1.1 Surface water treatment plants

By 2035, the estimated water demand would be 5268 MLD according to the master plan. To meet the demand, a huge number of DTWs need to be installed. The number can be determined from the sample calculation on production capacity of a DTW as given below:

Assume, average production of a DTW = 1500 liter/min

= (1500*60*24/1000000) MLD

= 2.16 MLD

So, the average production per DTW is about 2.16 MLD.

To meet the water demand of 5268 MLD in 2035, about 2500 DTWs need to be installed. That means around 1500 new DTWs are required. This practice would not be sustainable.

At present the groundwater is being extracted from the deeper aquifer. Therefore, both production cost and maintenance cost have increased a lot. Further extraction will also hamper the aquifer properties and the operation cost of the pumps will be higher. So, to meet the future demand in a sustainable way, Surface Water treatment Plant (SWTP) is the best option.

DWASA is investing in large scale SWTP. When the SWTPs will be completed, a huge stress on groundwater will be minimized. Abstraction from DTWs will be reduced and it will eventually increase the GWL.

During a KII, the Director (Technical) of Dhaka WASA shared his views on impacts of SWTP in groundwater level depletion and aquifer recharging. 40 DTWs had been forced to stop functioning, when the Padma (Jashaldia) SWTP ph-I started operating. Within one year, water table rose up to 10-15 m. So, when supply is augmented through SWTP, water production from DTWs will be lowered, automatically groundwater table rises and aquifer is recharged.

From experts‘ opinion, it is also suggested that not only large scale SWTP, small scale SWTP can also serve the purpose. This will reduce space, operational cost and energy and will eventually augment the supply from surface water sources.

6.2.1.2 Installing more deep tubewells

Commissioning of Surface Water Treatment Plants is a time lengthy procedure. All the projects will be delayed due to land acquisition purposes, political and local influences, delaying of loan and other unforeseen causes by at least 4-5 years to go into operation. For the time being, additional DTWs can be installed to replenish the deficit. Meanwhile, after the

SWTPs go on operation, these DTWs will be stopped operation or controlled in a moderate production level.

Excessive pumping from DTWs lowers the groundwater table and causes wells to no longer be able to reach groundwater. As the water table lowers, the water must be pumped further to reach the surface, using more energy. Breakdown of pumps occurs frequently. In extreme cases, using such a well can be cost prohibitive. Also, land subsidence occurs when there is a loss of support below ground. Installing DTWs on need basis can be only a temporary solution. This practice is not sustainable.

6.2.1.3 Sustainable groundwater plant

Sustainable groundwater plant like Tetuljhora Bhakurta Well Field Plant, Phase-I, is a great opportunity to increase the water supply in a sustainable way. More aquifers with enough recharge potential nearby Dhaka city have to be identified to construct such plants. But over pumping from those wells would cause temporary drawdown which would eventually affect local shallow tubewell production. So, proper study on the aquifer system including determination of hydraulic connectivity between upper and deeper aquifers is necessary before implementing any such project. By estimating annual potential recharge in Bhakurta aquifer, it is necessary to keep annual discharge less than the recharge, along with maintaining proper well spacing, said one of the informants.

6.2.2 Demand management strategies

6.2.2.1 Promoting optimum water demand

Water demand to reach the consumption levels that are equitable, efficient and sustainable is the key goal to water supply management. The chief motto of sustainable water consumption (SWC) is to reduce water footprint and pollution from consumption. Water conservation is also possible to attain by adopting the optimum water consumption pattern which is sustainable of course in terms of quantity. According to WHO, minimum of 50 lpcd is required to fulfill the needs for consumption and hygiene (Gleick and Iwra, 1996). Here, 5 lpcd are required for drinking water, 10 lpcd for food preparation, and 35 lpcd for bathing and sanitation services. For the highly populated cities, 50 lpcd is sustainable and also sufficient to ensure optimum water consumption (WHO, 2013). This will be also helpful for reducing water footprint, ensure conservation and manage water demand in the urban areas of the world. Here, 50 lpcd is considered as a SWC (Sustainable Water Consumption) level according to WHO minimum requirement (Howard and Bartram, 2003). At present, water demand per capita is considered as 140 lpcd. It emerges that if 50 lpcd can be consumed the water demand reduces by more than 60% and if 100 lpcd can be consumed the water demand trims down by 40% in Dhaka city. In the present condition if water footprint can be reduced by promoting the sustainable consumption, groundwater depletion can be reduced significantly. Initially it may be challenging to achieve 50 lpcd, but it can be started from 100 lpcd then gradually it can be turned to 70 lpcd and then to 50 lpcd. Since, our per capita water consumption is increasing per year, enough span is there to trim down the per capita water consumption. Simultaneously, it is also needed to keep in mind that 50 lpcd water are to be available to all.

6.2.2.2 Rainwater harvesting

Rainwater harvesting can be an alternative source of domestic water supply system. This system can be recommended in areas where rainfall is adequate and space is available for storing of rainwater and use it later for non-drinking purposes.Monsoon usually lasts from May to October and occasional rainfall in November. During this period, it gets ample rainwater, which could reduce the dependency on groundwater at least for 6 months. It is revealed from the literature that about 15% of the total supply can be met by harvested rainwater. Dhaka City has around 370 km^2 of land with a roof area of 75 km^2 as there are around 675,000 concrete houses (Islam et al, 2010). Afreen (2010) estimated from the mass curve analysis of Dhaka city, that the maximum excess water of $0.25m^3$ is available during the month of October and maximum deficit of $0.38m^3$ water occurs during April. As much as 33% of water demand can be met by RWH with individual harvesting system and up to 10% water demand can be met with community based RWH system.

From KIIs, it was found that if the harvested water can be used for toilet flushing and cleaning the house purposes, then 30 percent water can be saved from conventional piped water supply system.

Recently, IWM has estimated that around 1,49,160 million L of water can be harvested during the rainy season in Dhaka city (Islam et al, 2010). This would reduce the dependency on groundwater at least during the six months of monsoon. In addition, one-meter rise in water level due to the harvesting would save 0.40 kilowatt hour of electricity in the load shedding stricken city (UN-HABITAT, 2013). Under the normal year climate scenario, the potential savings of water from 500 to 1337 KL and energy from 174 to 401 kWh per year can be achieved and about 11% to 19% water can be supplemented from the RWH system (Karim et al., 2021). To put the system into practice, the government has already amended the Bangladesh National Building Code 2020, making the provision of rainwater harvesting mandatory for all new houses in Dhaka Metropolitan area (BNBC, 2020).

The Key Informants put emphasis on introducing awards or subsidies to encourage rainwater harvesting units to households. Because people will become reluctant to pay extra cost in additional plumbing work.

With a view to promote rainwater harvesting in the country, an exclusive policy in this regard is yet to be formulated. Professionals during KIIs informed that there are several water related public policies like National Water Policy 1999 and National Policy for Safe Water Supply and Sanitation 1998. Other policies related to water and environments are National Environmental Policy 1992, National Forestry Policy 1994 and National Fisheries Policy 1998. But all of the policies do not highlight the importance and proper process of rainwater harvesting.

In the National Water Policy 1999, policies in various aspects are set with a view to improve water resource management and environmental protection (MoWR, 1999). To address the prevailing situation in water supply and sanitation with respect to water availability both in urban and rural areas, government has taken the policy to facilitate availability of safe and affordable drinking water supplies through various means, including rainwater harvesting and conservation. Furthermore, in article 4.6 of section b of this policy, policies have been narrated to preserve natural depressions and water bodies in major urban areas for recharge of underground aquifers and rainwater management. In article 4.7 of section b, it is mentioned that groundwater development for irrigation would be encouraged by both the public and the private sectors subject to regulations that might be prescribed by the government from time to time. In article 4.15, the importance of research and information management is emphasized with a view to inform its stakeholders like specialists, planners, professionals, politicians and the general public to take proper decision about appropriate technology and options to meet policy goals and make them aware of their significance and impact. In this regard the government has taken policy to strengthen and promote the involvement of public and private research institutes and universities to develop and disseminate appropriate technologies for conjunctive use of all waters including rainwater (MoWR, 1999).

In national policy for safe water supply and sanitation 1998, in the definition of safe water supply it is said that ―Safe water supply means withdrawal or abstraction of either ground or surface water as well as harvesting of rainwater; its subsequent treatment, storage, transmission and distribution for domestic use" (MoLGRD, 1998).

Gaps in policies with respect to rainwater harvesting are not well addressed. The situations or cases where there might have been scopes of mentioning use of rainwater in those policies are discussed below.

In article 4.3 section c of national water policy 1999, it is said that ―For sustaining rechargeable shallow groundwater aquifers, the government will regulate the extraction of water in the identified scarcity zones with full public knowledge" (MoWR, 1999). Here promotion of groundwater recharging by rainwater could be introduced.

In article 4.8, there might have been a clause of mentioning use of rainwater and groundwater recharging for the industries primarily based on groundwater for its production or manufacturing and industrial process.

In article 4.11, development of artificial or manmade water recreation facilities depending exclusively on underground water could be discouraged. In limited cases, these could be allowed to develop incorporating rainwater harvesting and recycling of wastewater.

In article 4.12, protection and preservation of environmental resources particularly groundwater resources could be emphasized more by putting provision of encouragement in adopting alternative options of water collection like rainwater harvesting and recycling of wastewater.

In article 4.14 section g, incentives for rainwater harvesting could be mentioned along with other steps mentioned to cover almost all sustainable and practicing options.

In national policy for safe water supply and sanitation 1998, there is no provision of rainwater harvesting in policies for urban water supply. Here, policy could be taken incorporating provisions of rainwater harvesting in buildings or other establishments where water could not be supplied satisfying their rational demand for which permission is given for groundwater abstraction individually.

According to key informants, National water policy 1999, which has endorsed importance of rainwater utilization in some of its articles, should be reviewed and revised in the light of bridging the gaps pointed herein by incorporating rainwater harvesting in achieving various targets set in this policy. The national policy for safe water supply and sanitation 1998 should also be reviewed and revised accordingly. In future exclusive policy on rainwater harvesting may be formulated for better utilization of this potential source of water. Additionally following suggestions are put forward.

To promote rainwater harvesting system, in all the government projects at water scarce areas, incorporation of rainwater harvesting system needs to be ensured first. Then in private projects in particular areas, incorporation of rainwater harvesting system has to be made mandatory in phases. At first in Dhaka metropolitan area, in all public and private development projects, incorporation of rainwater harvesting has to be made mandatory (Haq, 2006).

6.2.2.3 Artificial recharge context in Dhaka city

Majority of Dhaka city is highly built up and paved preventing infiltration of rain or surface water and so therefore, rooftop rainwater harvesting for artificial recharge with lateral shafts with borewells is the most suitable method. Rainwater quality is good and so can be used to improve the quality of groundwater resources. The rooftops of all the buildings are suitable for acting as the catchment of rainfall. The road network of Dhaka city can be used as the rain drain pipe network which can easily direct the rainwater to recharge structures.

During KII with Project Director of Emergency Water Supply Project (EWSP), he emphasis that gravity inflow through injection well can be used as recharge structures because the construction is relatively easier and occupies less space which is suitable for highly urbanized areas. Therefore, rainwater harvesting methods of artificial recharge seem suitable for Dhaka city.

Also every key informant finds the significance that Dhaka City has the prospect of using Managed Aquifer Recharge (MAR) techniques to conserve excess rainwater. The upper Dupi Tila Aquifer provides suitable characteristics and storage capacities for a MAR implementation. The most beneficial results are obtained when MAR is coupled with long-term underground storage and with a water recovery system to supply individual households and industries. In general, four basic MAR techniques such as SAT (soil-aquifer treatment, only in limited spaces), recharge trenches or pits, ASR/ASTR (aquifer storage, transfer, and recovery), and natural wetlands can be suitable for Dhaka City (Rahman et.al., 2013). Some modifications may be required to adjust the techniques with respect to water sources and locations and to keep costs low. A minimum separation distance between the injection well and the recovery well is required to get the advantage of natural attenuation for improving groundwater quality. As the production wells of DWASA are densely located, the minimum spacing requirement might be problematic. In this case, the installation of injection wells in the unsaturated zone will allow sufficient time for the recharge water to reach the regional water table.

6.2.2.4 Effluent treatment plant

Industries such as textile, dyeing etc. are one of the largest water users in Bangladesh especially in Dhaka. When discharged as effluent, that water is polluting the rivers and surface water. Department of Environment (DoE) is working to enforce Effluent Treatment Plant (ETP) in the dye houses of the country. Setting up ETP is a pre requisite for having clearance from DoE for factory setting. As per DoE Director General, 52% of Bangladesh‘s existing industries have established ETP and other 48% industries have not (DoE, 2008).

Many of those factories are directly discharging to the water body. But the factories having ETP, all of them are also not running those 24*7 and many of those ETP‘s are not functioning properly. Many of those ETP‘s are being kept for displaying to the buyers and also to be in the safe position from DoE supervision. There are many factories (mainly medium to large scale) who are having state of the art ETP‘s and they are operating those always. Those factories‘s top managements are keen to protect surrounding environment and they are also complying the DoE regulations. Many of the times they discharge of even better quality then the regulation requires. For many of such cases their ETP‘s efficiency could easily be improved further to save money. There are many cases where ETPs didn‘t grow as the factory size grown. It was not always understood properly whether it is proportional or ETP size or capacity is a different issue and determined differently. There are numerous cases where ETPs are undersize and oversize. Scarcity of land is a common problem here in Bangladesh and so proper customization could not be done.

Key informants have given emphasis on full functional ETP can conserve the quality of river water. From KII it is acknowledged that DoE recently has asked a plan from existing wet processing for giving a plan for being zero discharge in certain period. That means being zero discharge is not a regulation yet but it is being envisioned as one of the future considerations in regulations. Not only from the regulations point of view, it should be considered from ETP management point of view as well. If it is not possible to be 100% zero discharge but still factories can make a plan for increasing its reusing and recycling percentage over the years through the plan and implementation of ‗Road to Zero Discharge‘. This ‗Road to Zero Discharge‘ can reduce the river water pollution to tolerable limit. This will not only help restoration of river water quality but also create path to install smaller version of surface water treatment plant to use the water for drinking purpose by DWASA.

6.2.2.5 Wastewater reuse and treatment

Key informants have paid attention that wastewater is the most underused available water resource while there are numerous technologies that can produce treated water for almost any application. They also added that treatment of wastewater to potable use is expensive; however different qualities of wastewater could be used in a fit-for-purpose manner and thus can help alleviating the pressure on freshwater resources. Rapid population growth in Dhaka will lead to increase number of wastewaters generated and discharged into the water streams. Reusing and reclaiming wastewater act as an efficient mechanism in conserving and extending available water supplies, moreover, they also reduce direct discharge into the water streams and thus serve as an important measure of pollution control (Nazari et al. 2012). Deputy Project Director of Saidabad Water Treatment Plant have admitted that wastewater reuse and reclamation (including grey water use) provide a great opportunity for water conservation and water should be used directly when the quality does not need to be improved for usage. He also points out that natural mechanisms should be first utilized if treatment is required and that natural and constructed wetlands are small-scale treatment options. When demand exceeds the opportunity and natural methods cannot be utilized, hi-tech solutions can be used for as far as the energy usage does not overweight the environmental benefit of using the grey water.

Key informants have agreed that the recycling and reuse of wastewater, non-potable and potable water storage and distribution systems will be required for this recycling effort. Wastewater reuse will require a system that can collect wastewater from users to be treated prior to various uses. This might be a serious challenge since the wastewater treatment in many developing countries in Asia and Africa is still lacking and only a fraction of the wastewater stream is being collected and treated into secondary treatment (Table 6.8).

Table 6.8: Summary of Wastewater Treatment in Different Parts of the World

(Source: Sato et al. 2013)

Region	Percentage (%) of wastewater treated
Africa	No data
Middle East and North Africa (MENA)	51
Asia	32
Latin America	20
Northern America	75
Australia	85
Oceania	No data
Russian Federation and independent states from Soviet Union	28
Europe	71

Key informants also said that wastewater reuse is likely to become one of the major technologies in the future, especially when coupled with aquifer storage and recovery (ASR). Groundwater banking can help overcome the problem of social aversion to drinking recovered water.

6.2.2.6 Greywater recycling and reuse

Greywater is a major fraction of domestic wastewater which is about 75% (volume basis) of the combined residential sewage (Eriksson, et. al., 2002). Greywater might be generated from wash basins, sinks, baths, showers, or washing machines. The volume of greywater produced from single households, multi-storied buildings and community residences seems to be enough to recycle and reuse. Besides these domestic sources, the greywater generated from mosques is a potential source of greywater in Dhaka. According to key informants, greywater has low level of contamination, it has higher potential for treatment and reuse. When greywater is treated and reused either onsite or nearby, it has the potential to reduce the demand for water supply, reduce the energy consumption and meet a wide range of socio-economic needs. By appropriately matching water quality to water need, the reuse of greywater can replace the use of potable water in non-potable applications.

There are several barriers which may impede the development of greywater recycling and reuse in Dhaka.These include limited human and financial resources, reliability of wastewater treatment, system energy demand, economic feasibility of the system, public perception and willingness, social and institutional acceptance, water right issues and political process, sufficient and consistent codes and guidelines etc. In Bangladesh, guidelines and standards for greywater reuse does not exist. Regulations and guidelines for grey water reuse mainly focus on the healthy and environmental impacts and are often established by local authorities. From aesthetic point of view, public acceptance for reusing recycled water can be a big challenge. Greywater recycling system includes collection, storage, treatment and reuse. Recycling of greywater is based on exclusion of black water. For this purpose the plumbing systems should be modified so that the disposal of greywater and black water is facilitated through different pipes. In fact dual plumbing system is essential for successful implementation of greywater reuse schemes. Dhaka is an unplanned urbanized city. The major part of its urban development has been completed. Hence, implementation of a separate plumbing system for collecting greywater for treatment and reuse could be difficult. The costs of retrofitting an existing home with separate plumbing, storage and treatment unit could limit the attempt of wide-scale reuse of greywater in the country. These expenses mainly depend on the current regional cost of tap water and the availability of retrofitting incentives. Moreover, location of installation of a legal, properly designed grey water system can be an issue. If codes are vague or contradictory or if permitting staff and contractors do not have knowledge and experience with grey water systems, the process of installing and permitting could be difficult. Possibly most important to the adoption of grey water reuse, is homeowners‘ acceptance. The willingness of homeowners to incur the expense associated with maintenance and installation of grey water systems is central to widespread voluntary adoption. To overcome these challenges, practical strategies should to be employed depending on the socio-economic condition for implementation of greywater recycle systems in Bangladesh.

6.2.2.7 Reforming water tariff system

Changing in water tariff system was highlighted by the key informants. Present uniform flat tariff system actually is not feasible, reported by the informants. Urban poor and rich people should not pay the same rate. There is high opportunity in reforming the water tariff system. It can be Increasing Block Tariff (IBT) system or Area basis Tariff System or both. Many south Asian cities such as Bengalore, Chennai, Hayderabad, Colombo, Kathmandu have already introduced IBT structures whereas Dhaka is still far behind (Brocklehurst et al., 2002). Seasonal Water and Time of Use tariffs can be set according to water demands and weather conditions. But service quality should also be reformed accordingly. This implementation will eventually achieve at least operation and maintenance cost resulting in an effective water management system.

At the same time, taxes and tariffs should be imposed in private withdrawal of water. At present, private deep tubewell users pay an annual renewal fee. Provision should be added for certain limit of abstraction. Apart from annual fee, monthly or volume based tariff can be introduced in private abstraction.

6.2.2.8 100% metering

The use of meters to measure water consumption and bill for its use is an integral part of many water pricing policies. At present, DWASA is covering 95% of flow meter in deep tubewells. All of the deep tubewells should be incorporated into an effective metering system. But every household is not fully metered. Around 85-95 % of household are metered, which may vary zone wise. From an effective metering system from source to end user, system loss can be calculated. Smart metering and automated operation of flow meter along with household meter can make a drastic change in water consumption. Household connection can also be segregated to apartment level and thus exact consumption of each family can be calculated. This type of management strategy can significantly change the perception of water use and eventually reduce wastage of water.

For example, the development of electronic and mechanical prepayment systems in South Africa stemmed from the need to change the attitude of non-payment for services (Deverill et. el., 2001). A number of individual and community meter systems based on smart card technology have been developed. These can be programmed with a local tariff structure, and also can give managers the information about potential leaks and other problems. This innovation has brought tremendous change in water supply system and it has eventually stopped the local vandalism.

6.2.2.9 Reducing non-revenue water

Non-revenue water (NRW) is water that has been produced and is "lost" before it reaches the customer (non-revenue water, 2021). This is a loss of water. Losses can be of two categories: real losses and apparent losses. Real losses can also be termed as physical losses which occur through leaks or burst of pipes, joints, etc. Apparent losses are sometimes called administrative losses which are through theft, meter inaccuracies, etc.

The DMA initiative by DWASA will replace and rehabilitate the existing distribution network (reason) and aims at reducing NRW from 40% to 15%. As per its definition, the DMA will be extensively metered to gage network status (Alvisi, S. & Franchini, M., 2014). However, the key informants have apprehended that if leakage monitoring and control is not properly implemented, the 24 hour pressurized system may incur significant NRW through its leakages. Also, continuous supply of water in DMA system needs to be ensured to establish a 24 hour pressurized flow. Otherwise, the ultimate goal to reduce NRW will be futile.

6.2.2.10 Ensuring public acceptability and support

Whilst technological and financial improvements to systems can make a significant contribution to water demand management, these are of little value if they are rejected by people because they do not take user perceptions and demands into account, and are perceived as irrelevant or inappropriate.

Public participation is central to ensuring that the overall strategies, policies and individual measures are fully informed by people's perceptions, needs and capacities. This applies very much to the poor, who may easily be excluded from such a process. Many decisions concerning service levels, cost recovery and management systems can and should be made by informed users either individually or collectively, rather than by outsiders making assumptions on their behalf.Effective public participation is therefore needed at different stages throughout the project cycle in order that:

- The approaches adopted are informed of peoples‛ perceptions, needs and capacities, are appropriate;
- People are able to make fully informed individual and collective decisions about the service they are to receive and how it is to be delivered;
- Planners are able to draw on the capacity of people to formulate appropriate strategies, policies and measures; their local implementation and financing; and monitoring and evaluating performance; and
- Users are able to voice their opinions concerning the service they receive, and the utility is able to respond accordingly.

Measures which influence the use of water by the public, or which effect the public's perceptions of the water service provider, need to be supported by measures that ensure public acceptance. Pilot surveys using a range of techniques, such as questionnaires, interviews and focus group discussion, can give indications as to the public acceptability of particular measures. It is important to cover the range of existing and potential consumers, including poor groups who may not have access to the formal infrastructure networks.

6.2.2.11 Promoting public awareness

The involvement of stakeholders in developing a public awareness strategy is key to its success and sustainability. Participation, already discussed above, ensures that the views of different user groups are reflected in acceptable policies, which can then be marketed accordingly. By comparison, a lack of awareness can result in a policy being rejected.

According to informants' view, all of the supply augmentation strategies and demand management strategies should be highlighted through media coverage. Social awareness raising campaign to establish optimum consumption level, encourage rainwater harvesting techniques, install water saving devices should be emphasized. On the other hand, quarterly, half yearly and annual newsletter with a reflection of DWASA's services should be published. DWASA should publish their achievements and liabilities to the consumers.

6.2.2.12 Water saving devices and practices

The key informants have put significant emphasis on potential to conserve water in domestic and non-domestic premises through the adoption of water saving devices and practices. These are likely to focus on higher income households with multiple tap connections, institutional and industrial users. The impact can be considerable in terms of the quantity of water saved. Some water saving devices that may be appropriate in the context of developing countries are compared in Table 6.9.

If a significant quantity of water saving devices are needed, it may be necessary to facilitate the local manufacturing. Low flow shower units, spring fitted faucets and water closets (WC) cistern conversion kits from single to dual flush, or simply to reduce the flush volume) are relatively simple to manufacture. It is important to check that the existing regulations allow for water-saving devices to be installed.

Table 6.9: **Water Saving Devices and Options (Source: Deverill et al., 2001)**

Water Saving Device/ Measure	Remarks
Replacing seals and conversion of existing Water Closet to low or dual flush	In many higher income areas, WCs may account for a substantial proportion of domestic and institutional consumption. Many flush WCs fitted with a flap valve leak. The flush volume of many existing WCs can be reduced by 20% or more with a water filled bottle or similar. Cisterns can be converted into dual flush with a simple kit that may be suitable for local manufacturing.
Installation of water efficient washing machines	Washing machines are a major water user in many higher income areas. Promoting their eventual replacement with water efficient models is a long-term strategy funded completely by users.
Water saving Urinals	Flush controllers may be a highly cost-effective water saving measure for institutional users in particular. Because people use the water frequently and for different purposes. Waterless urinals have been developed, but need special filters that may not be locally available.
Low flow shower Installation	A shower kit that plumbs into the bath taps is a cheaper option. The average shower uses about half the volume of a bath.
Recycling of grey Water	For households, grey water (from sinks, baths and showers) can be used directly to irrigate a vegetable garden. With minimal treatment, it can also be used to flush WCs. This may be cost effective for hotels, commercial and institutional users.

6.2.2.13 Efficiency improvement

To increase efficiency in the management system more improvement is required. Capacity building for smooth performance of DWASA officials along with field level staff is mandatory. Key informants have informed that DWASA is practicing as passive respondents to any operational and maintenance problem. There is still many lacks of managerial capacity to make DWASA response actively to any problems. Technological improvement of total systems along with training facilities to build skilled management is important for smooth running of DWASA.

Supply oriented management of water supply is an important tool to meet water demand of consumers. But on the other hand, if demand management strategies cannot be implemented, only augmentation of flow will not result in successful water supply management. The role of water demand management in averting potential water shortages will become increasingly important. However, to take advantage of its full potential, water demand management has to be fully incorporated into water management practice. Summary of proposed adaptation strategies according to the level of responses from the key informants is presented in Table 6.10.

Table 6.10: Summary of Findings on Potential Adaptation Strategies from KIIs

Name of Adaptation Strategies	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
Surface Water Treatment Plants	√				
Installing more Deep				√	

Tubewells					
Sustainable Groundwater Plant		√			
Promoting Optimum Water Demand		√			
Rainwater Harvesting and Artificial Recharge	√				
Reforming Law and Regulation Regarding Rainwater Harvesting and Artificial Recharge	√				
Effluent Treatment Plant		√			
Wastewater Treatment			√		
Greywater Recycling and Reuse		√			
Reforming Water Tariff System		√			
100 % Metering	√				
Reducing NRW	√				
Ensuring Public Acceptability and Support	√				
Promoting Public Awareness	√				
Water Saving Devices and Practices		√			

Efficiency Improvement	√				

Most of the strategies got high acceptance and only few got a low acceptancefrom key informant‘s level of responses. Installing new deep tubewells is disagreed by most of the respondents. On the other hand, wastewater treatment is a great alternative to conserve fresh water. But the procedure is so expensive for a country like Bangladesh. So, respondents give mixed responses regarding this and most of them want to stay neutral. Other strategies are agreed by the respondents and all the strategies can be implemented if properly planned.

From the emphasis put by the informants on different strategies, area wise adaptation has come forward as a source of solution in better management of water supply. Well known areas with their surroundings have been categorized according to major problems and adaptation strategies are suggested according to source of supply. Summary of area wise adaptation strategies are given below:

Table 6.11: Suggested Area Wise Adaptation Strategies

Location	Major Problems	Suggested Approach
Demra, Matuail, Shyampur, Donia,	GW depletion, poor network system, bad smell etc.	Mandatory provision for RWH and AR, greywater reuse in suitable places, controlled GW flow through SCADA, major proportion of supply should be meet up through surface sources (Saidabad Water Treatment plant), leakage monitoring to reduce NRW, Convert the whole network system to DMA.

Gendaria, Old Dhaka, Lalbagh, Azimpur	GW depletion, faulty meter, poor network system, bad smell, suspended solids etc.	Mandatory provision for RWH and AR, greywater reuse in suitable places, controlled GW flow through SCADA, major proportion of supply should be meet up through surface sources (Padma Water Treatment plant), changing faulty meter, leakage monitoring to reduce NRW, Convert the whole network system to DMA.
Dhanmondi, Mohammadpur	GW depletion	Mandatory provision for RWH and AR, greywater reuse in suitable places, controlled GW flow through SCADA, major proportion of supply should be meet up through surface sources (Padma Water Treatment plant).
Gabtoli, Mirpur, Cantonment	GW depletion	Mandatory provision for RWH and AR, greywater reuse in suitable places, controlled GW flow through SCADA, Creating SW sources from nearby river (Turag, Buriganga etc.).
Uttara	GW depletion	Mandatory provision for RWH and AR, greywater reuse in suitable places, controlled GW flow through SCADA, major proportion of supply should be meet up through surface sources (Gandrarbpur Water Treatment plant) and creating alternative SW sources.
Badda, Boshundhora	GW depletion, poor network	Mandatory provision for RWH and AR, greywater reuse in suitable places, controlled GW flow through

Residential Area	system, bad smell, suspended solids etc.	SCADA, major proportion of supply should be meet up through surface sources (Gandrarbpur Water Treatment plant).
Motijheel, Khilgaon, Bashabo, Banashree, Moghbazar	GW depletion, faulty meter, poor network system, bad smell, suspended solids etc.	Mandatory provision for RWH and AR, greywater reuse in suitable places, controlled GW flow through SCADA, 75-85% of supply should be meet up through surface sources (Saidabad Water Treatment plant), leakage monitoring to reduce NRW, Convert the whole network system to DMA.
Tejgaon, Mohakhali, Banani, Gulshan, Baridhara	GW depletion	Mandatory provision for RWH and AR, greywater reuse in suitable places, controlled GW flow through SCADA, major proportion of supply should be meet up through surface sources (Gandrarbpur Water Treatment plant).

Chapter Seven

Conclusions and Recommendations

7.1 Conclusions

Water requirement in Dhaka city is increasing day by day due to increasing population. The present water supply system of Dhaka is heavilydependent on groundwater source. As the rate of groundwater recharge is not equal to the rateof extraction, there is a sharp decline of groundwater table. Rapid depletion of groundwater could lead to a more disastrous situation for Dhaka city.

This study was conducted to assess the spatial variability in groundwater level depletion trends in Dhaka city using available time series data, assess the present DWASA practices to meet the city water demand and identify potential adaptation strategies in managing water supply for Dhaka cityfollowing an interdisciplinary approach. The specific conclusions drawn from the study aresummarized in the following:

- Water level hydrographs of observation wells have been prepared by plotting the depth to groundwater level against time for the upper Dupi Tila Aquifer. The hydrographs illustrated that all the wells are in critical condition. All of the wells, except GT2662016, exhibits water level depletion situation. At Khilgaon and South Basabo, the annual maximum depletions of GWL are about 2.63 m/yr and 2.15 m/yr, respectively. Surface water supply from the Saidabad Surface Water Treatment Plants adds water to these areas to meet the demand. The declination trend is also statistically significant which is derived from the Mann-Kendall trend test.

- Contour map of maximum groundwater level declining trend of the upper aquifer exhibits that water flows from all around to central area in Dhaka city. Maximum declination was found near South Khilgaon area (around -2.4 m/yr) which indicates more withdrawal of water from upper aquifer and/or less recharge.
- Groundwater flowing situation associated with groundwater abstraction was better depicted from the contour map of minimum groundwater level trend. Maximum declination was also found for South Khilgaon area (around -2.4 m/yr).
- From all the contour maps, it was found that there is little impact of monsoon on groundwater recharge. Groundwater level of all the areas is declining at an alarming rate without any remarkable recovery in the monsoon. Groundwater mining is happening in many parts of the city such as Khilgaon, Sobujbag, Motijheel, Dhanmondi, Sutrapur and Mirpur.
- For excessive abstraction of groundwater, water stressed areas are also identified from the contour map of minimum groundwater level trend. The most water stressed area is found to be Khilgaon. Every year about 2.2 m groundwater level is declining with little or no recharge.
- To reduce the dependency on groundwater, DWASA has undertaken some steps according to its master plan which would be completed by 2035. These include four Surface Water Treatment Plants, one sustainable groundwater treatment plant, improving water supply network system, and emergency water supply through new and regenerated deep tube wells.
- SWOT analysis of existing practices by DWASA is conducted to identify the present and future possibilities of each practice. Surface water treatment plants, strengthening

of distribution network, rainwater harvesting and artificial recharge are found to be the most suitable practices adopted/proposed by DWASA for sustainable water supply management.

- The water demand from population projection is estimated to be 5268 MLD by 2035. Saidabad Surface Water Treatment Plant (Phase – I, II, III) would contribute 900 MLD, Gandharbpur Surface Water Treatment Plant (Phase – I, II, III) 1500 MLD, Padma Jashaldia Surface Water Treatment Plant (Phase – I, II) 900 MLD, and Singair (Savar) Well Field 300 MLD. The rest of the demand would be met through groundwater extraction from DTWs. With the completion of the projects, DWASA plans to reduce its dependency on groundwater and eventually reach to a sustainable water supply.
- According to opinion ofthe key informants, structural interventions (Surface Water Treatment Plants, DMA construction to reduce NRW, new deep tubewells,etc.) can change the water supply system in a better way, but it needs sufficient time and budget. On the other hand, demand management strategies like RWH,AR, new tariff system with IBT structures, water saving devices and promoting optimum water demand just needs a managed approach. These strategies do not need significantbudget to implement, just need a planned management approach. DWASA should focus more on demand management strategies to reduce the water use and conserve the water sources. These will eventually reduce the pressure on groundwater sources.

7.2 Recommendations

Based on the findings of this study, some recommendations are made to improve the water supply system of Dhaka city as follows:

- Increase surface water collection rate and improve the quality of surface water by adopting new technology.
- The city dwellers should be motivated and encouraged to preserve rainwater for their daily use for at least certain period of the year.
- Pollutant load to existing riversshould be minimized by introducing ETP in every industry, be it small or big.
- Recycling of wastewater and reusing it in different works and ways should be promoted.
- Sewage treatment system should be made more efficient so that effluents do not pollute their destinations.
- Devise and implement pro-poor water policies by taking climate change, future urban growth, and consumers‘ water demand and preference into consideration.
- Proper awareness campaign through print and electronic media should be carried out to inform and aware people regarding the right to water and the reduction in misuse of water.
- Private and international investment efforts may be welcomed and regulated in such a way that it could enhance the capacity building of government institutions in order to get drinking water at an affordable cost.
- Decentralization of urban population in Dhaka city will make a better Dhaka in respect to water supply.In Dhaka city, population is increasing day by day. Thermally stressed

area is a consequence of overpopulation which results in health deteriorations of dwellers. It requires more water to treat an ill person of an overpopulated area than to provide water to a healthy person. This leads to increase in water consumption and hence generation of GW and SW.Thus, it is very important to decentralize the population of Dhaka city to avoid passive consequence of increased water demand as discussed above.

- Coordination among different organizations presentin Dhaka city should be increased.
- The misconception regarding price hike of water every year by DWASA should be removed. The increase in water tariff is mainly due to currency inflation.
- In this study, GWL trend analysis is done with time series data from BWDB. This represents only shallow aquifer data for a limited number of stations. Available deep aquifer data from DWASA is not adequate for trend analysis. Hence it is recommended to install more observation wells targeting deeper aquifer in particular and record water level regularly.

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Appendix A

Groundwater Level Hydrograph of Observation Wells from BWDB

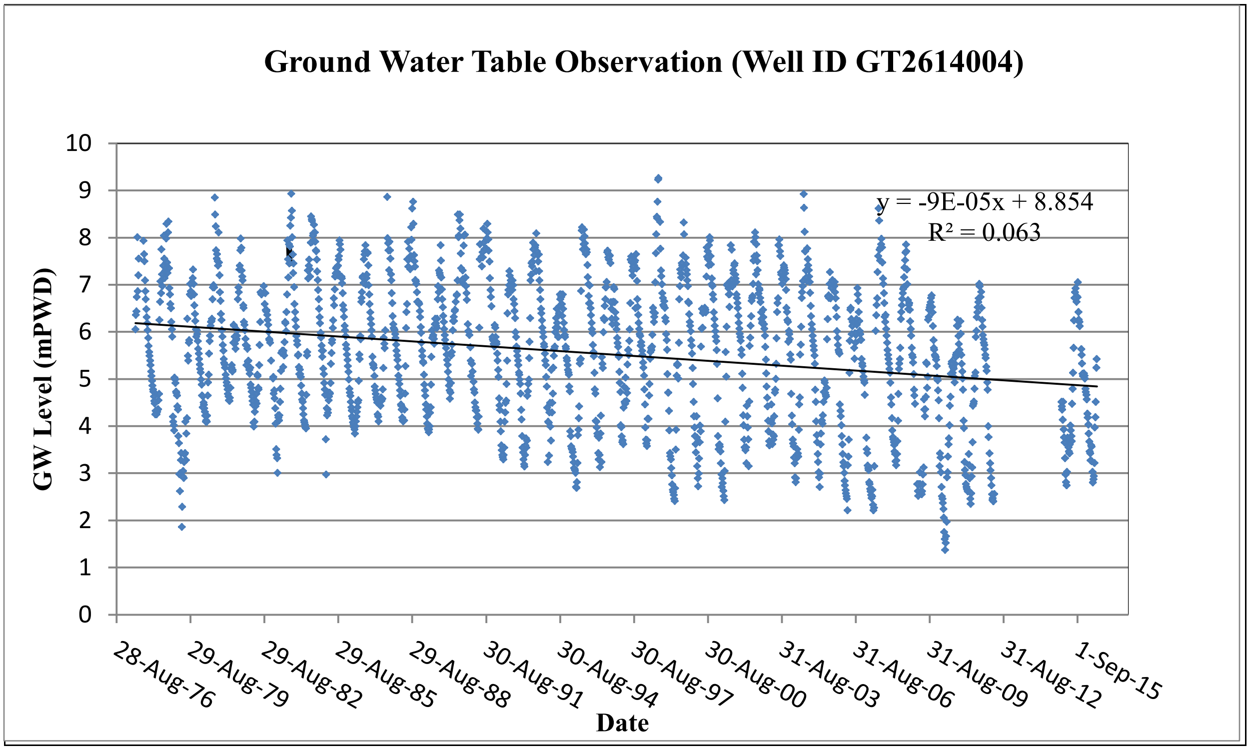


Figure A.1: Groundwater level hydrograph (Location: Well ID GT2614004, Shaha Balishwa, Dhamrai)

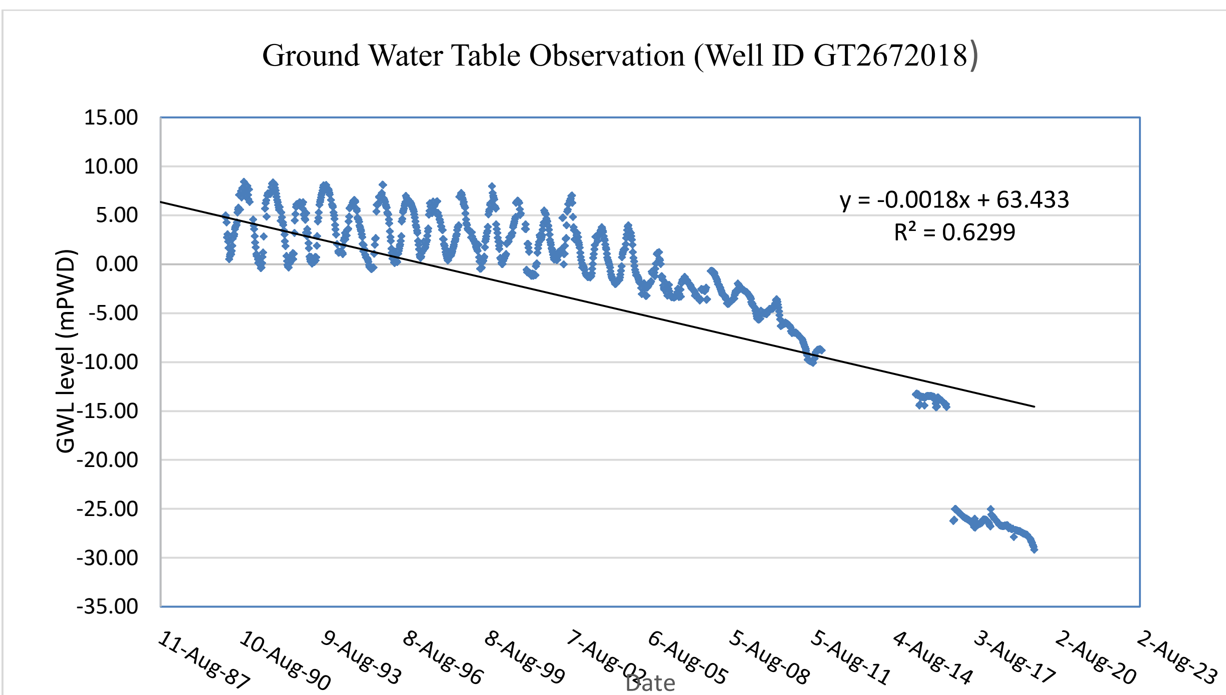


Figure A.2: Groundwater level hydrograph (Location: Well ID GT 2672018,Subandi, Savar)

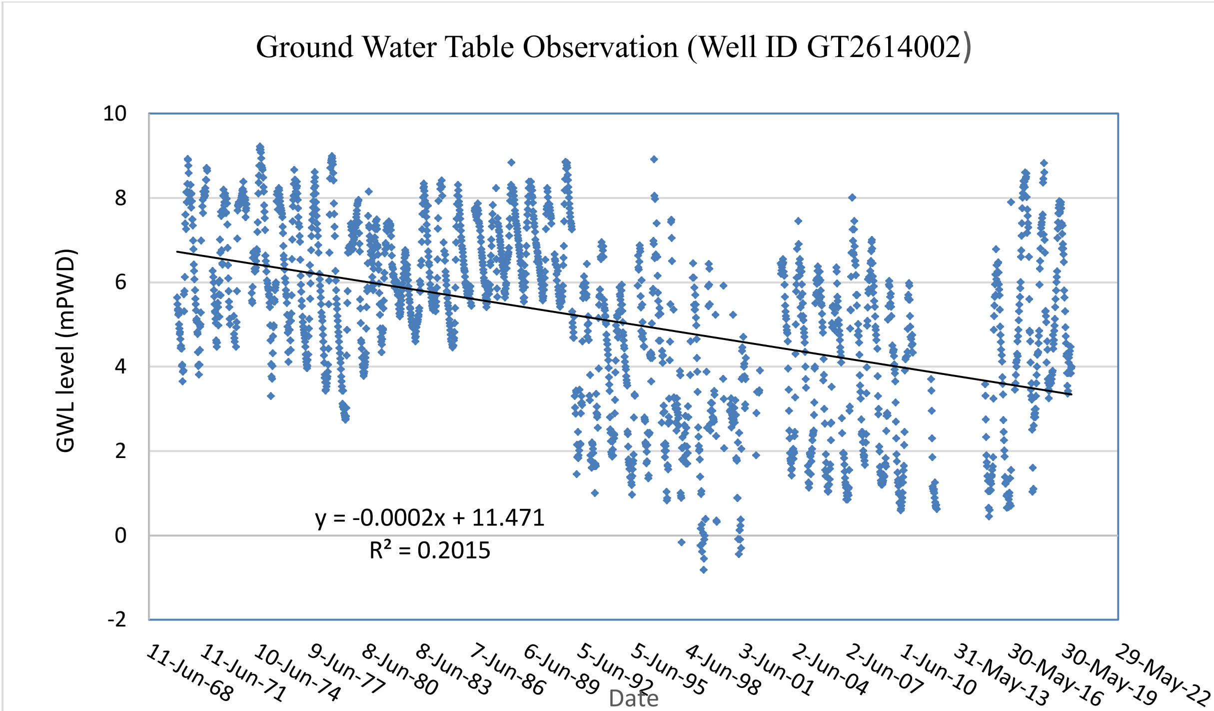


Figure A.3: Groundwater level hydrograph (Location: Well ID GT2614002,Bannal, Dhamrai)

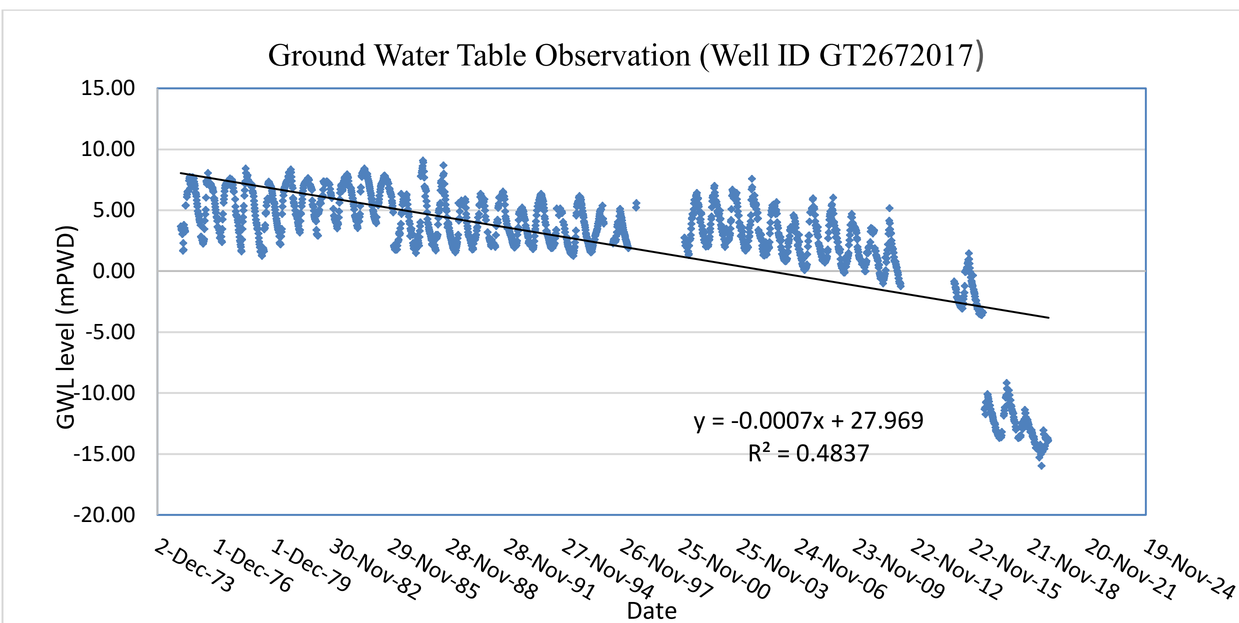


Figure A.4: Groundwater level hydrograph (Location: Well ID GT2672017, Savar)

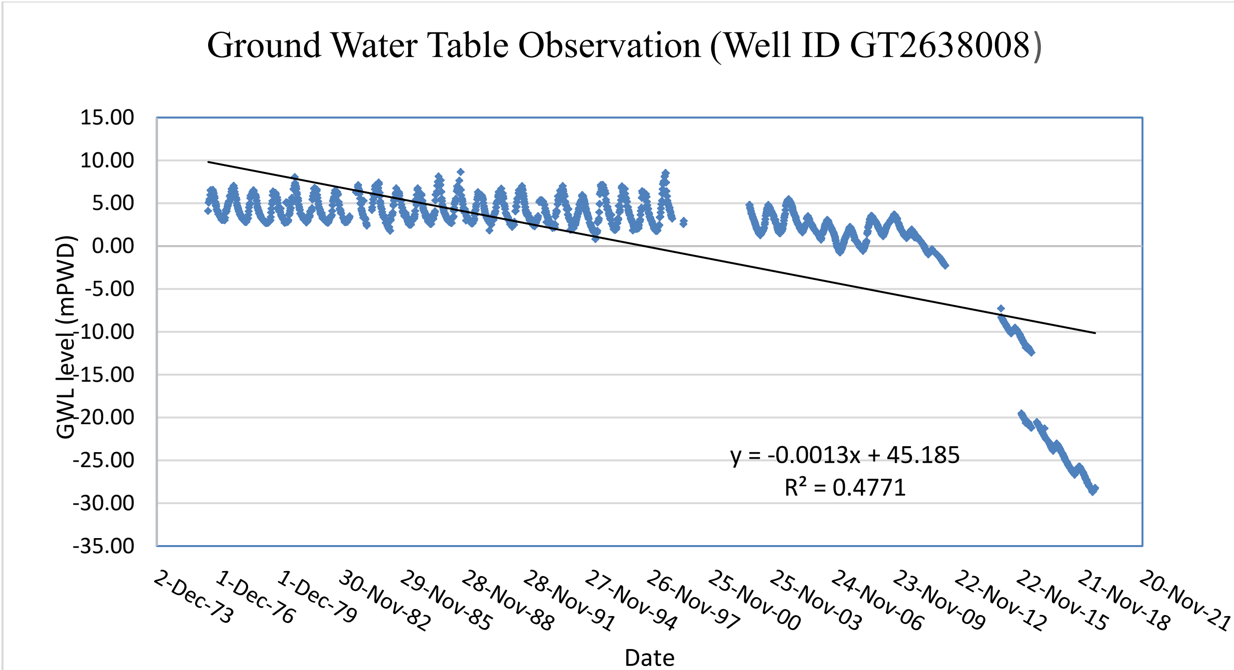


Figure A.5: Groundwater level hydrograph (Location: Well ID GT2638008,Bamonsur, Keraniganj)

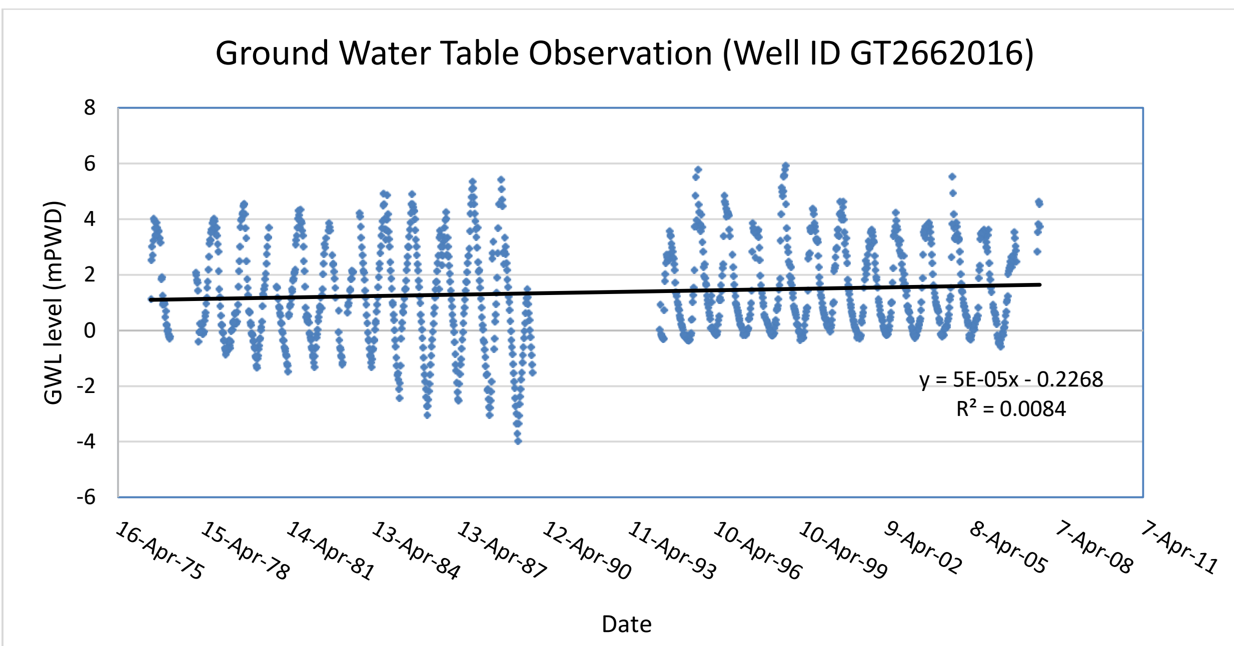


Figure A.6: Groundwater level hydrograph (Location: Well ID GT2662016,Paragram, Nawabganj)

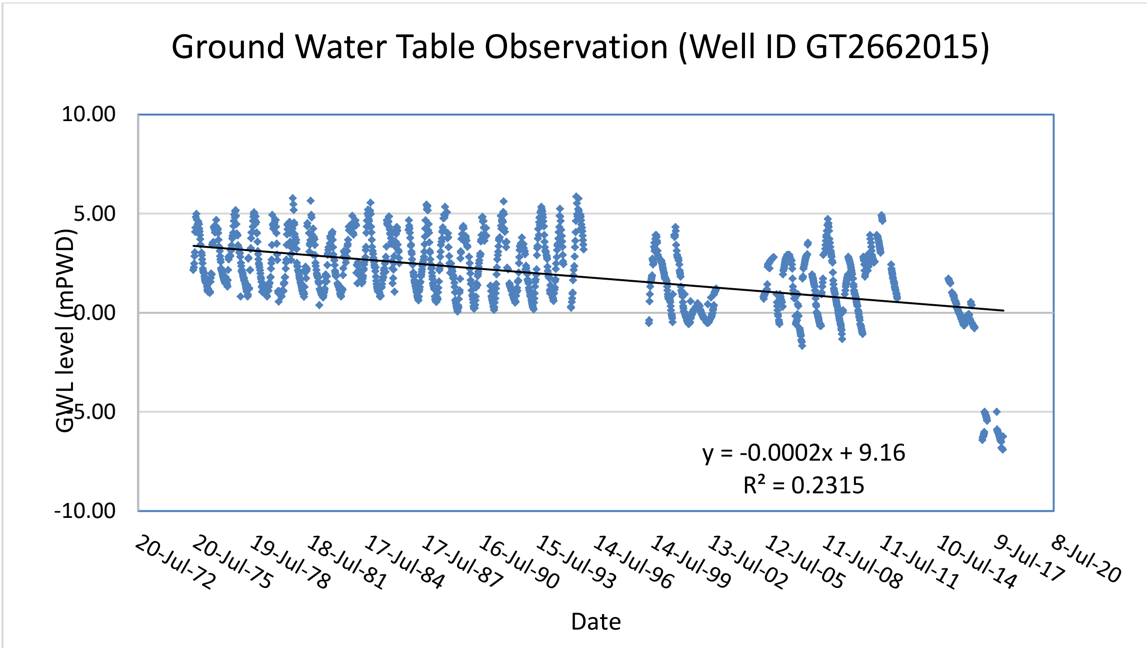


Figure A.7: Groundwater level hydrograph (Location: Well ID GT2662015,Nawabganj School, Nawabganj)

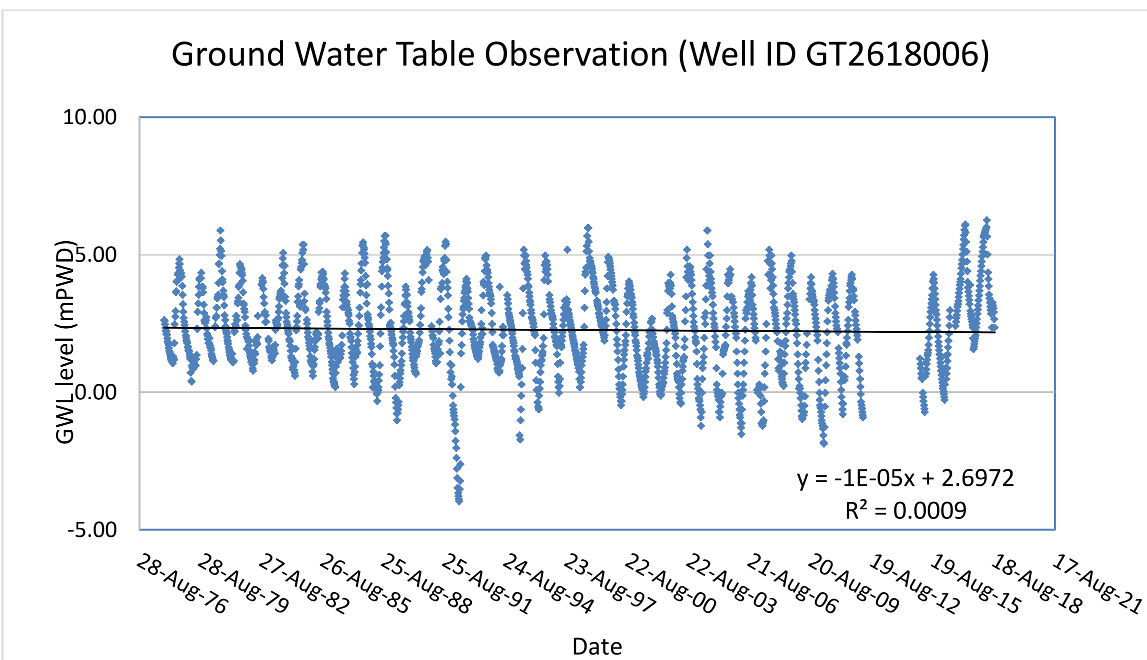


Figure A.8: Groundwater level hydrograph (Location: Well ID GT2618006,Dayagajaria, Dohar)

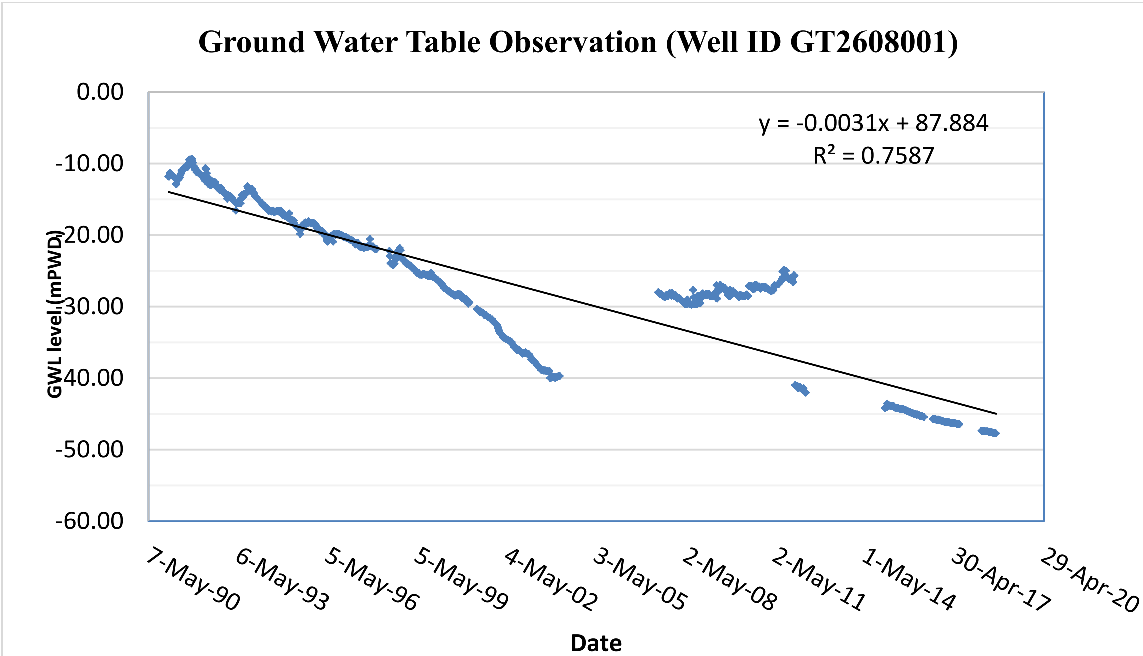


Figure A.9: Groundwater level hydrograph (Location: Well ID GT2608001,Joar Shahara, Cantonment)

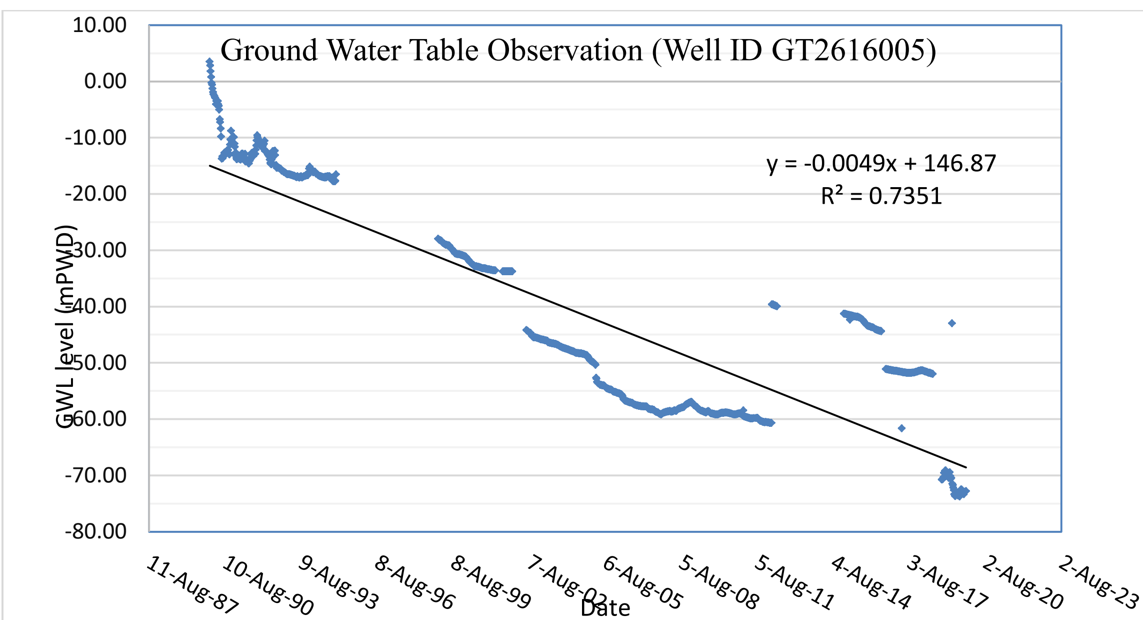


Figure A.10: Groundwater level hydrograph (Location: Well ID GT2616005,Green road, Dhanmondi)

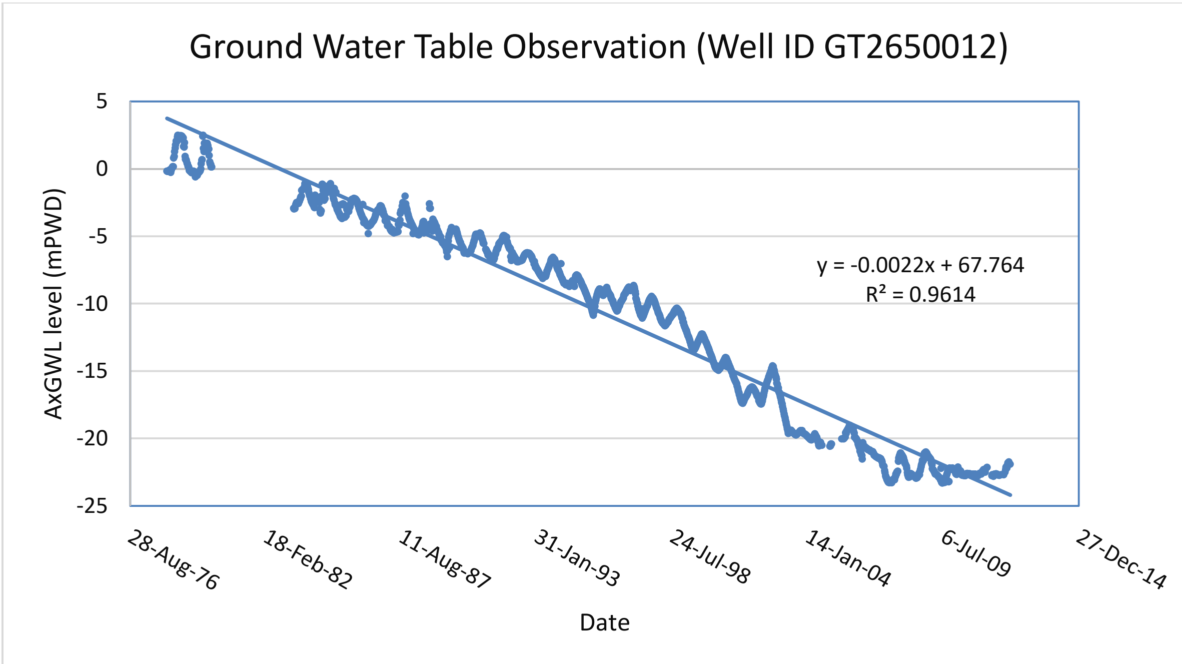


Figure A.11: Groundwater level hydrograph (Location: Well ID GT2650012,Sultangonj, Mohammadpur)

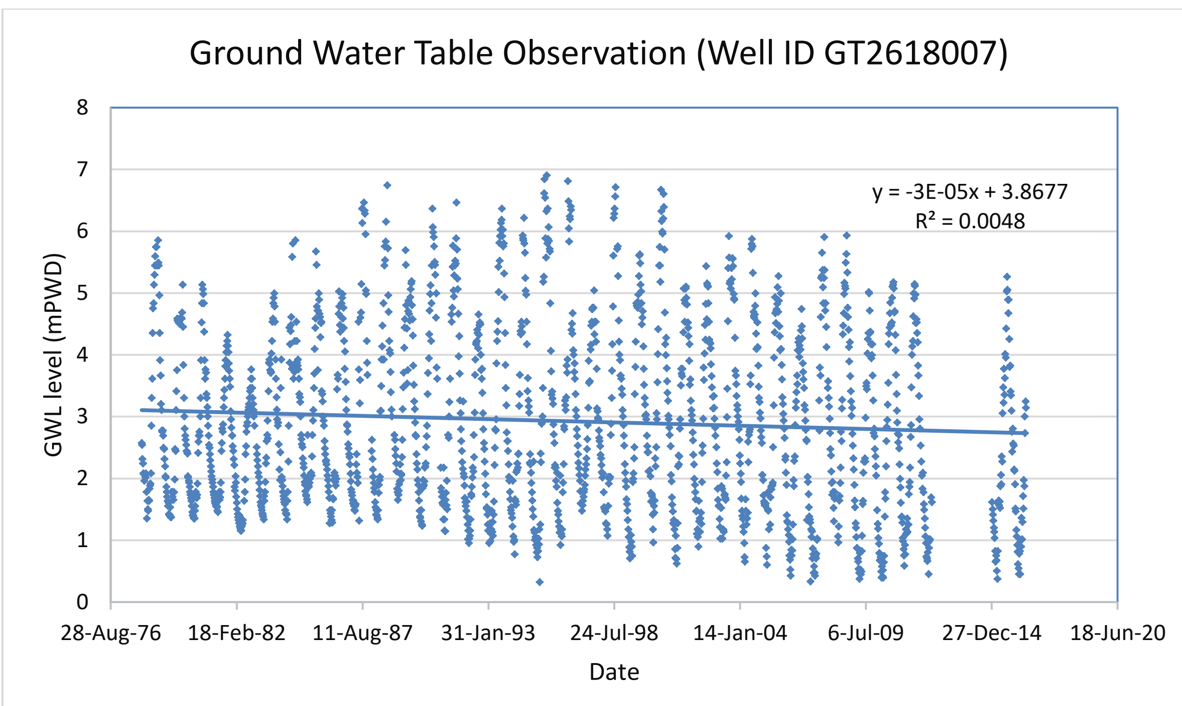


Figure A.12: Groundwater level hydrograph (Location: Well ID GT2618007,Sundaripara, Dohar)

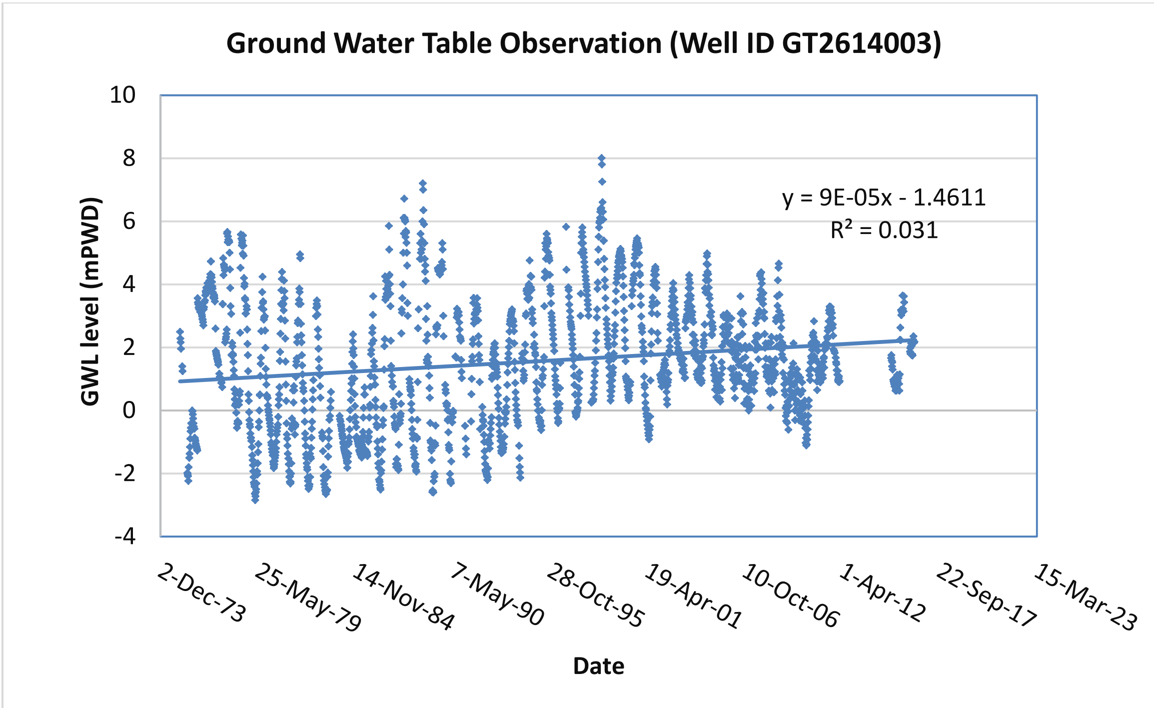


Figure A.13: Groundwater level hydrograph (Location: Well ID GT2614003, Dhamrai)

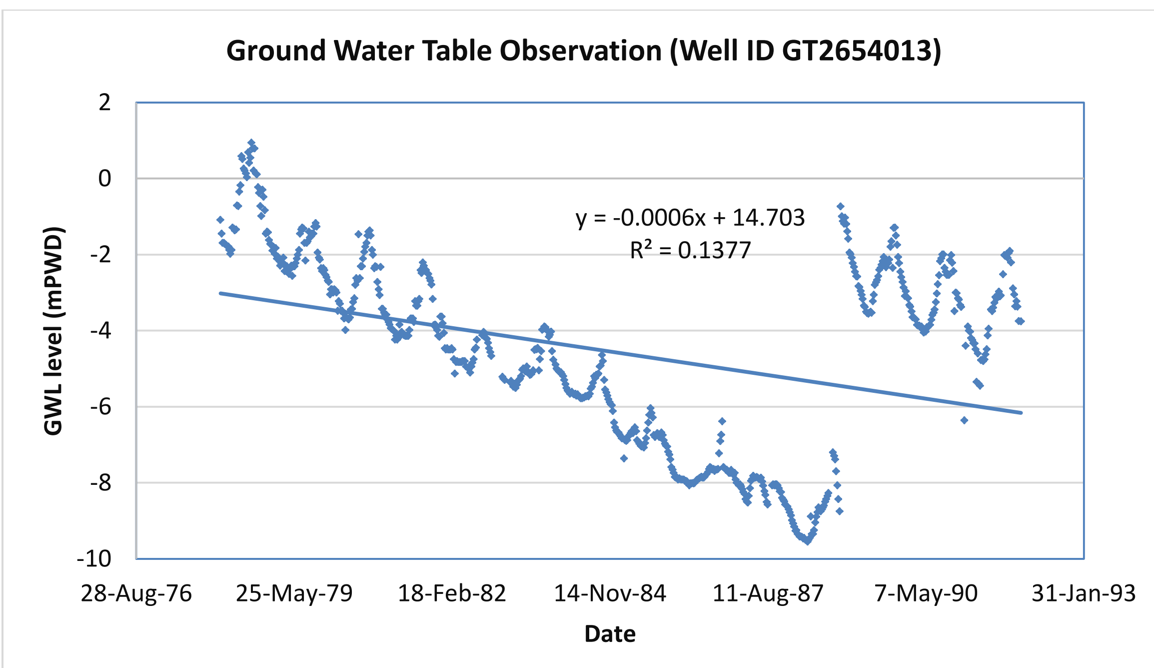


Figure A.14: Groundwater level hydrograph (Location: Well ID GT2654013, Maniknagar, Motijheel)

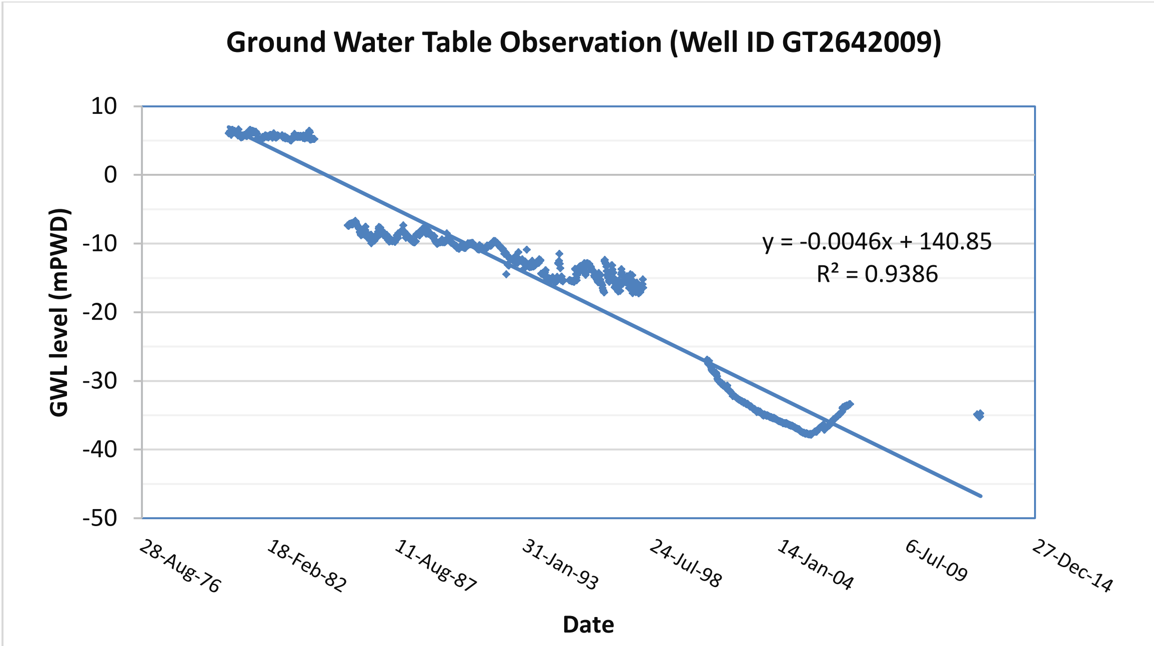


Figure A.15: Groundwater level hydrograph (Location: Well ID GT26142009, Bakshibazar, Lalbagh)

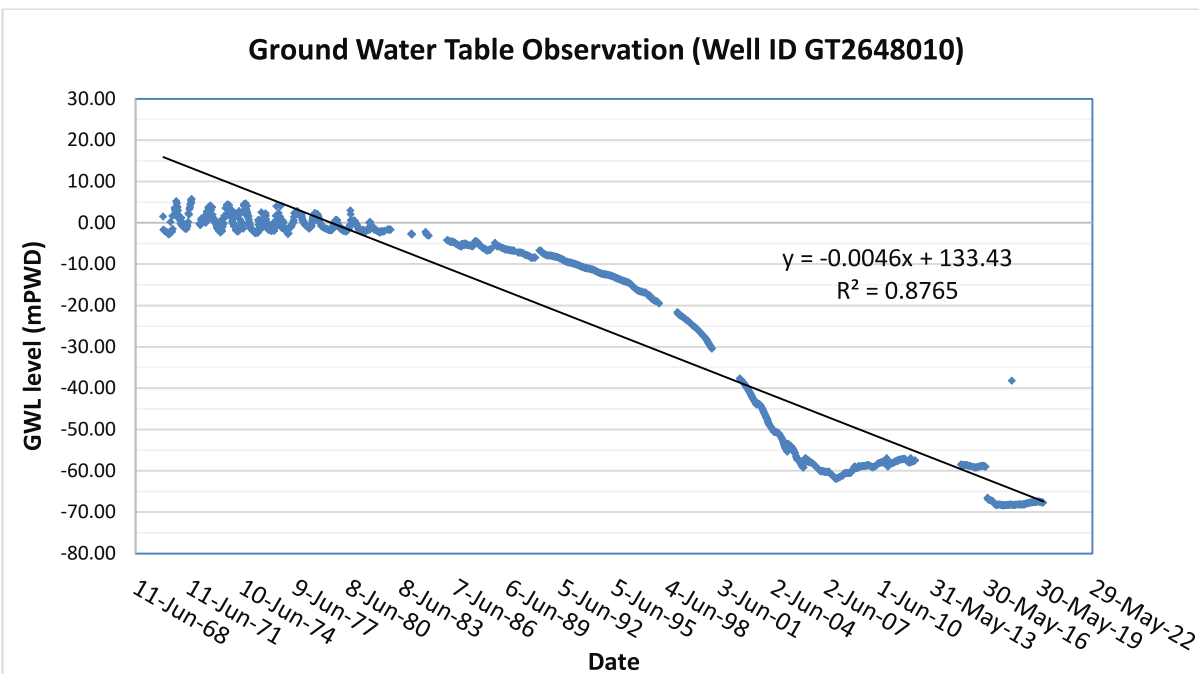


Figure A.16: Groundwater level hydrograph (Location: Well ID GT26148010, New Shewrapra, Mirpur)

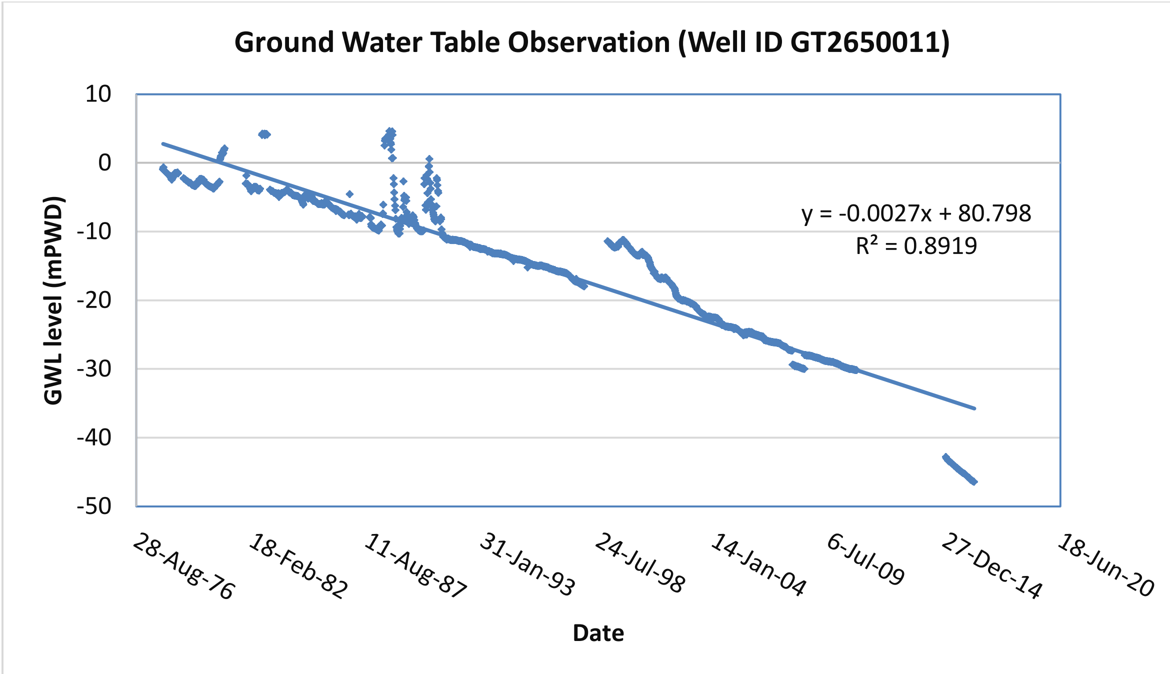


Figure A.17: Groundwater level hydrograph (Location: Well ID GT2650011, Mohammadpur)

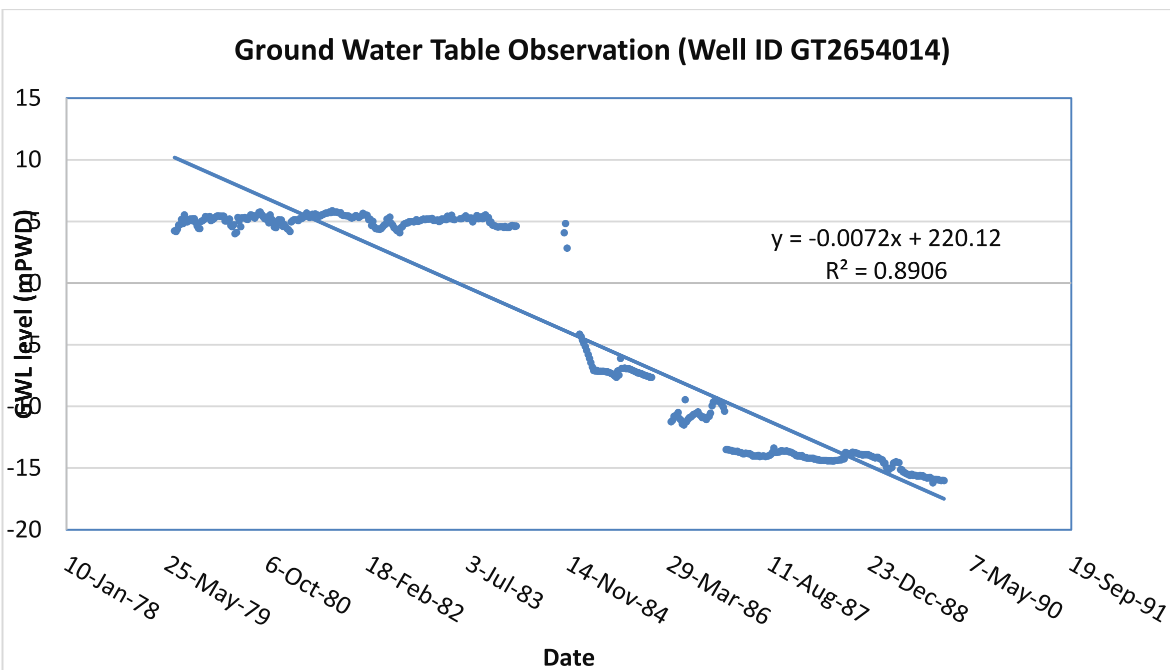


Figure A.18: Groundwater level hydrograph (Location: Well ID GT2654014, South Khilgoan, Motijheel)

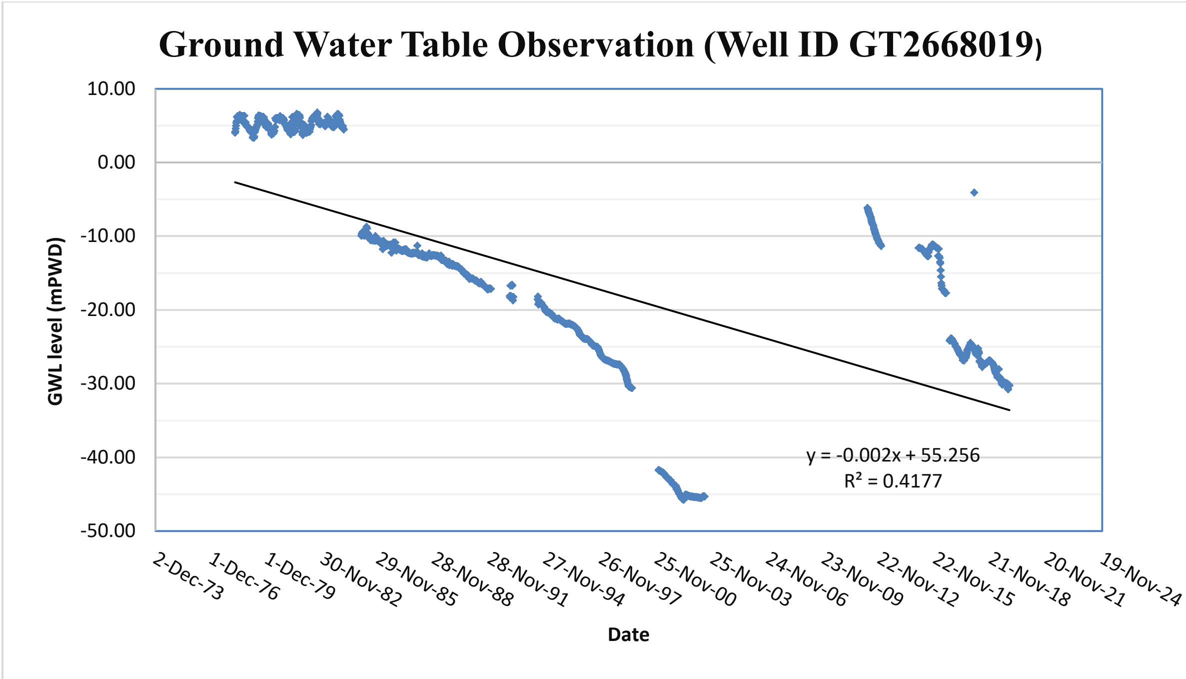


Figure A.19: Groundwater level hydrograph (Location: Well ID GT2668019, Khilgoan, Sobujbag)

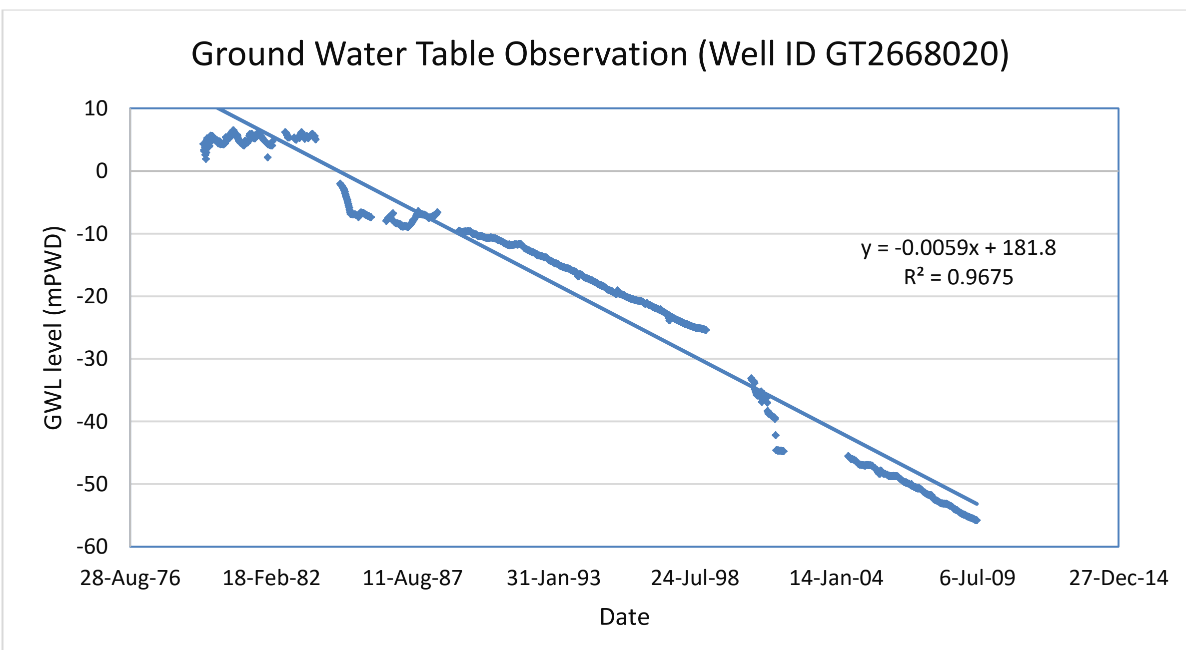


Figure A.20: Groundwater level hydrograph (Location: Well ID GT2668020, South Basabo, Sobujbag)

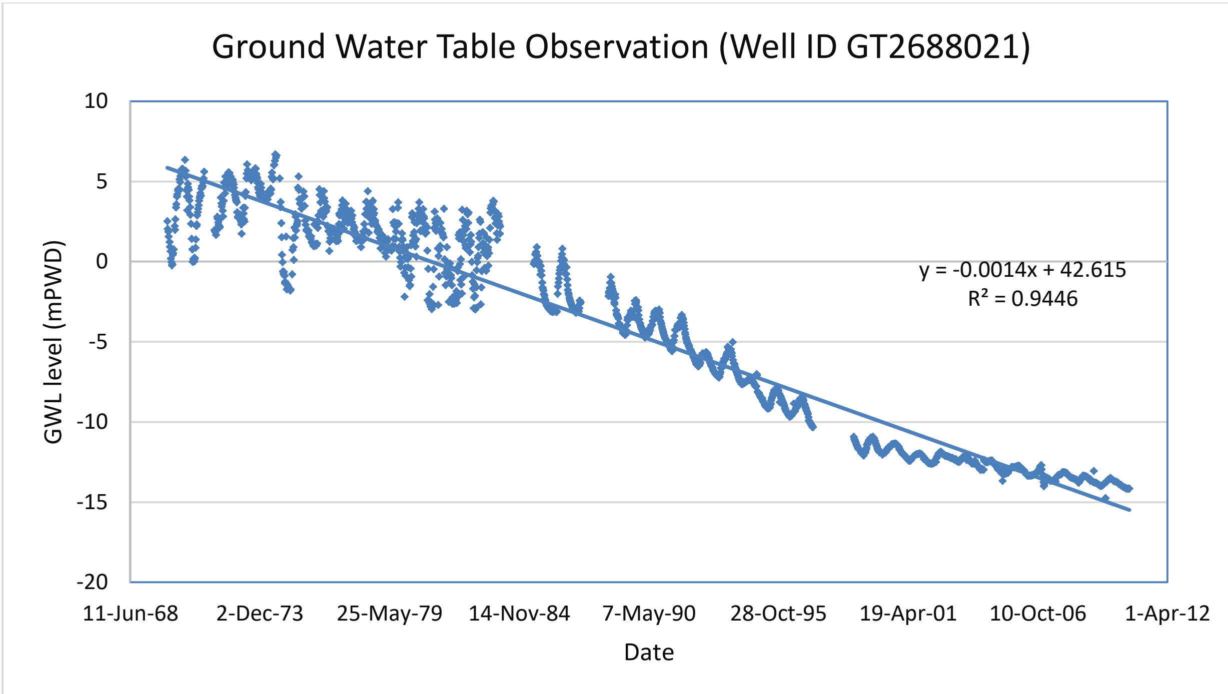


Figure A.21: Groundwater level hydrograph (Location: Well ID GT2668021, Jagannath University, Sutrapur)

Appendix B

Maximum, Minimum and Median Groundwater Level Hydrographs of Observation Wells from BWDB

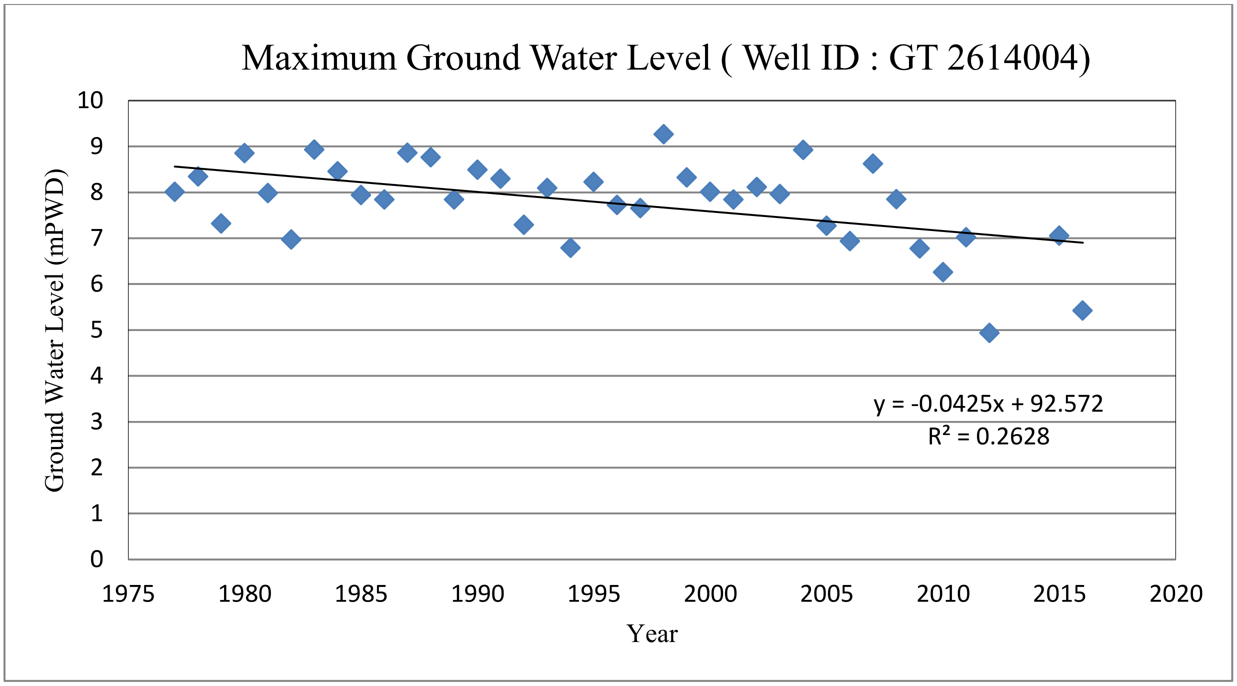


Figure B.1: Annual Maximum Groundwater Level Hydrograph (Location: Well ID GT2614004, Shaha Balishwa, Dhamrai)

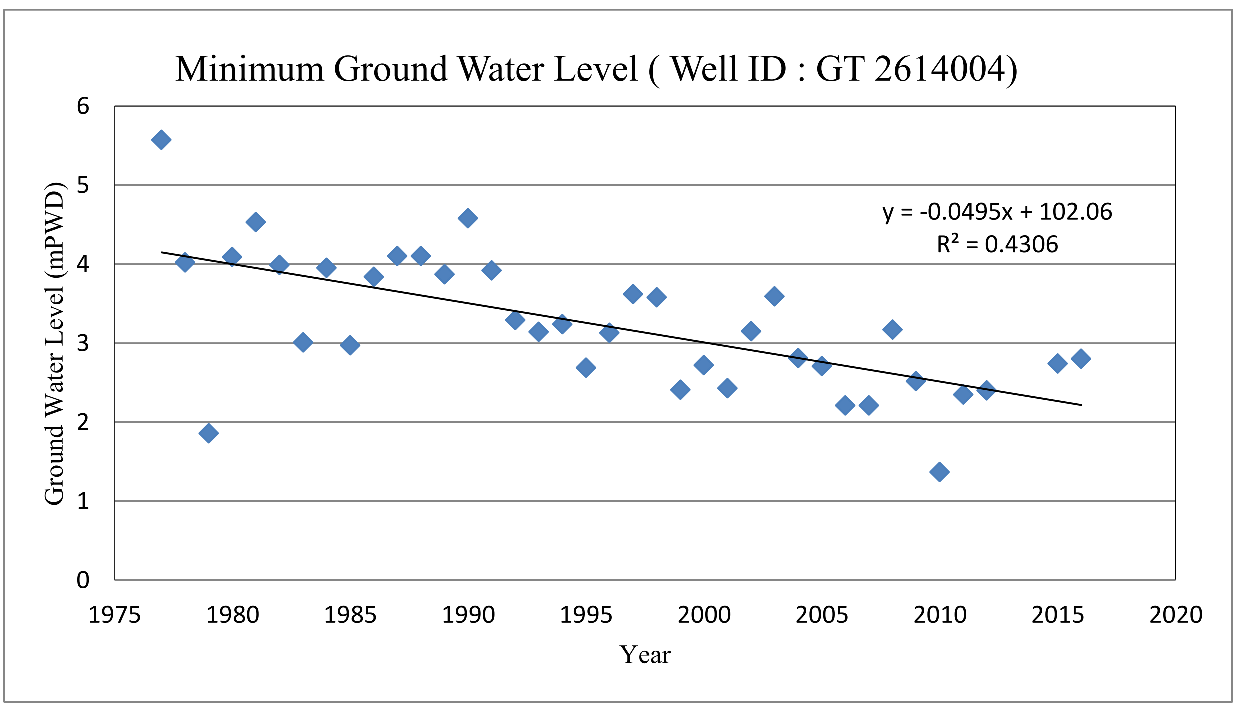
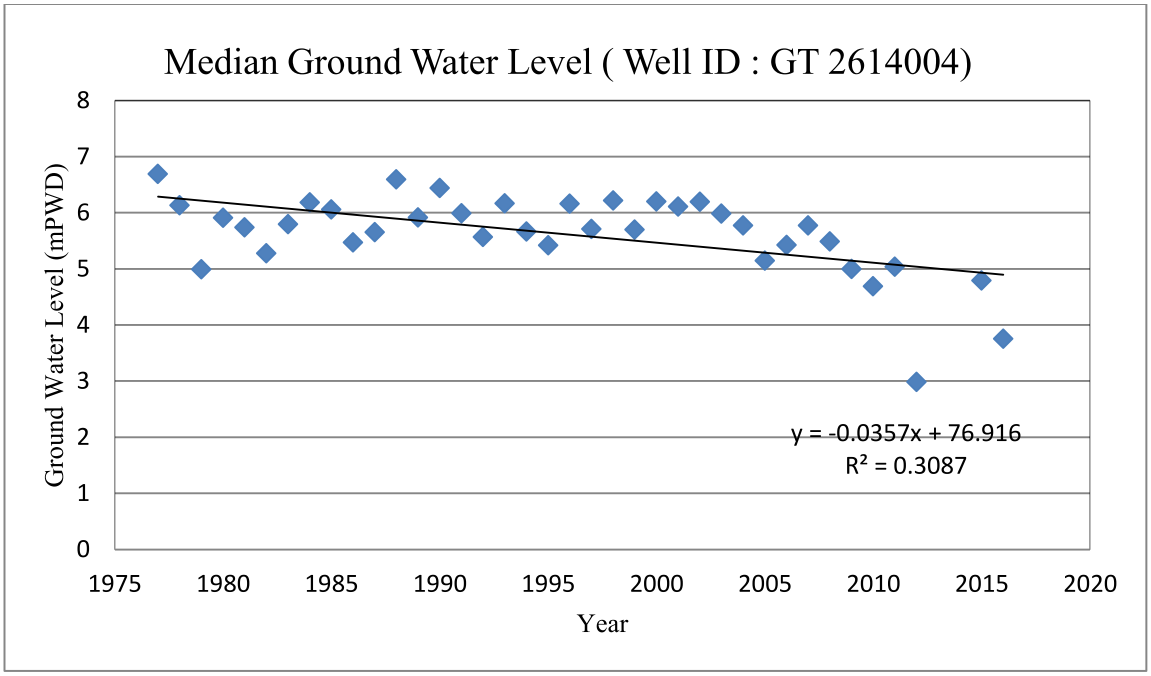


Figure B.2: Annual Minimum Groundwater Level Hydrograph (Location: Well ID

GT2614004, Shaha Balishwa, Dhamrai)



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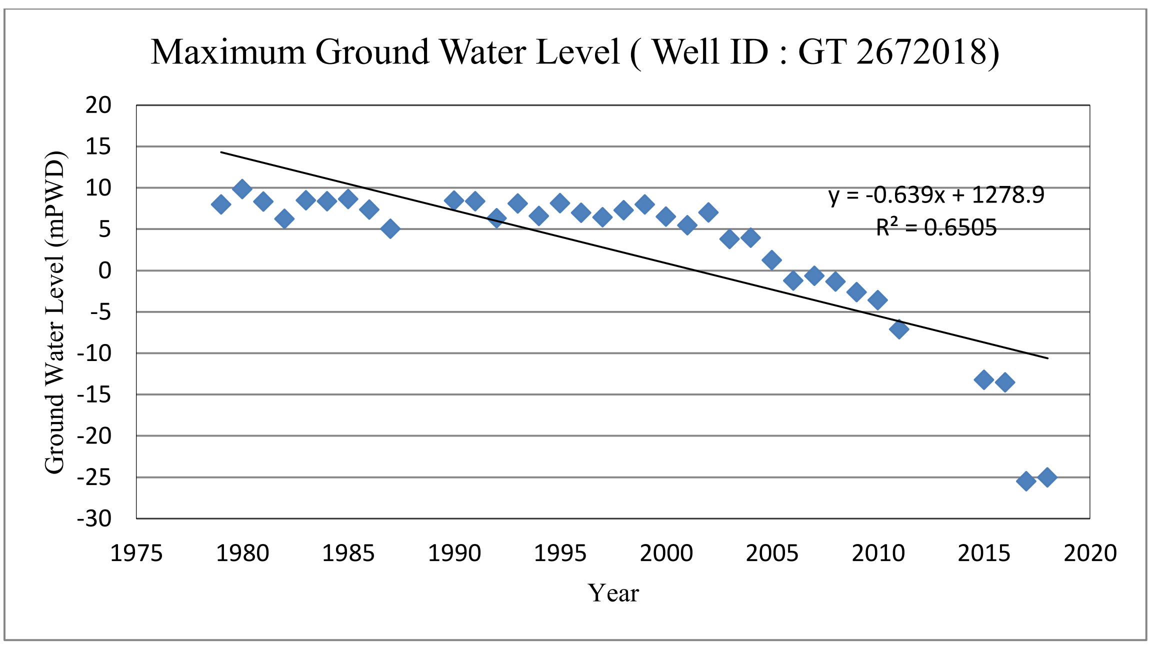

Figure B.4: Annual Maximum Groundwater Level Hydrograph (Location: Well ID GT2672018,Subandi, Savar)

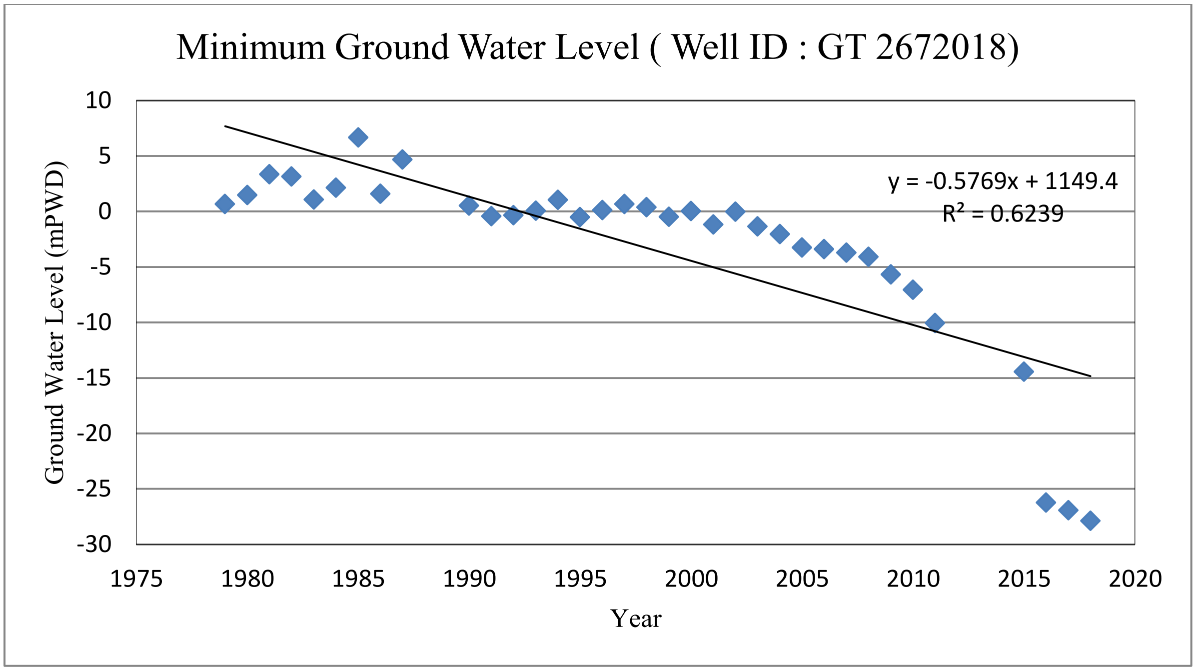

Figure B.5: Annual Minimum Groundwater Level Hydrograph (Location: Well ID GT 2672018, Subandi, Savar))

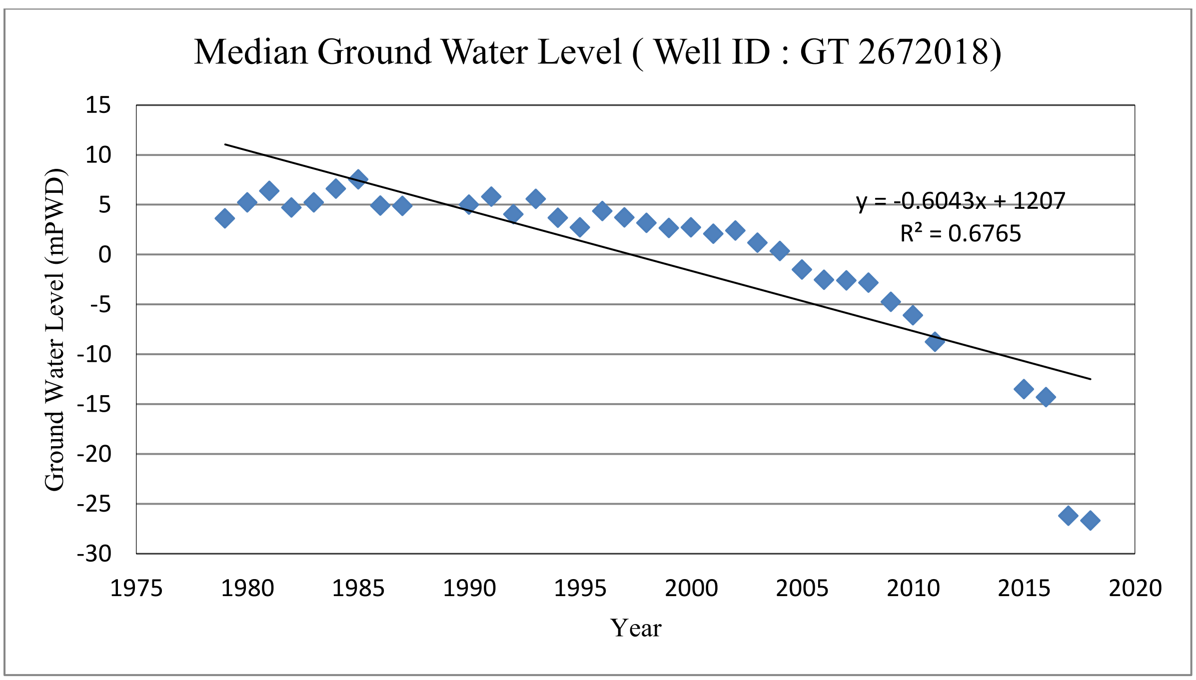

Figure B.6: Annual Median Groundwater Level Hydrograph (Location: Well ID GT 2672018, Subandi, Savar))

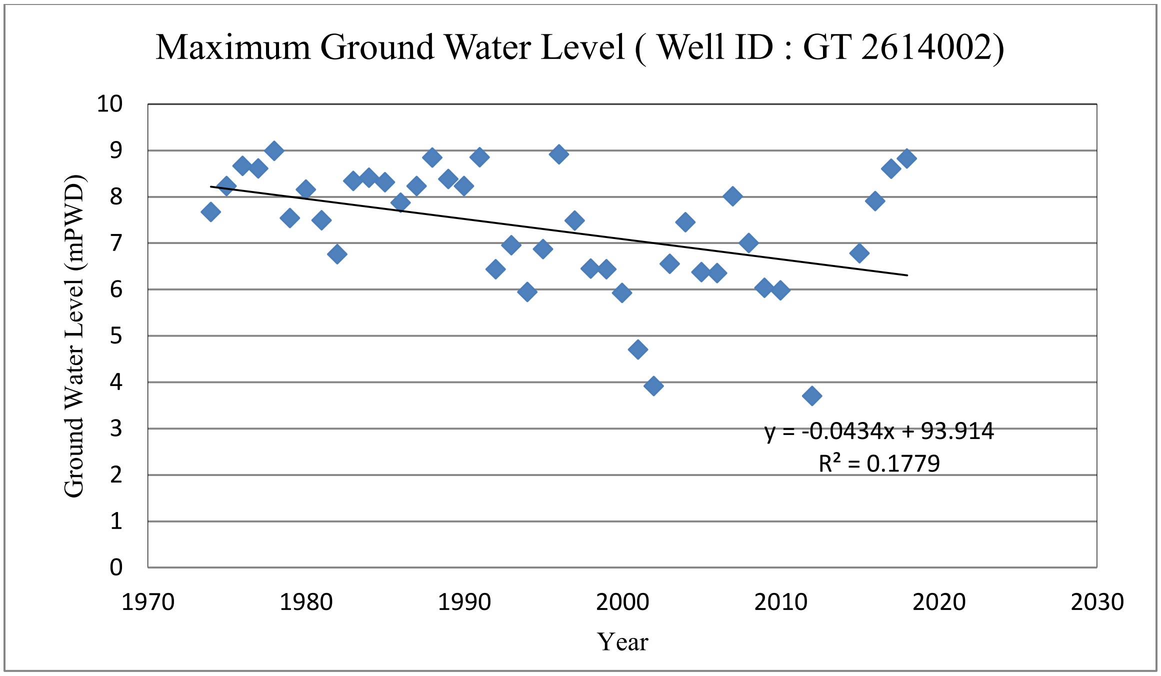

Figure B.7: Annual Maximum Groundwater Level Hydrograph (Location: Well ID GT 2614002, Bannal, Dhamrai)

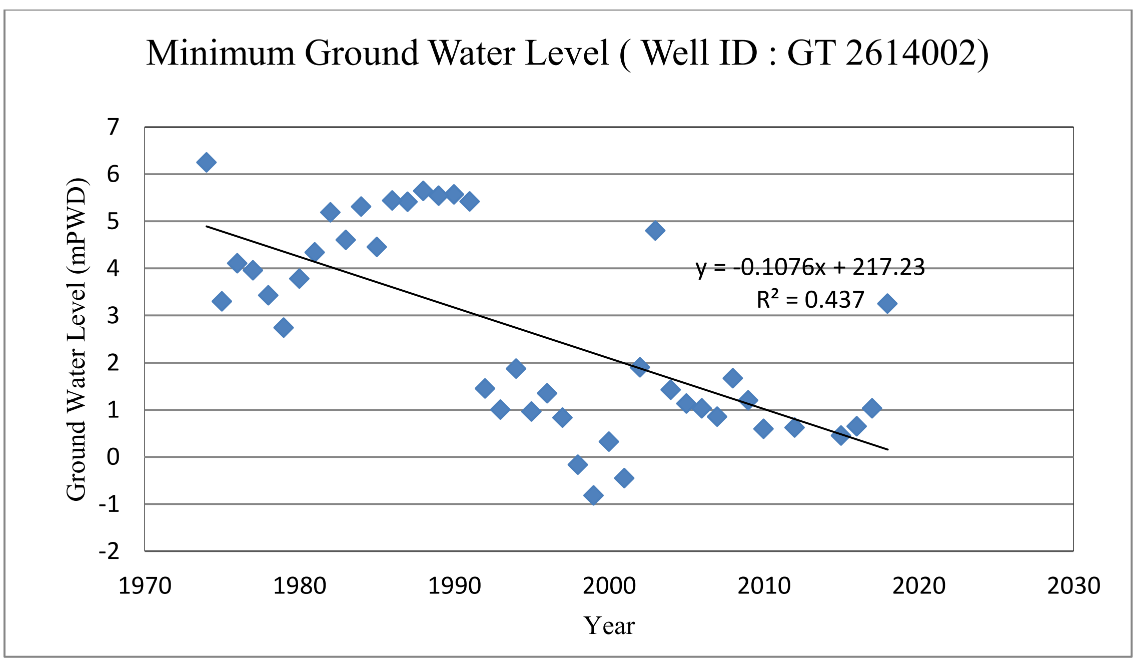

Figure B.8: Annual Minimum Groundwater Level Hydrograph (Location: Well ID GT 2614002, Bannal, Dhamrai)

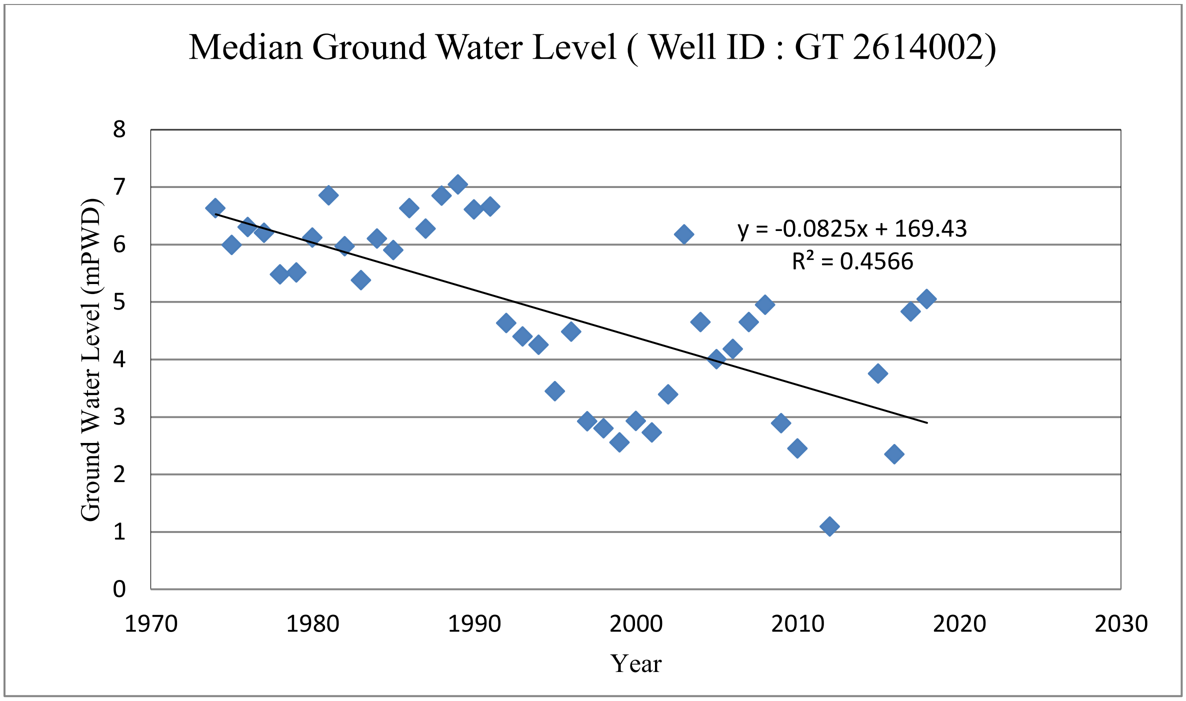

Figure B.9: Annual Median Groundwater Level Hydrograph (Location: Well ID GT 2614002, Bannal, Dhamrai)

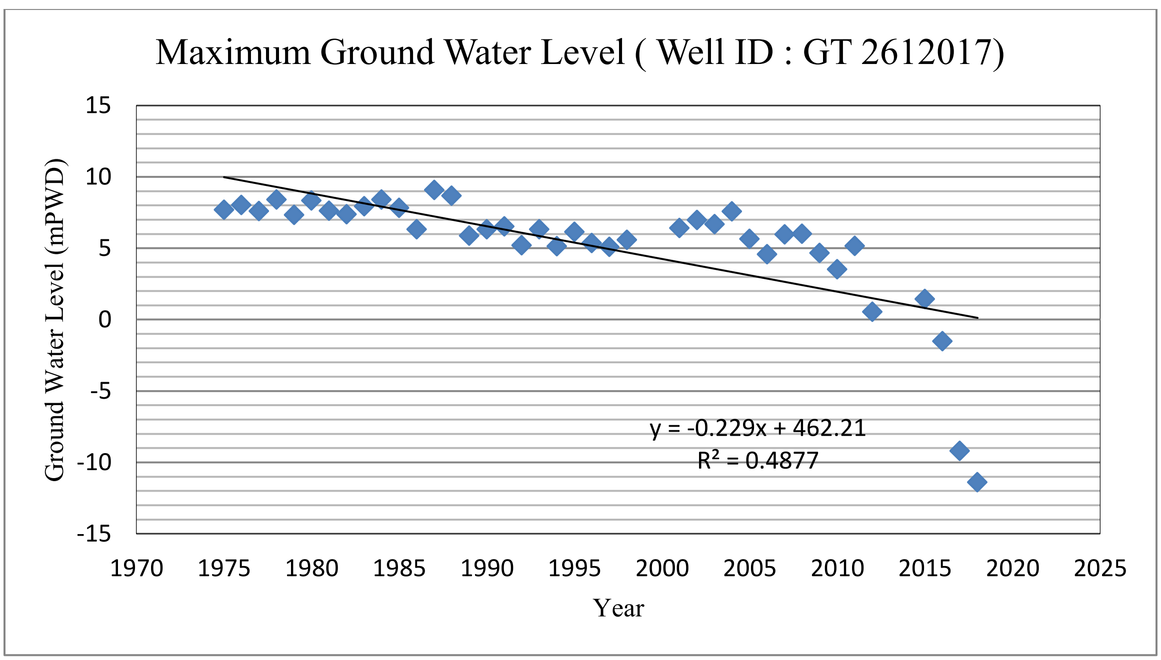

Figure B.10: Annual Maximun Groundwater Level Hydrograph (Location: Well ID GT 2672017, Savar)

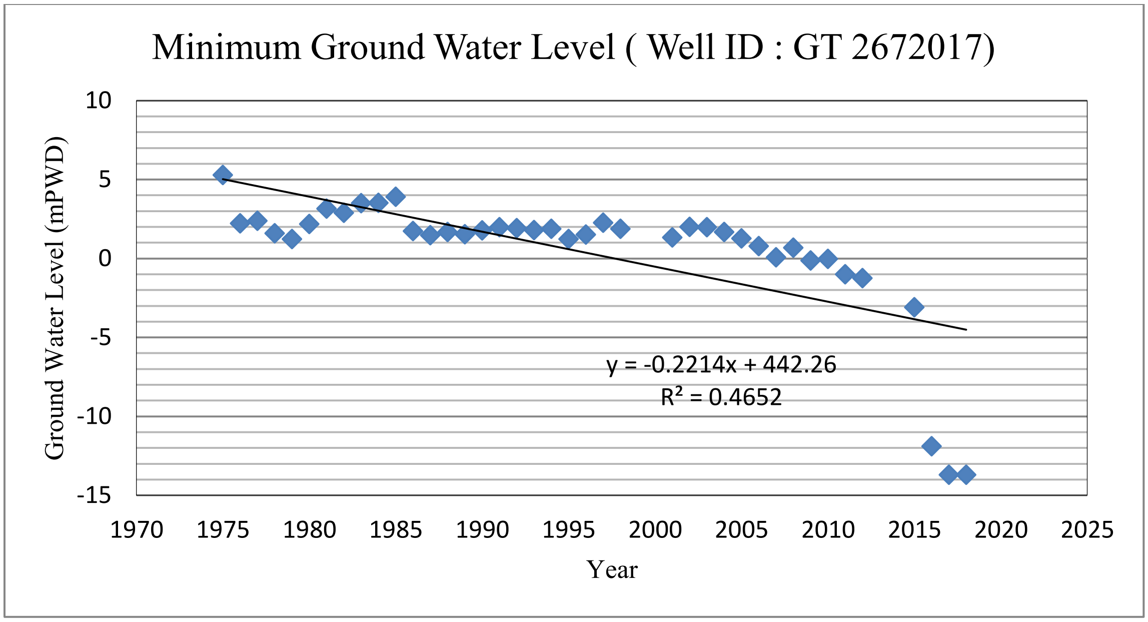

Figure B.11: Annual Minimum Groundwater Level Hydrograph (Location: Well ID GT 2672017, Savar)

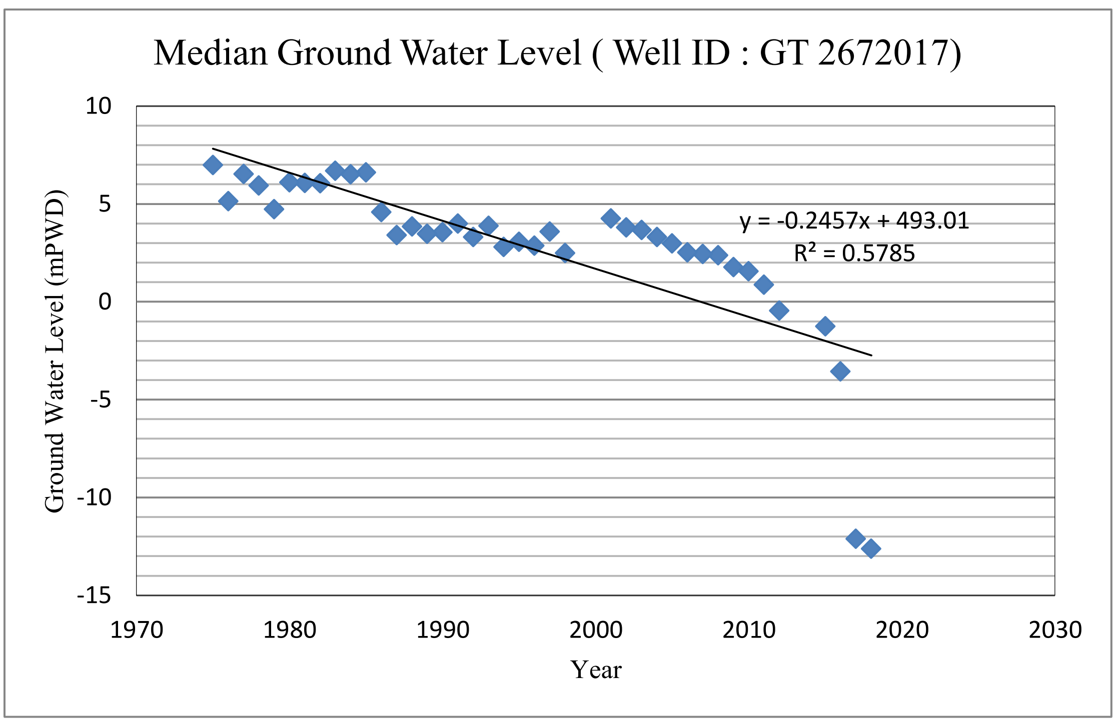

Figure B.12: Annual Median Groundwater Level Hydrograph (Location: Well ID GT 2672017, Savar)

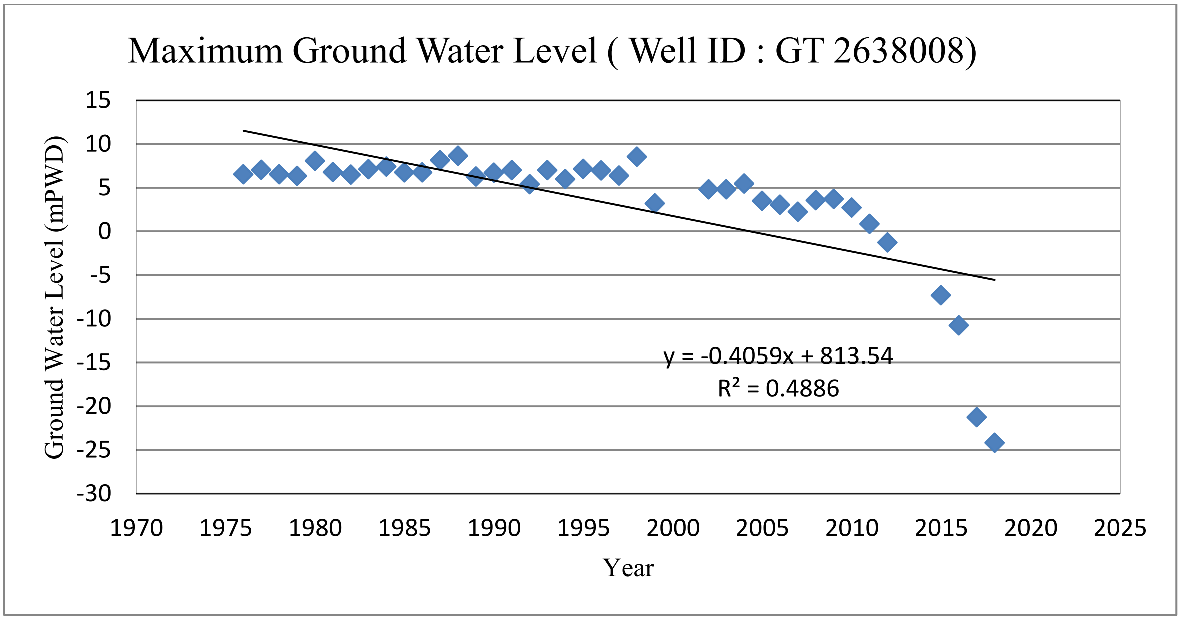

Figure B.13: Annual Maximum Groundwater Level Hydrograph (Location: Well ID GT 2638008, Bamonsur, Keraniganj)

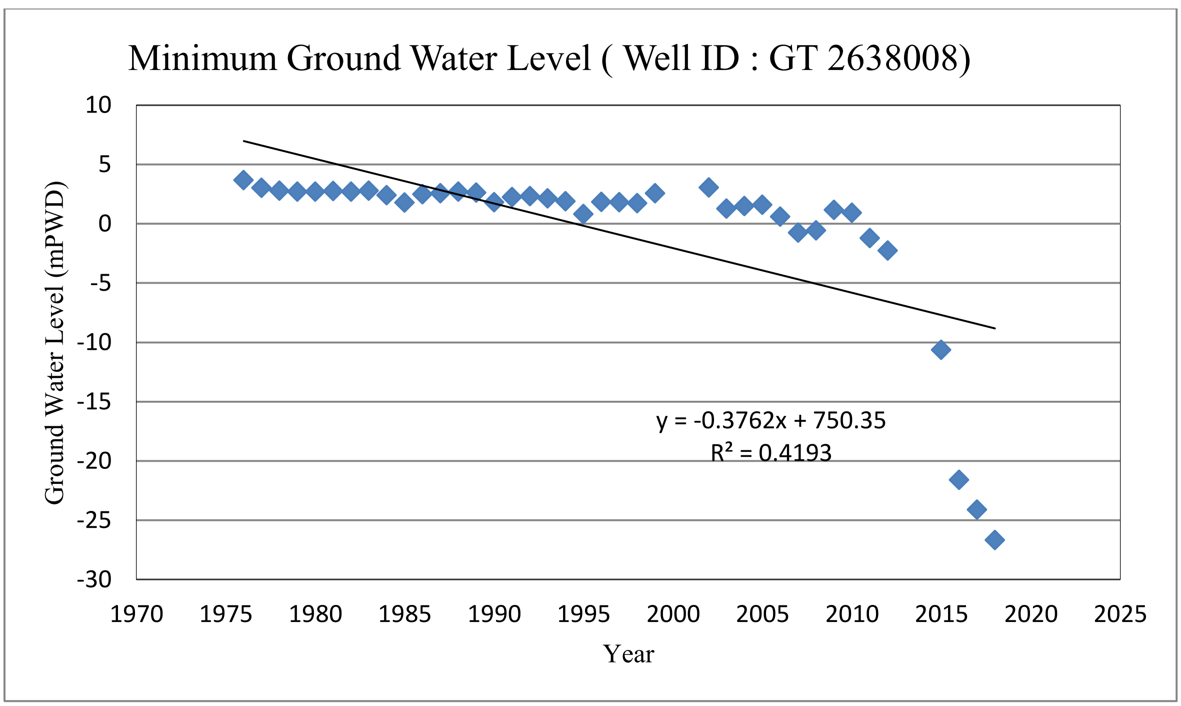

Figure B.14: Annual Minimum Groundwater Level Hydrograph (Location: Well ID GT 2638008, Bamonsur, Keraniganj)

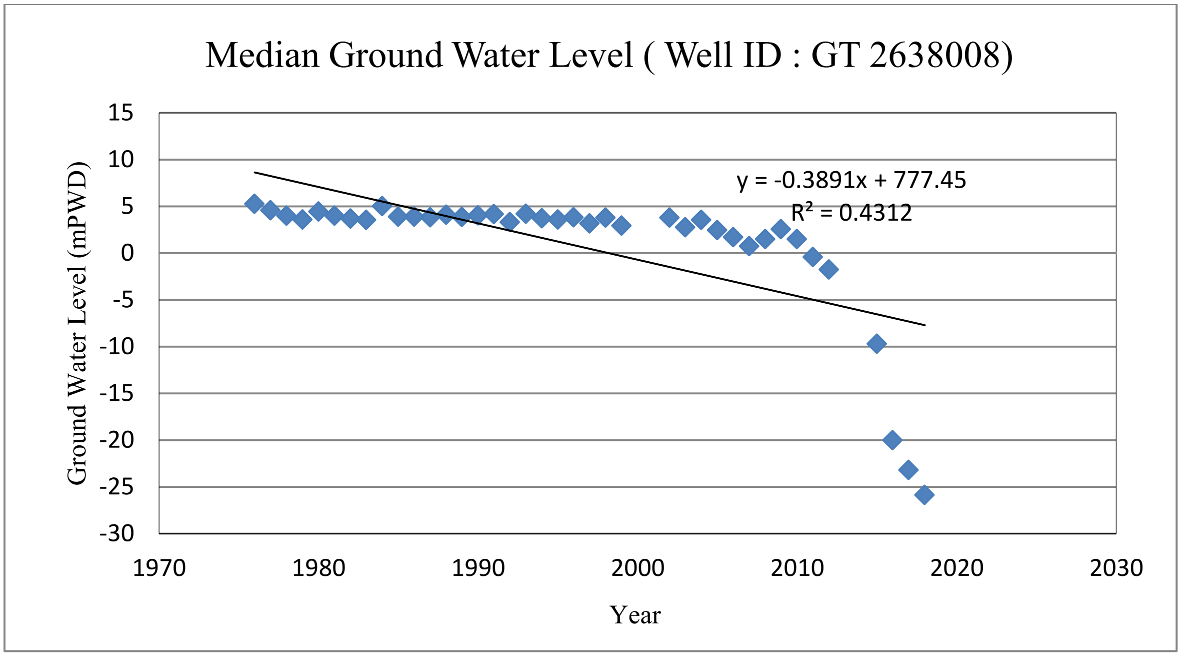

Figure B.15: Annual Median Groundwater Level Hydrograph (Location: Well ID GT 2638008, Bamonsur, Keraniganj)

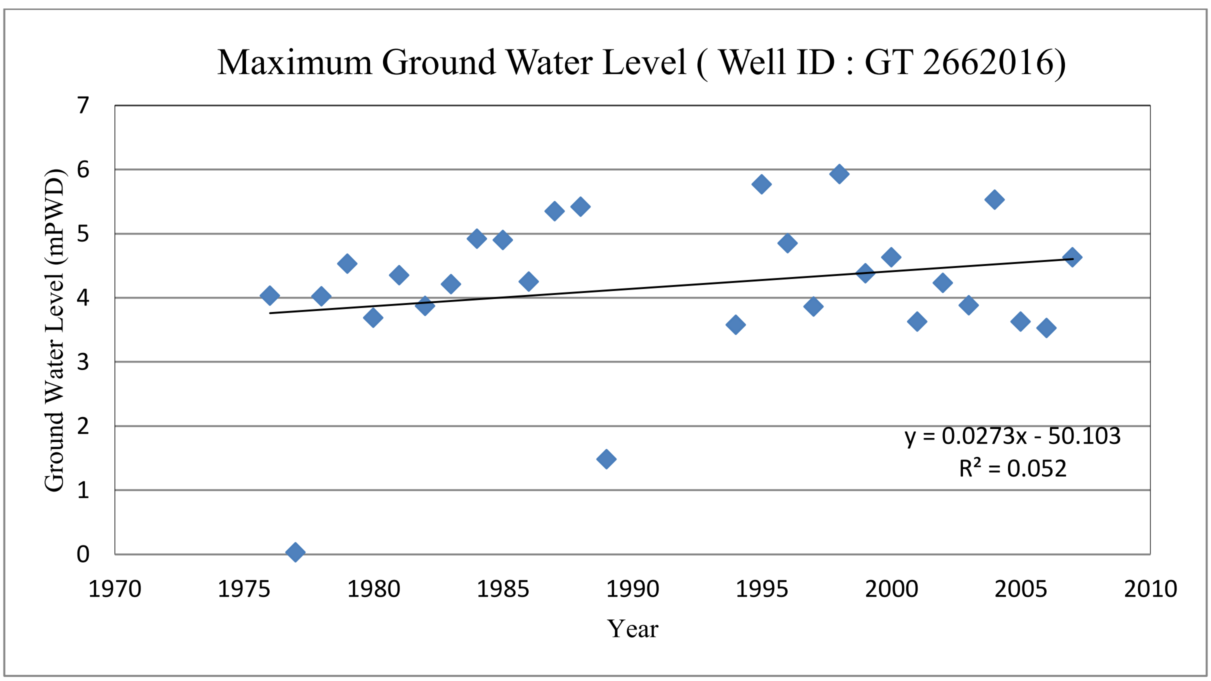

Figure B.16: Annual Maximum Groundwater Level Hydrograph (Location: Well ID GT 2662016, Paragram, Nawabganj)

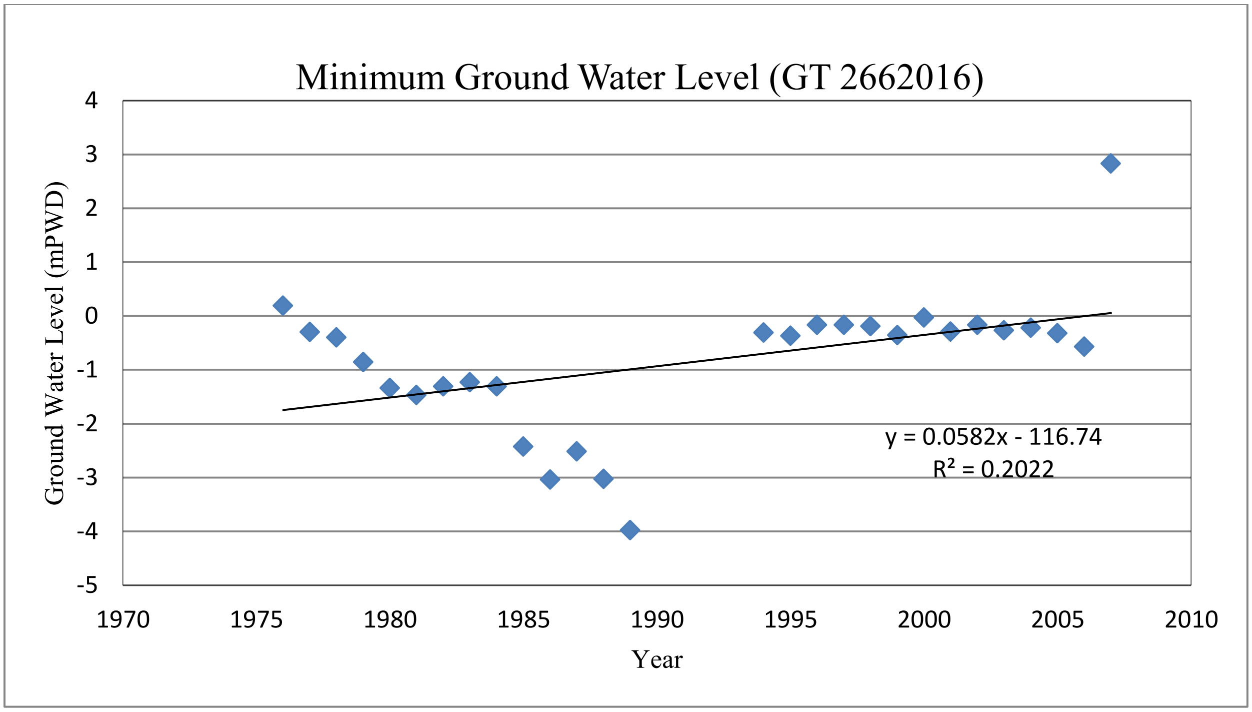

Figure B.17: Annual Minimum Groundwater Level Hydrograph (Location: Well ID GT 2662016, Paragram, Nawabganj)

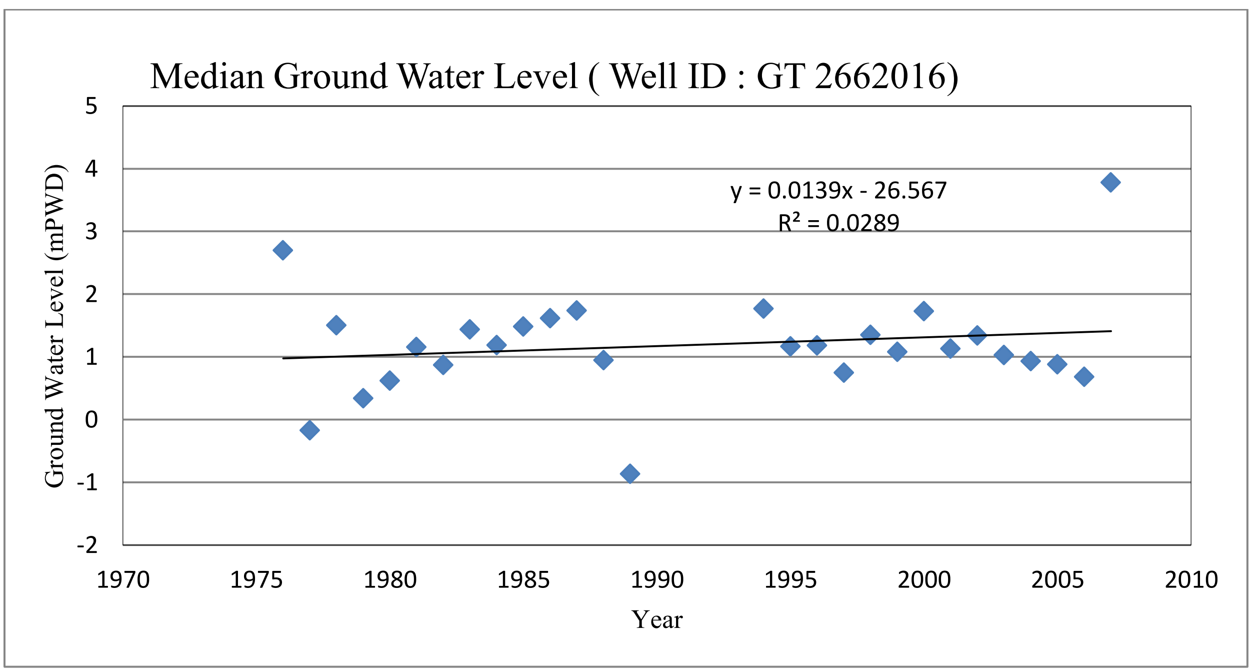

Figure B.18: Annual Median Groundwater Level Hydrograph (Location: Well ID GT 2662016, Paragram, Nawabganj)

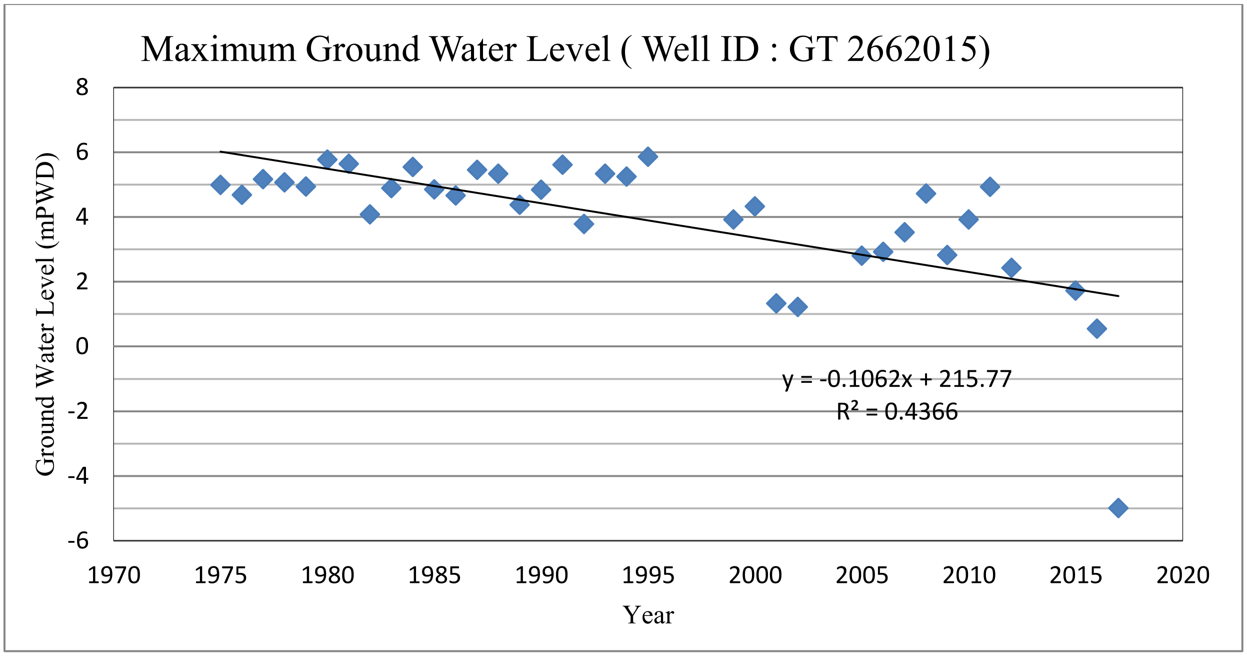

Figure B.19: Annual Maximum Groundwater Level Hydrograph (Location: Well ID GT 2662015, Nawabganj School, Nawabganj)

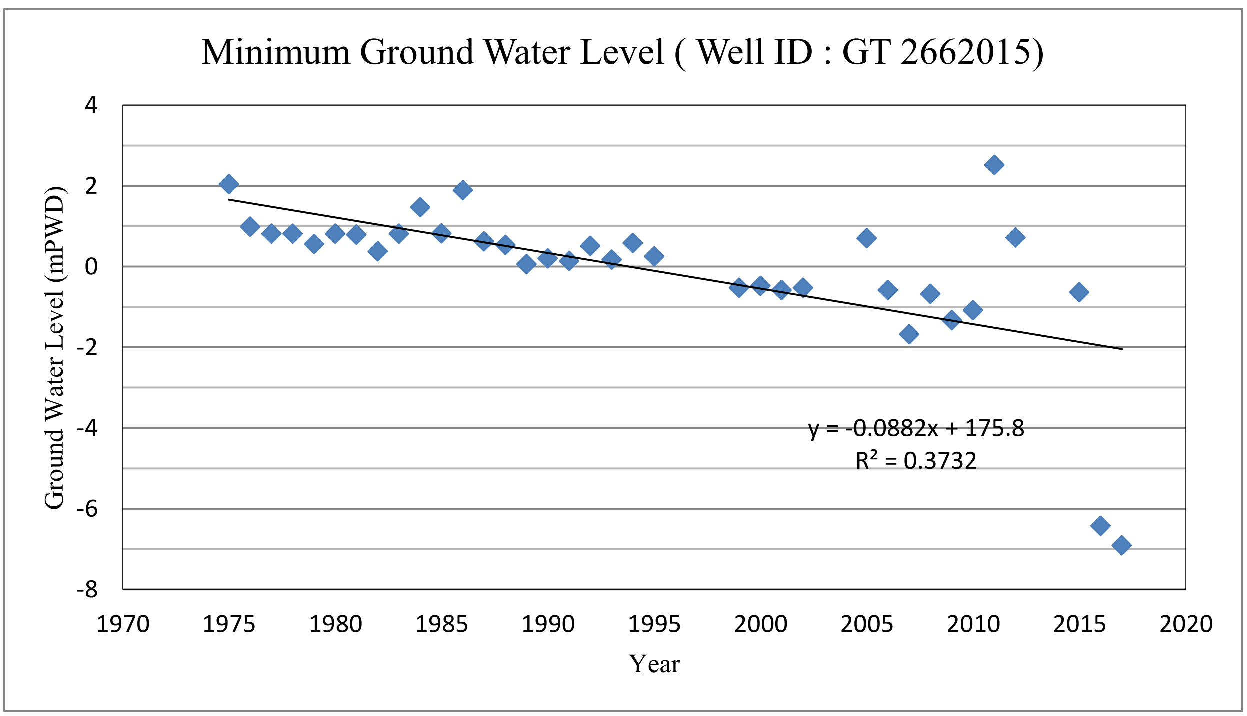

Figure B.20: Annual Minimum Groundwater Level Hydrograph (Location: Well ID GT 2662015, Nawabganj School,Nawabganj)

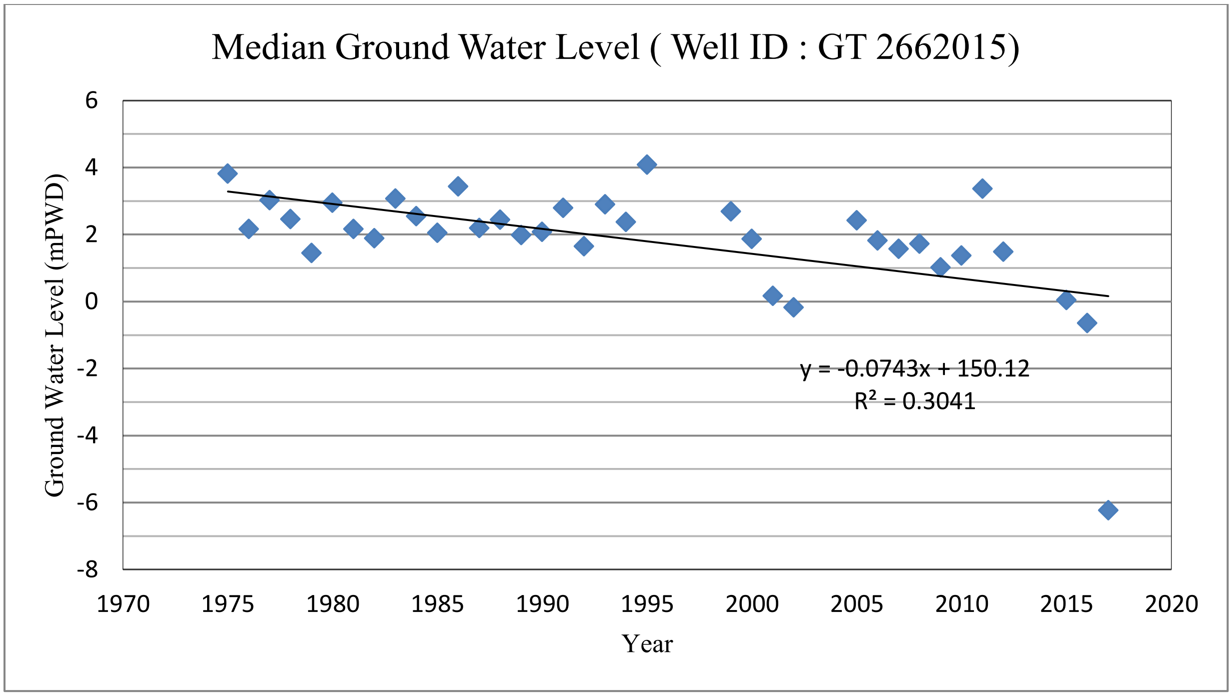

Figure B.21: Annual Median Groundwater Level Hydrograph (Location: Well ID GT 2662015, Nawabganj School, Nawabganj)

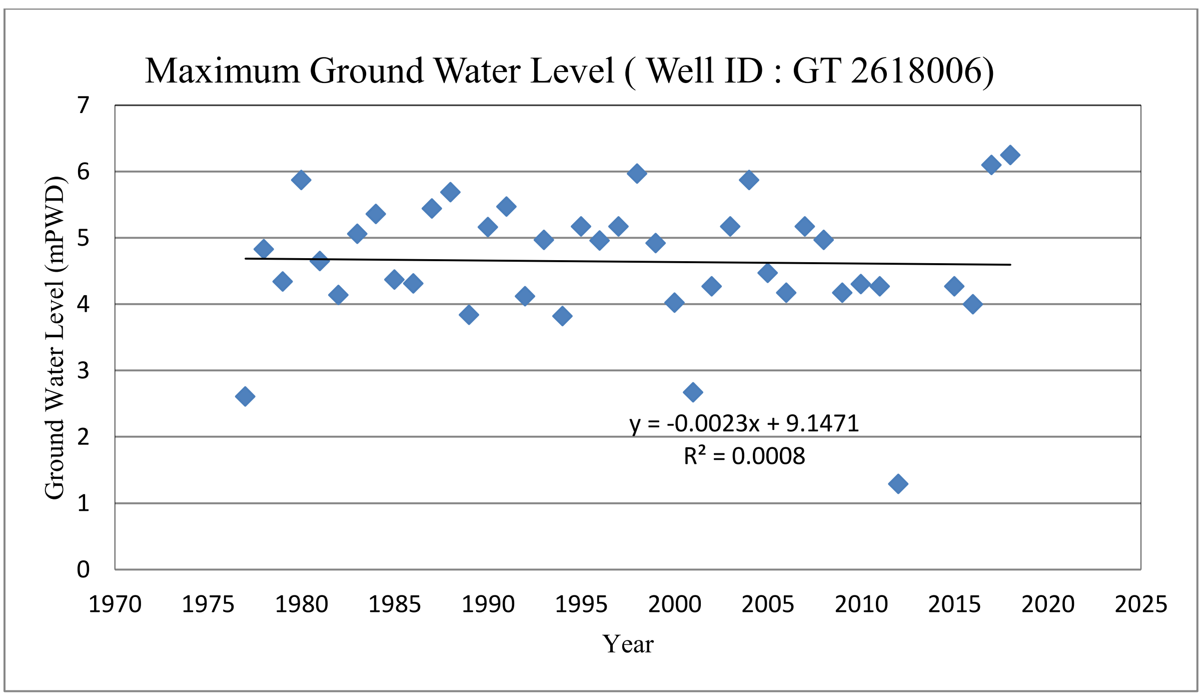

Figure B.22: Annual Maximum Groundwater Level Hydrograph (Location: Well ID GT 2618006, Dayagajaria, Dohar)

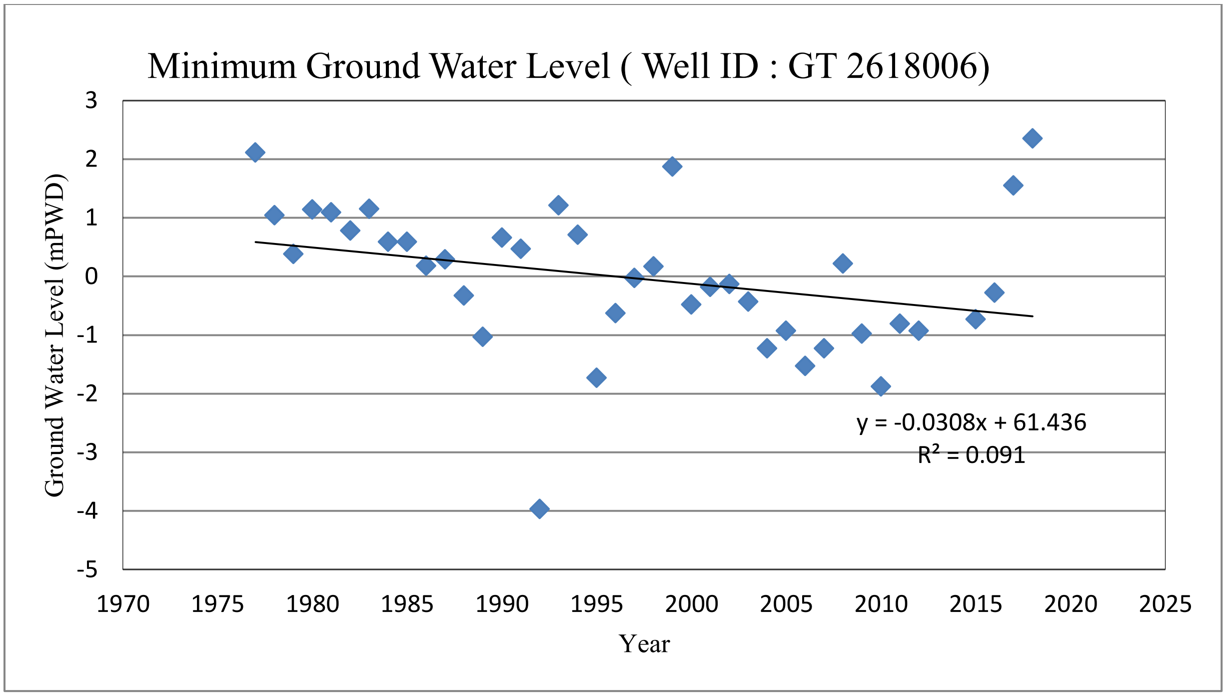

Figure B.23: Annual Minimum Groundwater Level Hydrograph (Location: Well ID GT 2618006, Dayagajaria, Dohar)

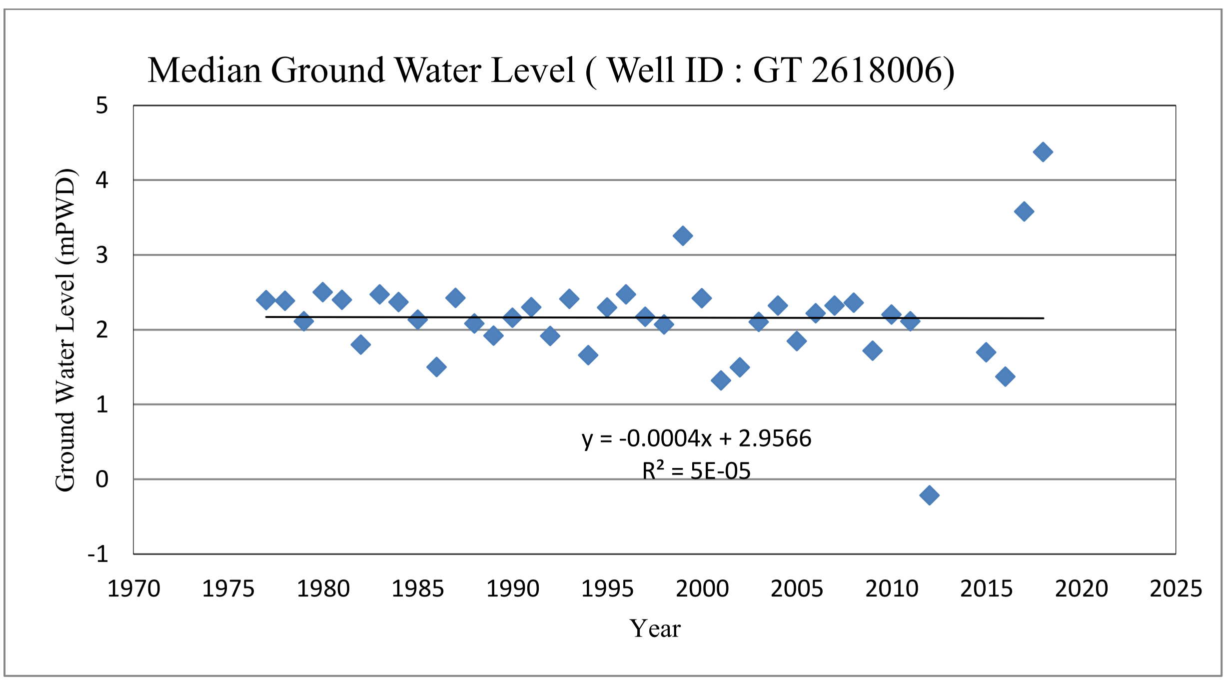

Figure B.24: Annual Median Groundwater Level Hydrograph (Location: Well ID GT 2618006, Dayagajaria, Dohar)

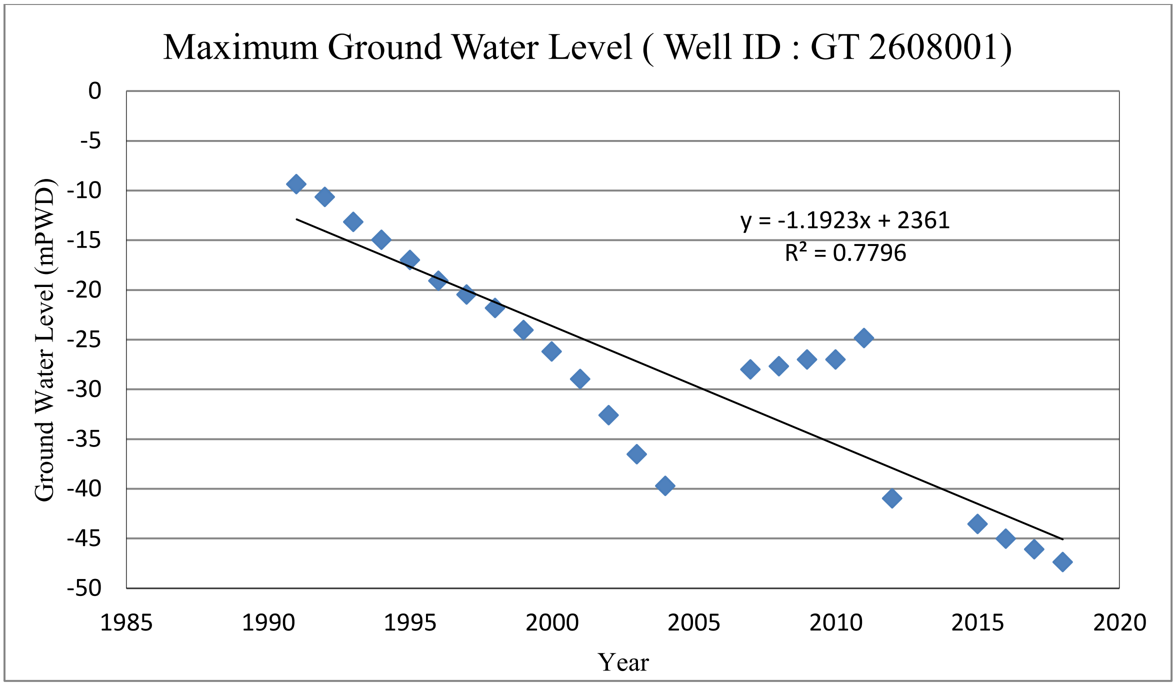

Figure B.25: Annual Maximum Groundwater Level Hydrograph (Location: Well ID GT 2608001, Joar Shahara, Cantonment)

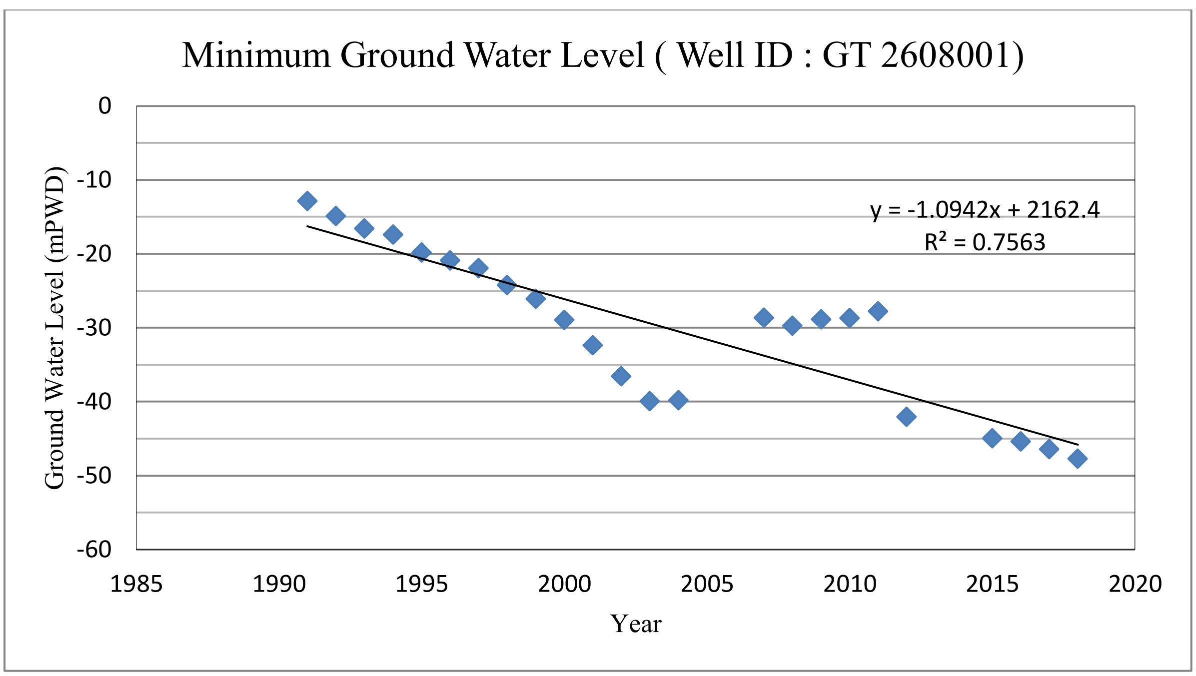

Figure B.26: Annual Minimum Groundwater Level Hydrograph (Location: Well ID GT 2608001, Joar Shahara, Cantonment)

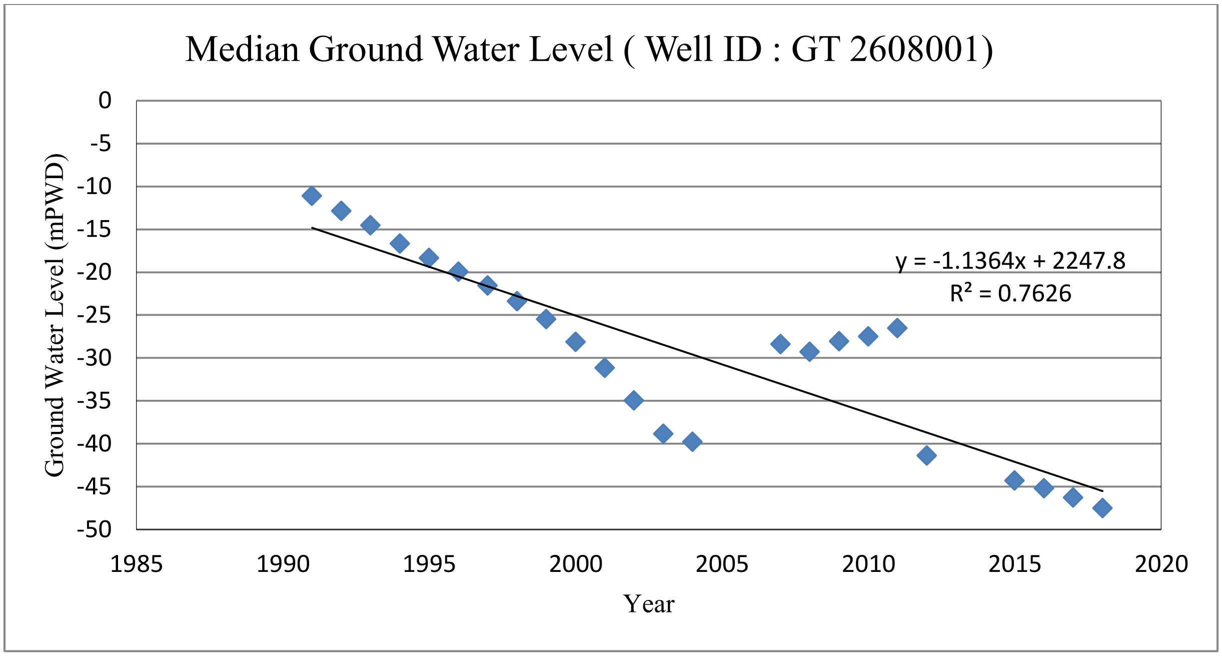

Figure B.27: Annual Median Groundwater Level Hydrograph (Location: Well ID GT 2608001, Joar Shahara, Cantonment)

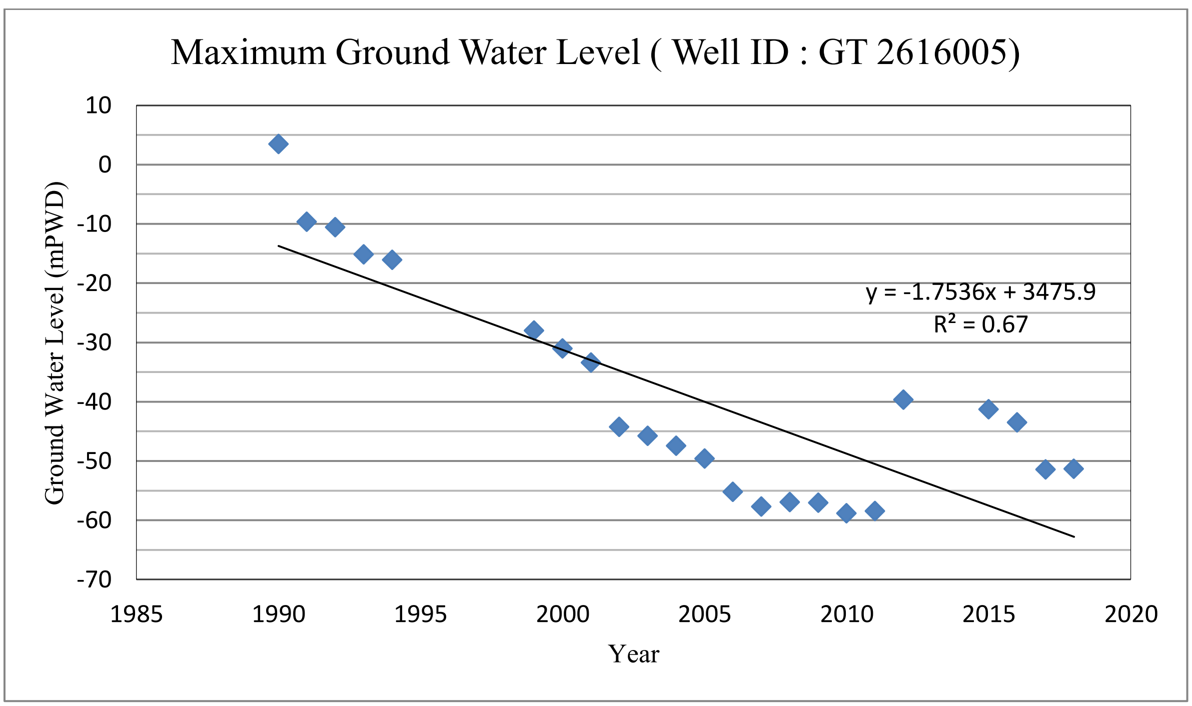

Figure B.28: Annual Maximum Groundwater Level Hydrograph (Location: Well ID GT 2616005, Green road, Dhanmondi)

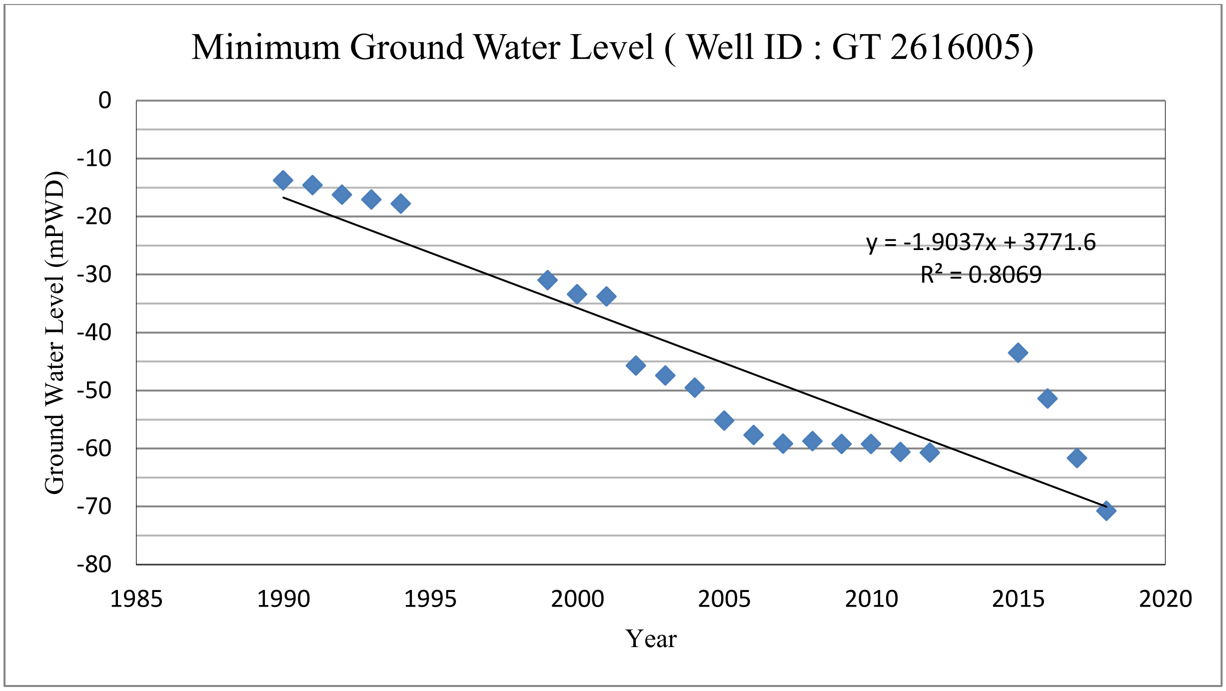

Figure B.29: Annual Minimum Groundwater Level Hydrograph (Location: Well ID GT 2616005, Green road, Dhanmondi)

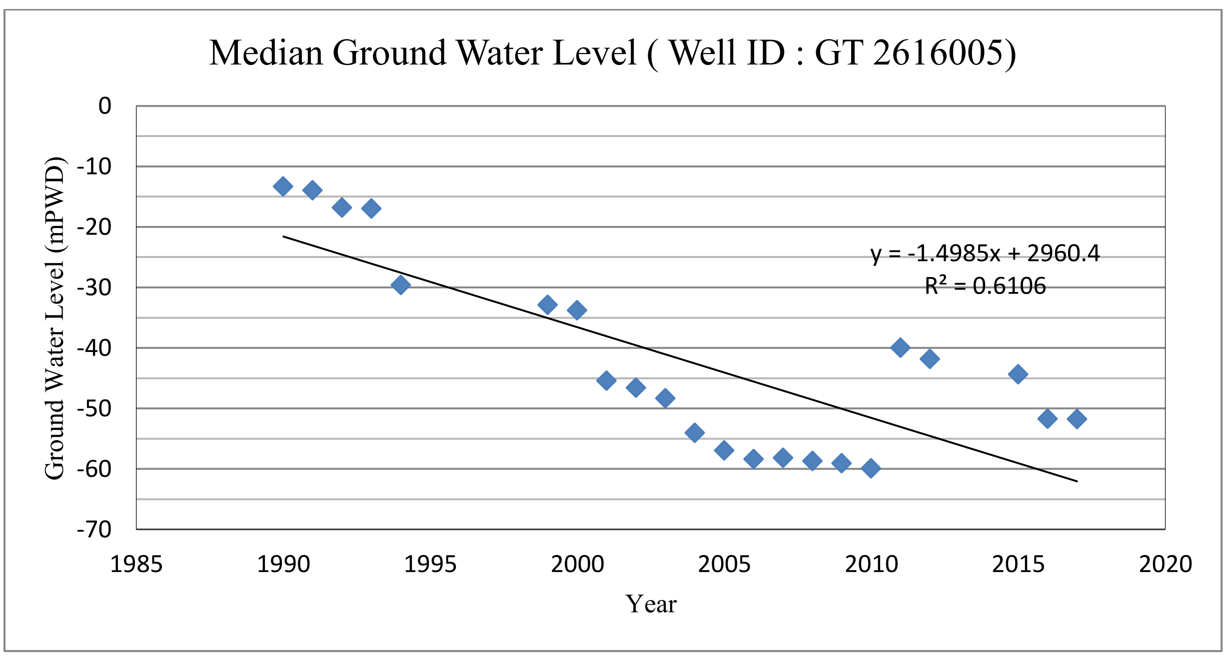

Figure B.30: Annual Median Groundwater Level Hydrograph (Location: Well ID GT 2616005, Green road, Dhanmondi)

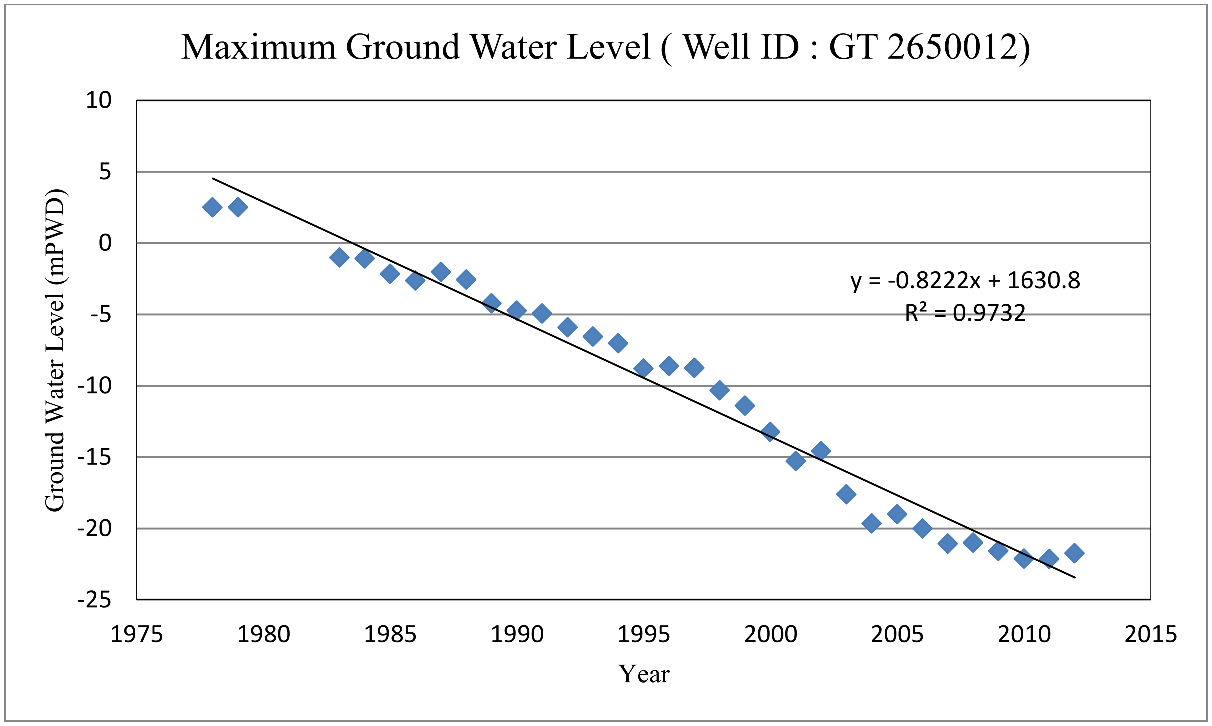

Figure B.31: Annual Maximum Groundwater Level Hydrograph (Location: Well ID GT 2650012, Sultangonj, Mohammadpur)

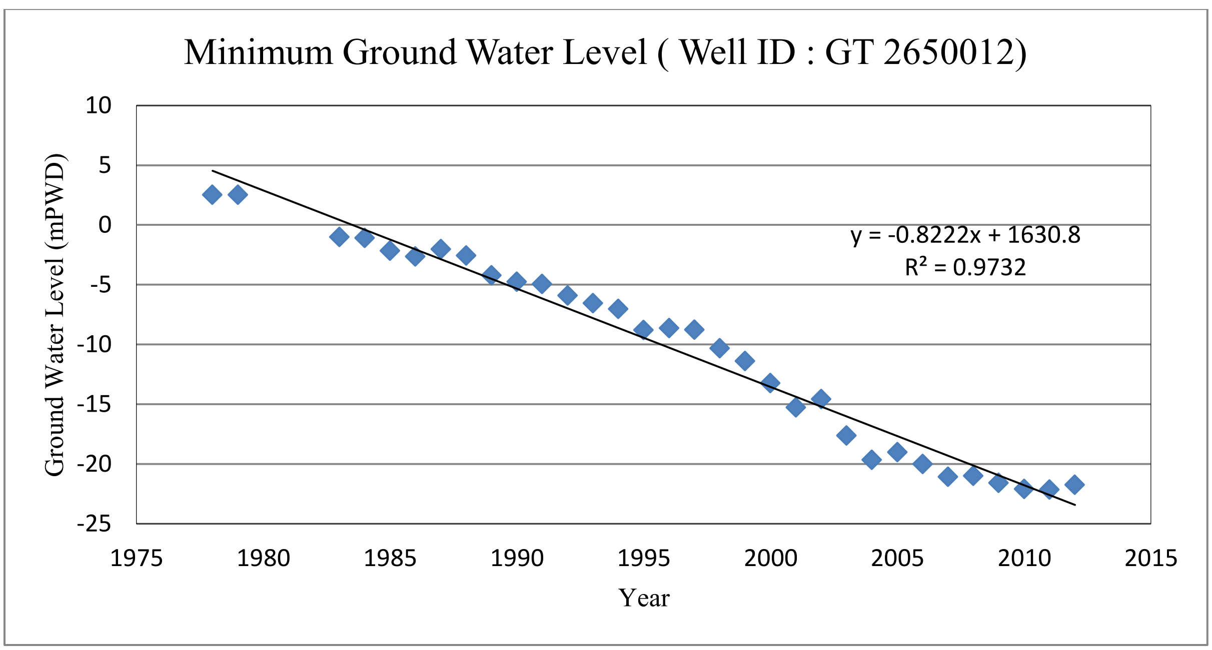

Figure B.32: Annual Minimum Groundwater Level Hydrograph (Location: Well ID GT 2650012, Sultangonj, Mohammadpur)

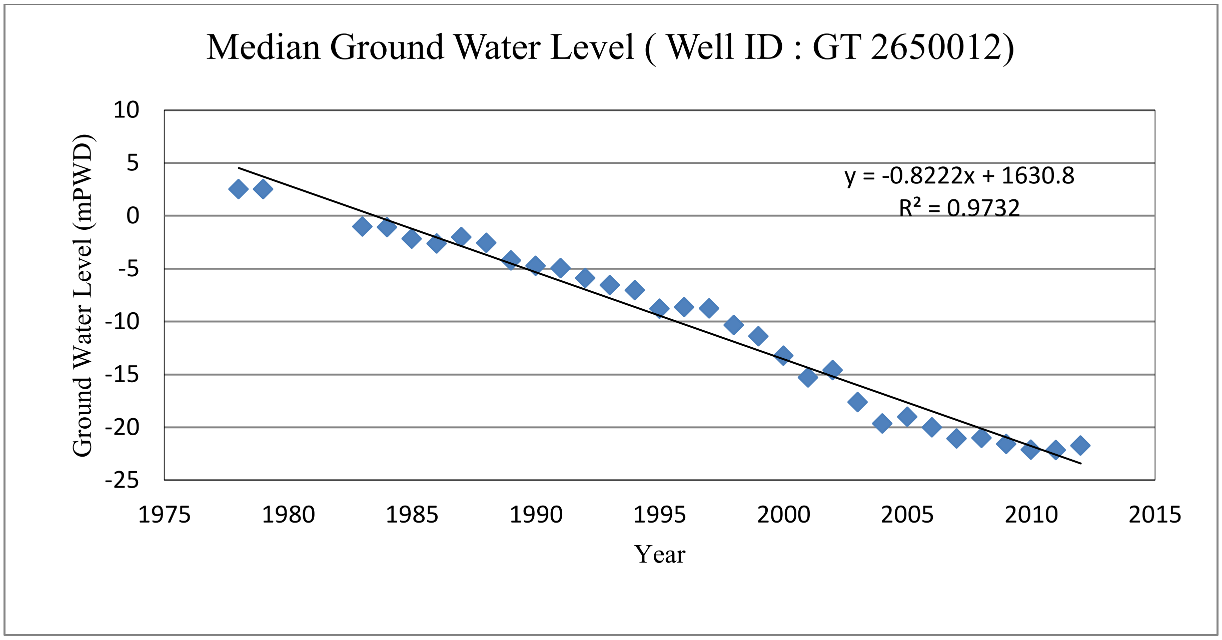

Figure B.33: Annual Median Groundwater Level Hydrograph (Location: Well ID GT 2650012, Sultangonj, Mohammadpur)

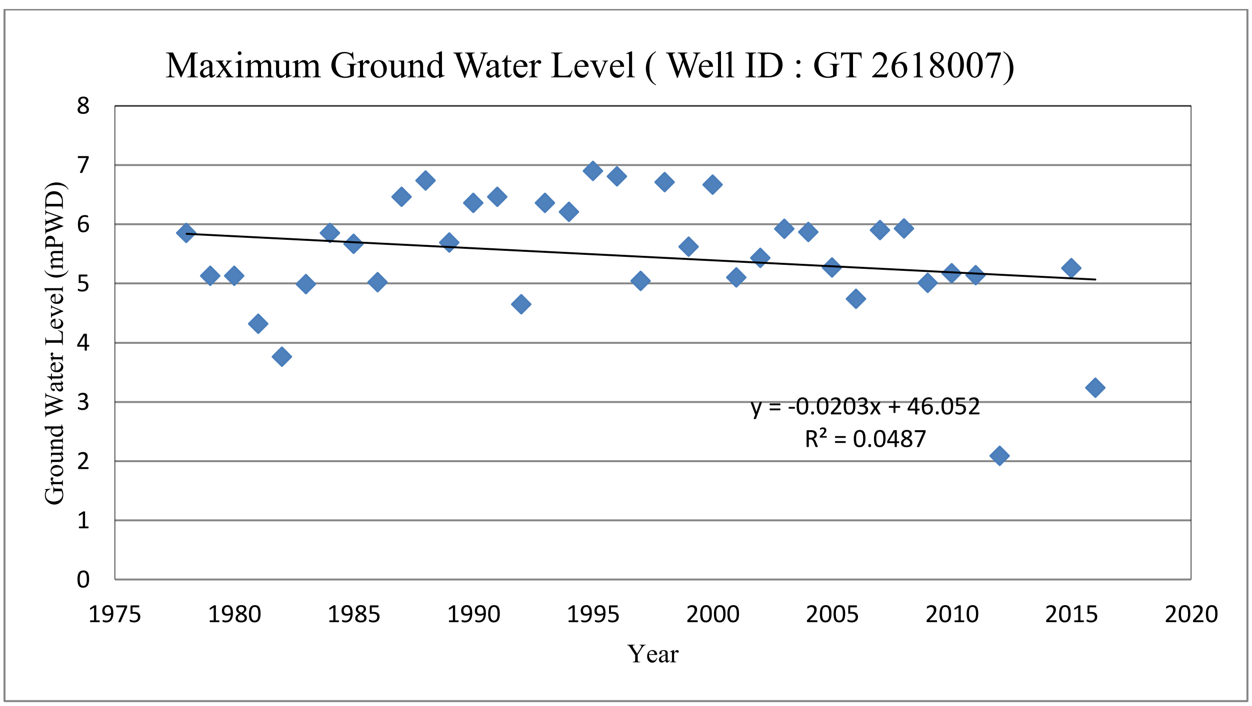

Figure B.34: Annual Maximum Groundwater Level Hydrograph (Location: Well ID GT 2618007, Sundaripara, Dohar)

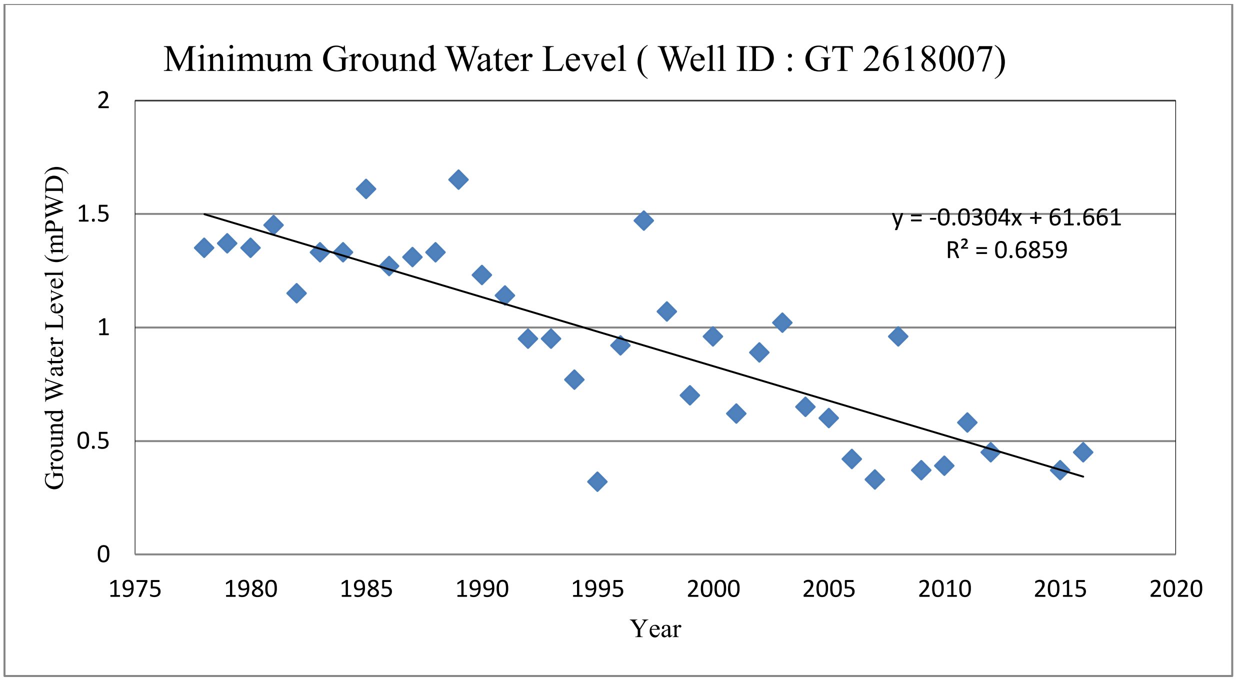

Figure B.35: Annual Minimum Groundwater Level Hydrograph (Location: Well ID GT 2618007, Sundaripara, Dohar)

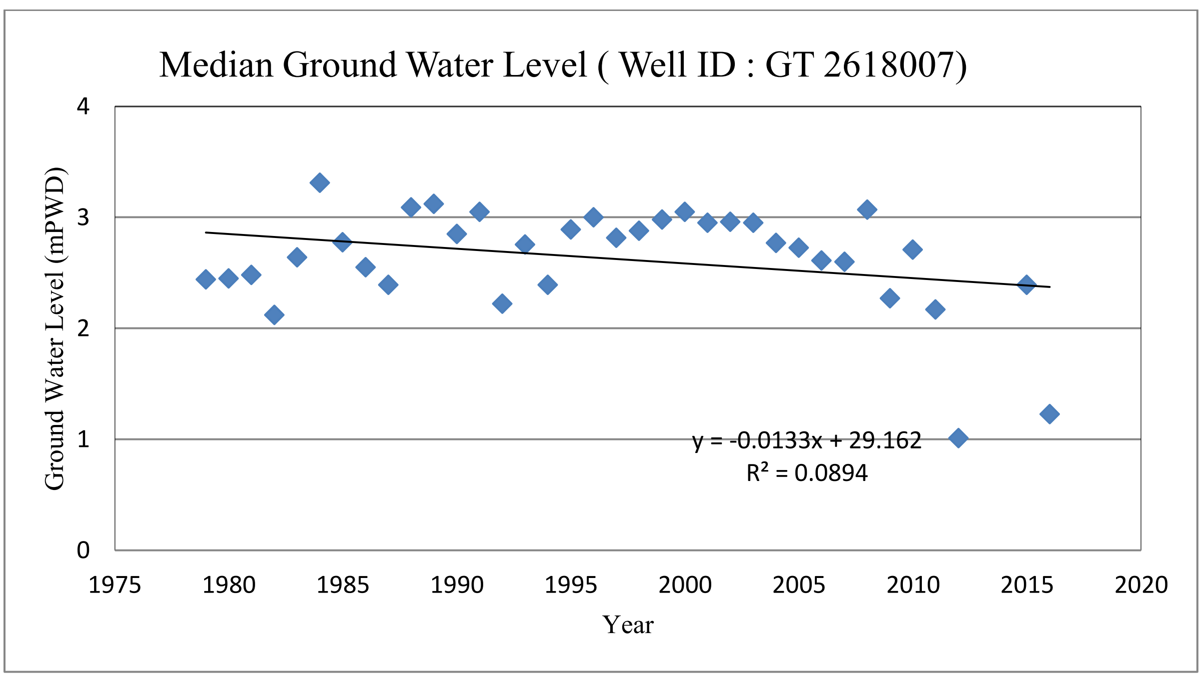

Figure B.36: Annual Median Groundwater Level Hydrograph (Location: Well ID GT 2618007, Sundaripara, Dohar)

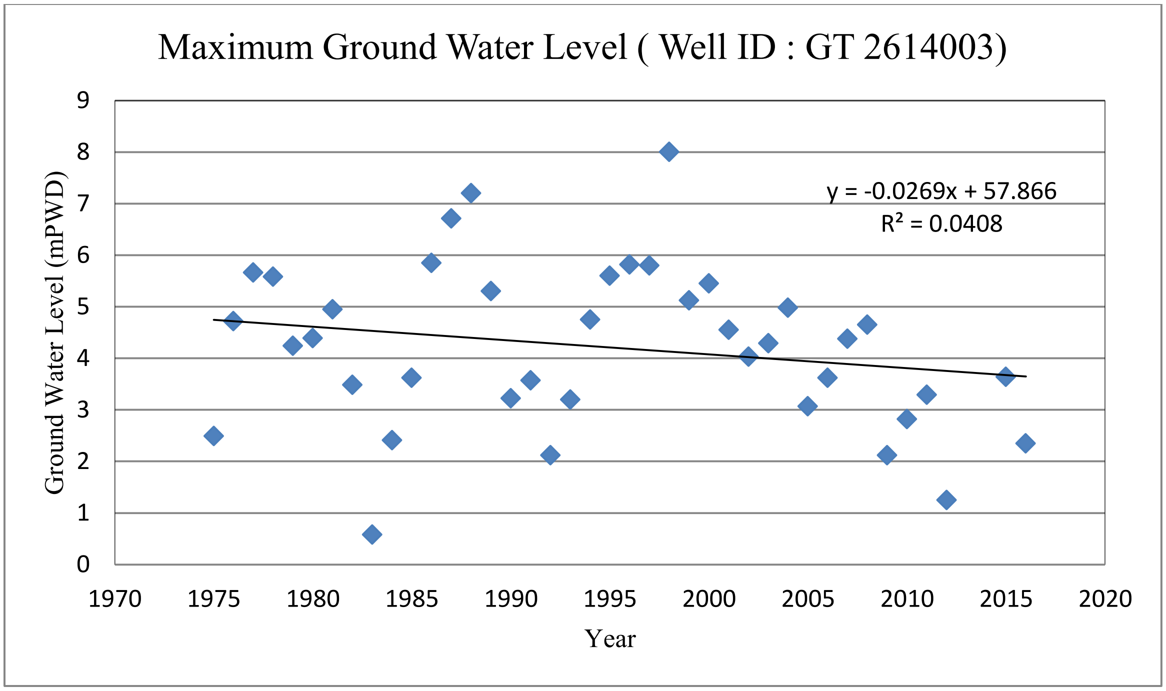

Figure B.37: Annual Maximum Groundwater Level Hydrograph (Location: Well ID GT 2614003, Dhamrai)

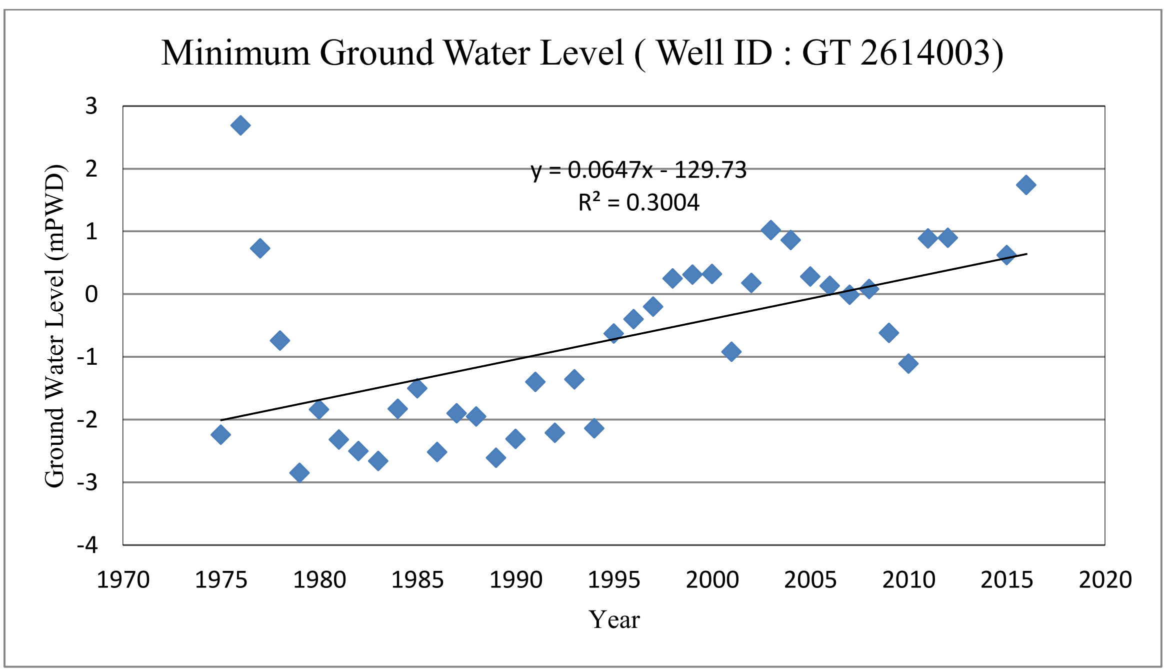

Figure B.38: Annual Minimum Groundwater Level Hydrograph (Location: Well ID GT 2614003, Dhamrai)

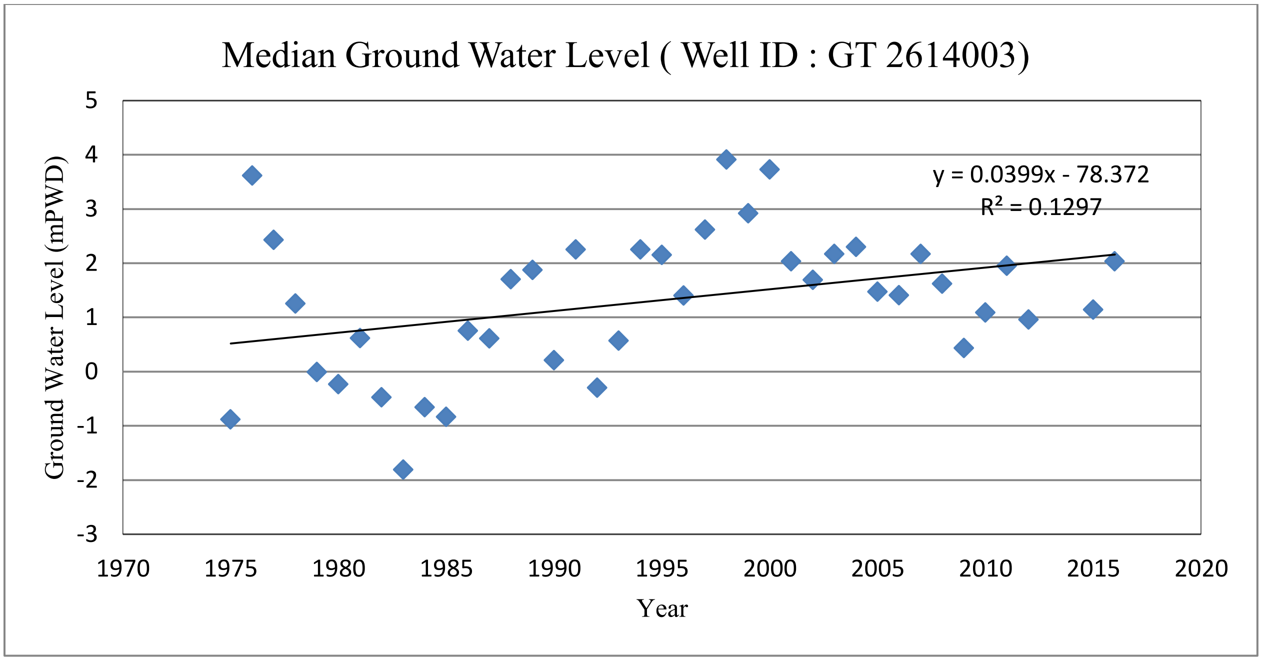

Figure B.39: Annual Median Groundwater Level Hydrograph (Location: Well ID GT 2614003, Dhamrai)

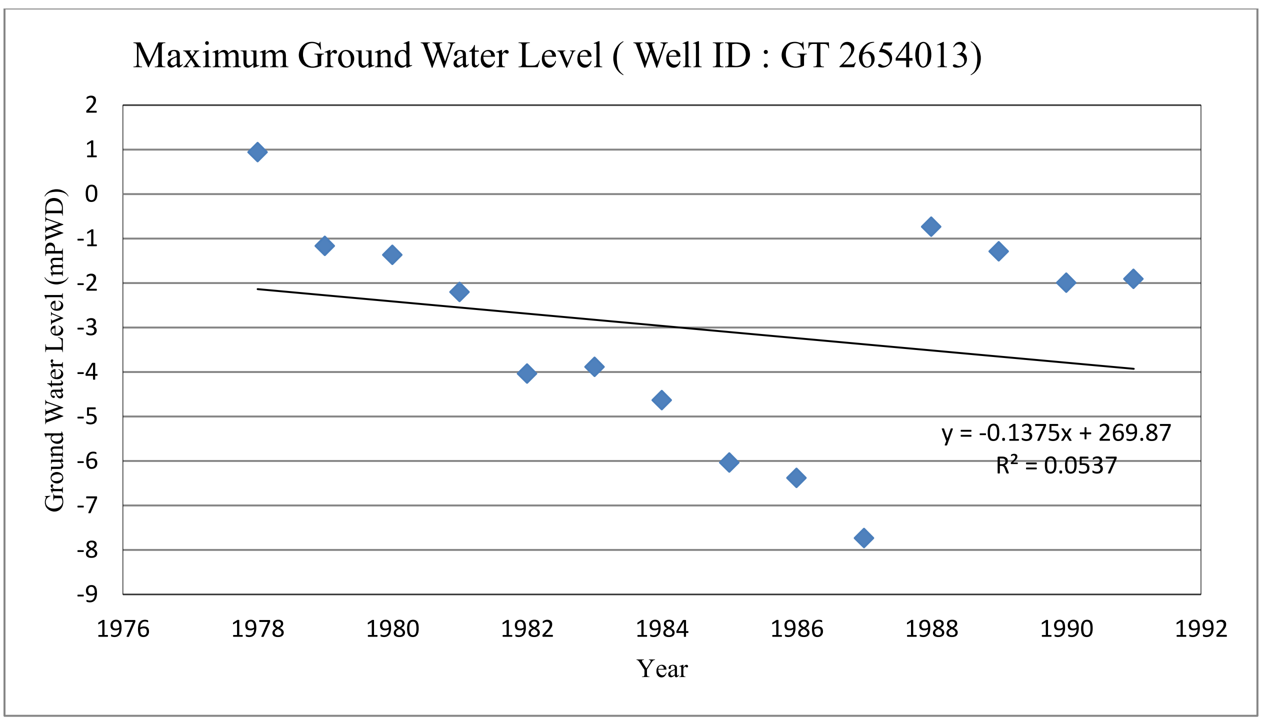

Figure B.40: Annual Maximum Groundwater Level Hydrograph (Location: Well ID GT 2654013, Maniknagar, Motijheel)

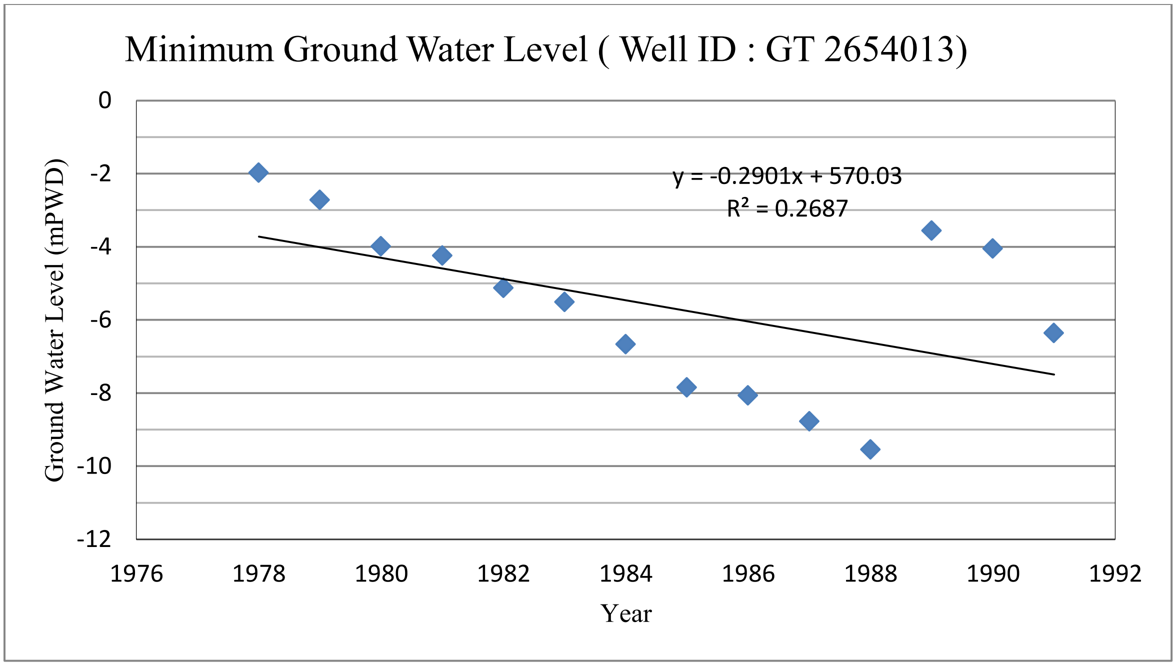

Figure B.41: Annual Minimum Groundwater Level Hydrograph (Location: Well ID GT 2654013, Maniknagar, Motijheel)

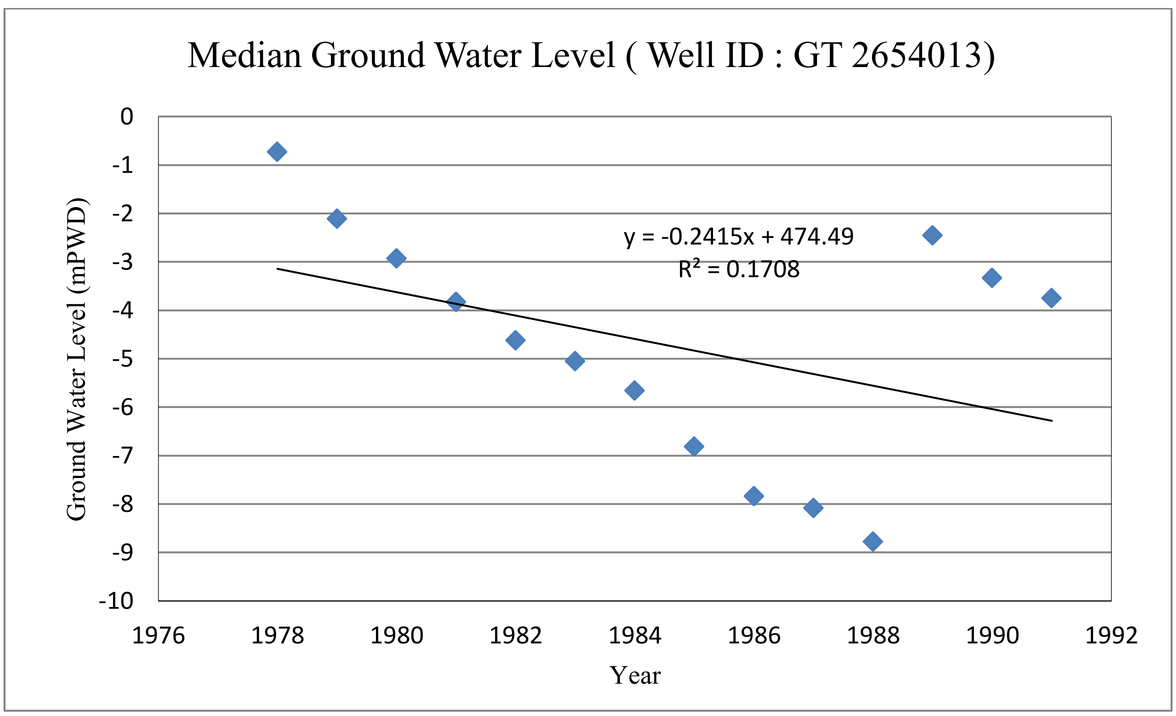

Figure B.42: Annual Median Groundwater Level Hydrograph (Location: Well ID GT 2654013, Maniknagar, Motijheel)

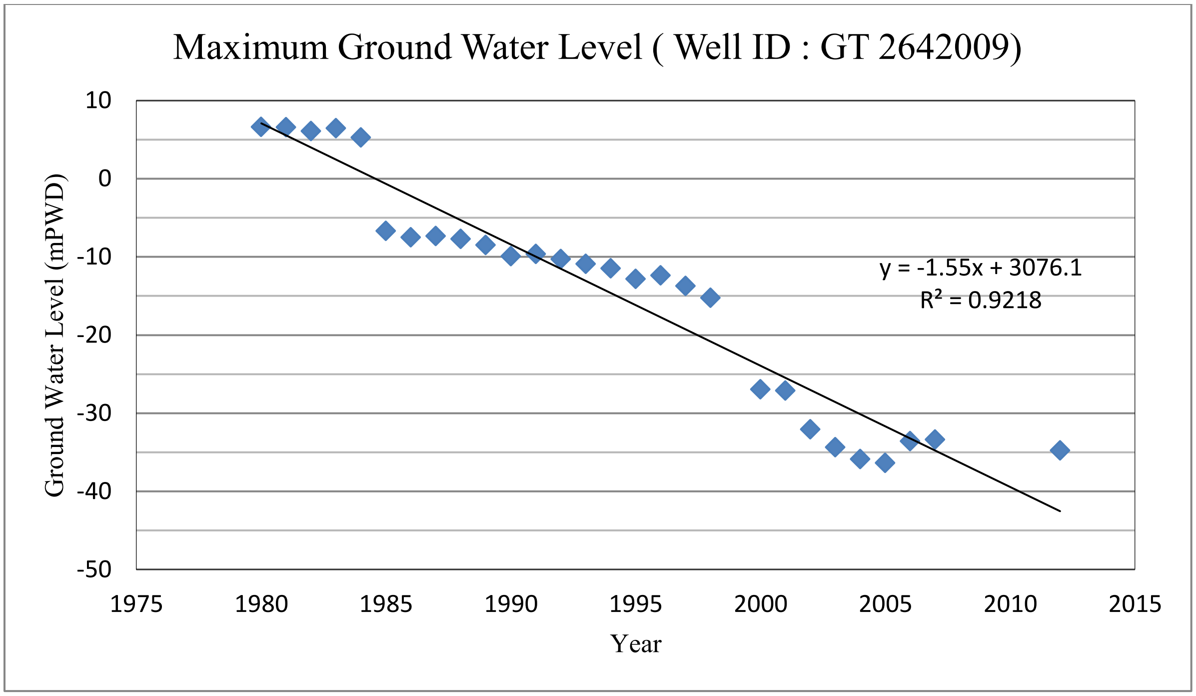

Figure B.43: Annual Maximum Groundwater Level Hydrograph (Location: Well ID GT 2642009, Bakshibazar, Lalbag)

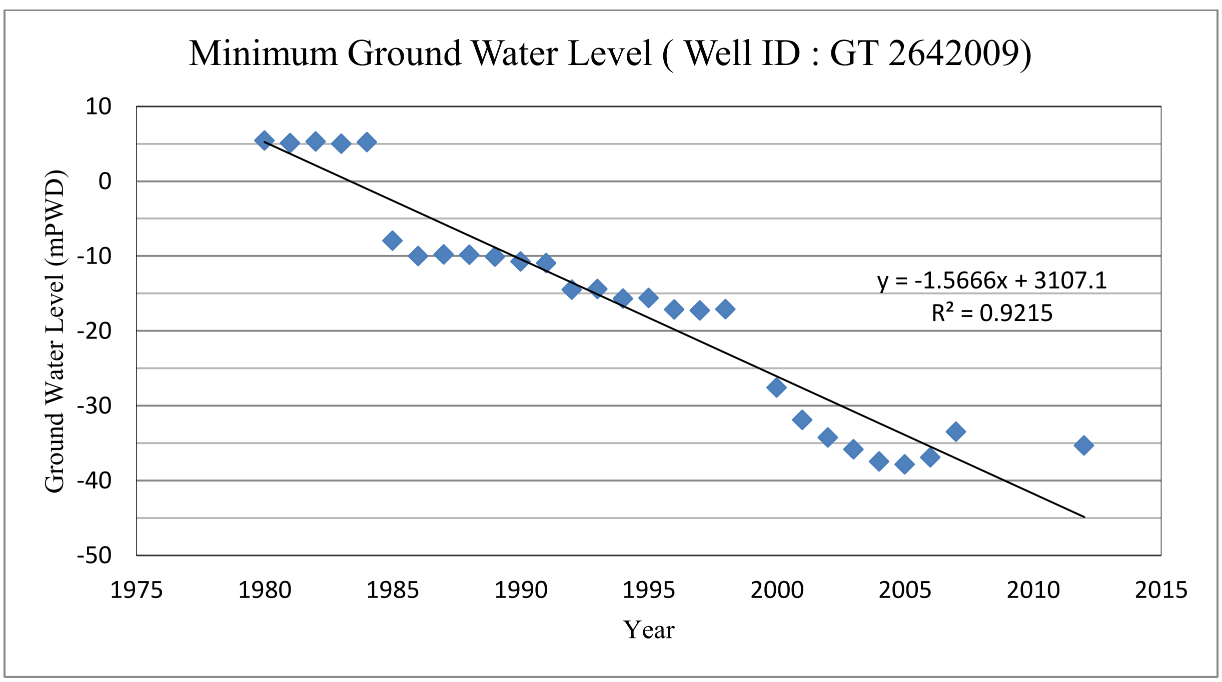

Figure B.44: Annual Minimum Groundwater Level Hydrograph (Location: Well ID GT 2642009, Bakshibazar, Lalbag)

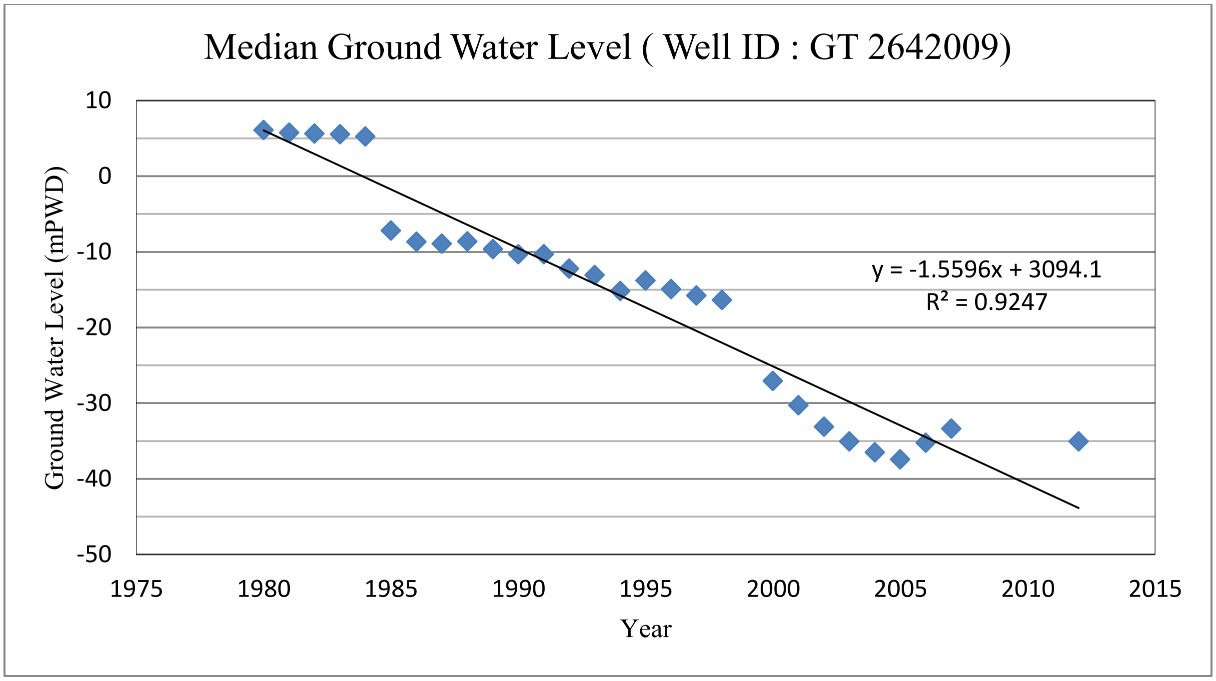

Figure B.45: Annual Median Groundwater Level Hydrograph (Location: Well ID GT 2642009, Bakshibazar, Lalbag)

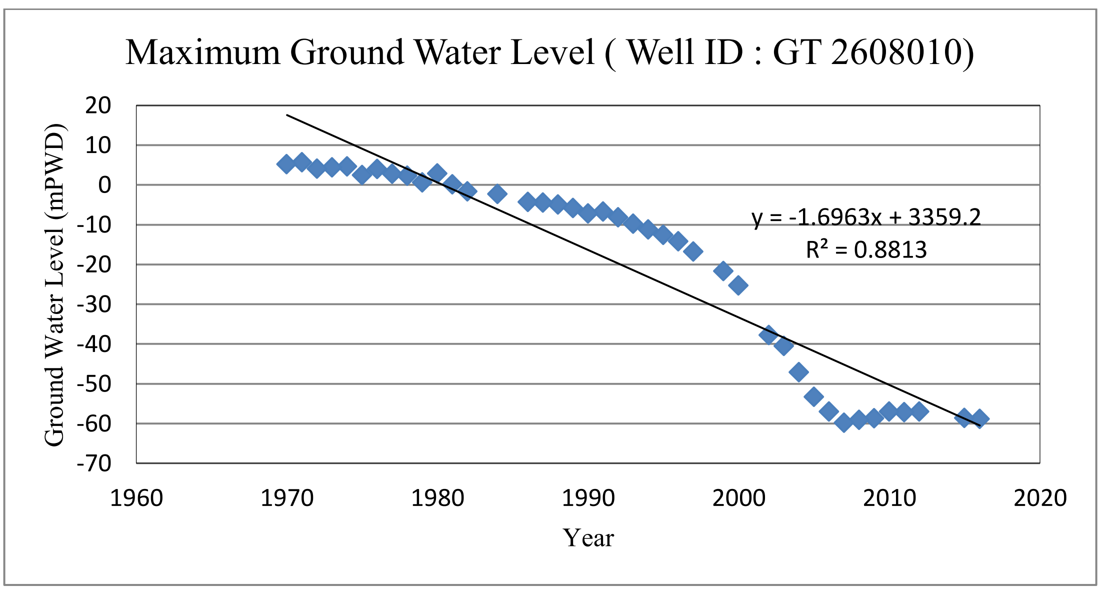

Figure B.46: Annual Maximum Groundwater Level Hydrograph (Location: Well ID GT 2648010, New Shewrapara, Mirpur)

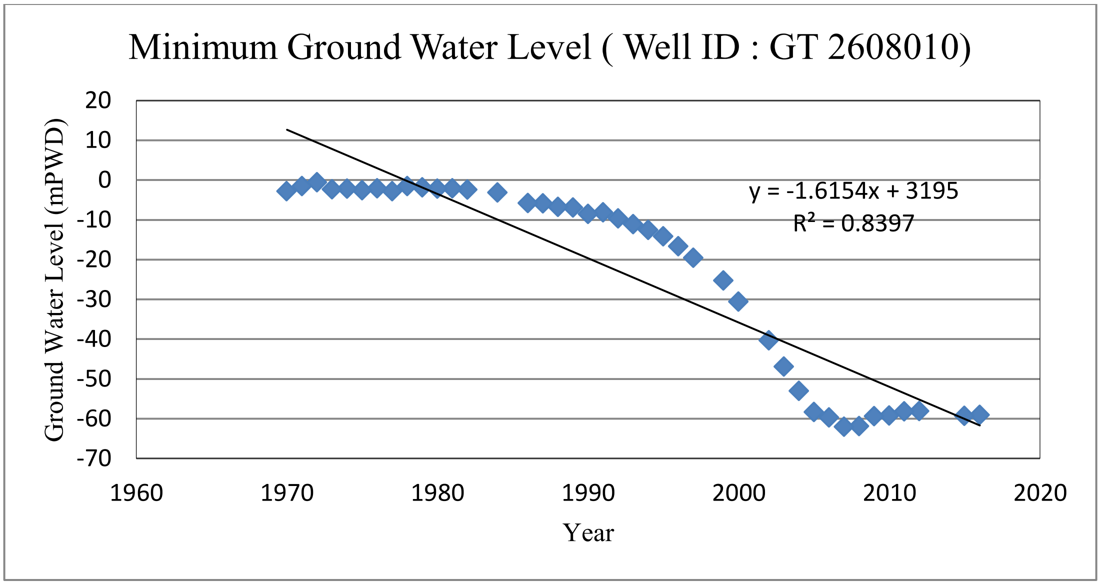

Figure B.47: Annual Minimum Groundwater Level Hydrograph (Location: Well ID GT 2648010, New Shewrapara, Mirpur)

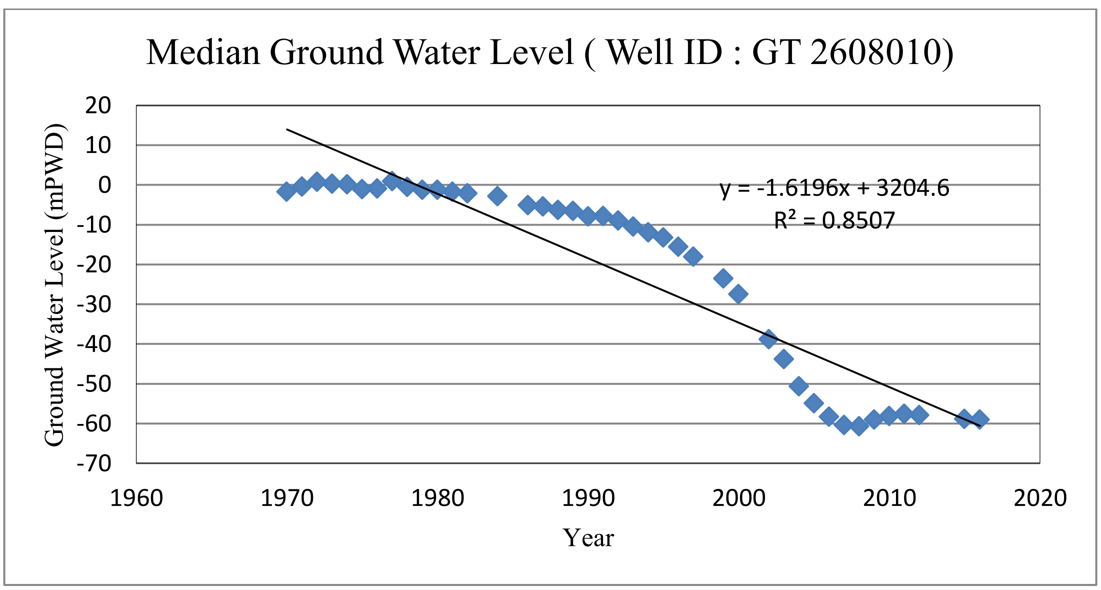

Figure B.48: Annual Median Groundwater Level Hydrograph (Location: Well ID GT 2648010, New Shewrapara, Mirpur)

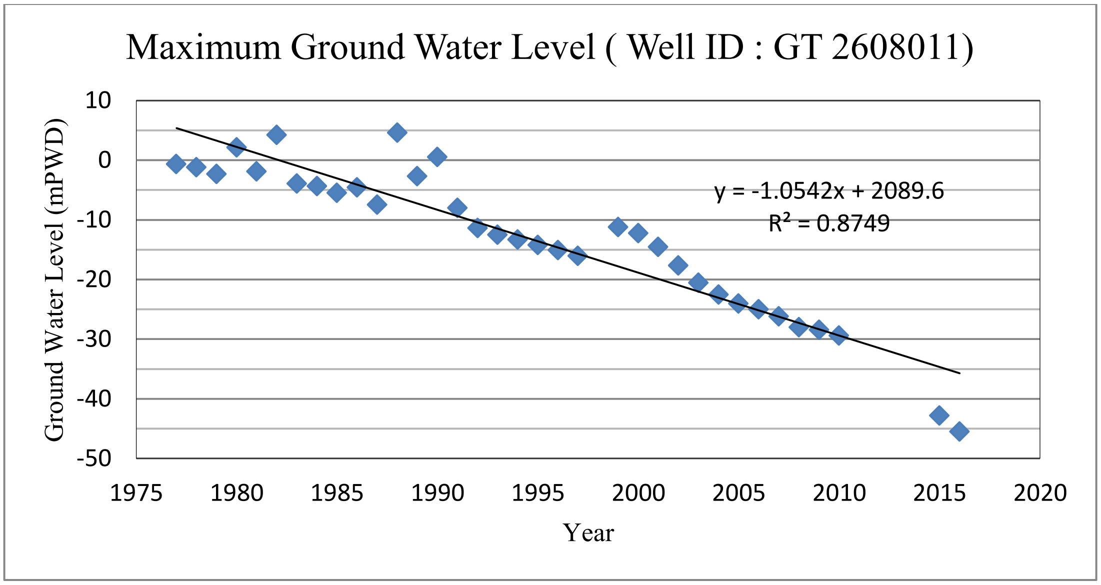

Figure B.49: Annual Maximum Groundwater Level Hydrograph (Location: Well ID GT 2650011, Mohammadpur)

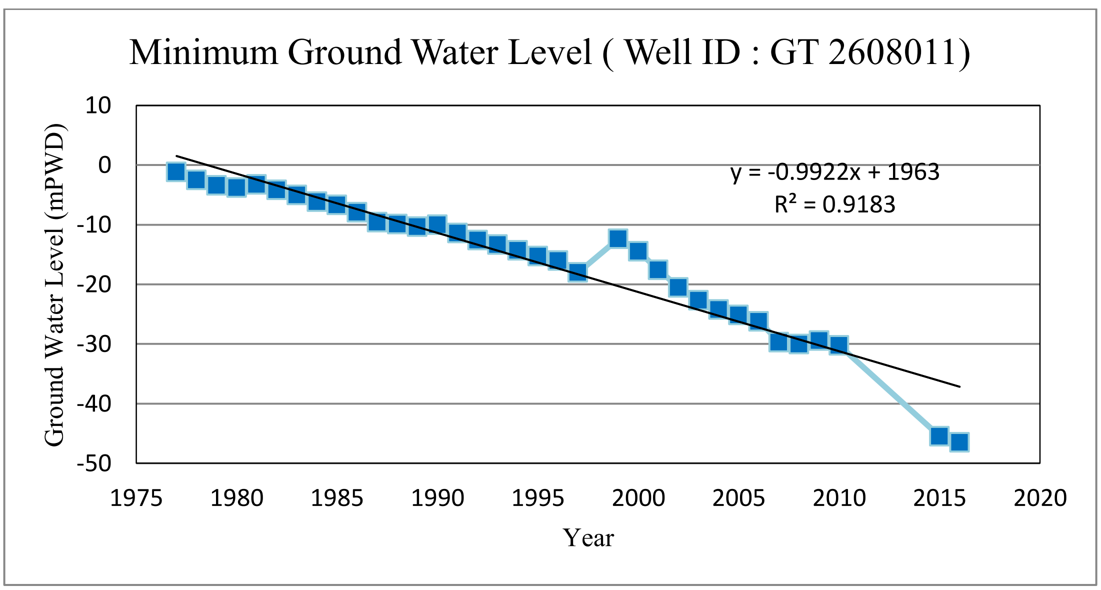

Figure B.50: Annual Minimum Groundwater Level Hydrograph (Location: Well ID GT 2650011, Mohammadpur)

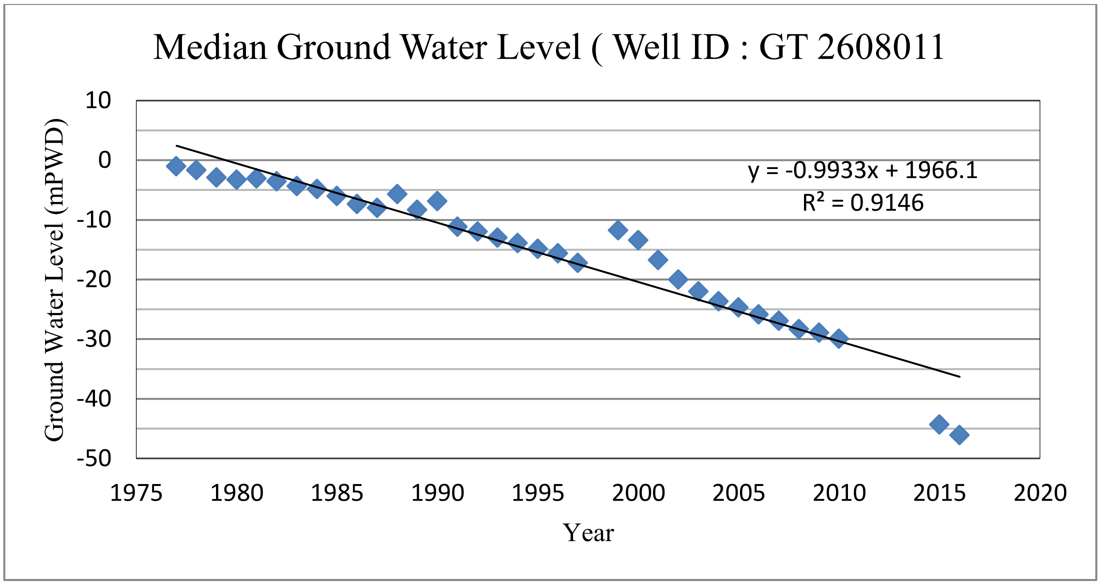

Figure B.51: Annual Median Groundwater Level Hydrograph (Location: Well ID GT 2650011, Mohammadpur)

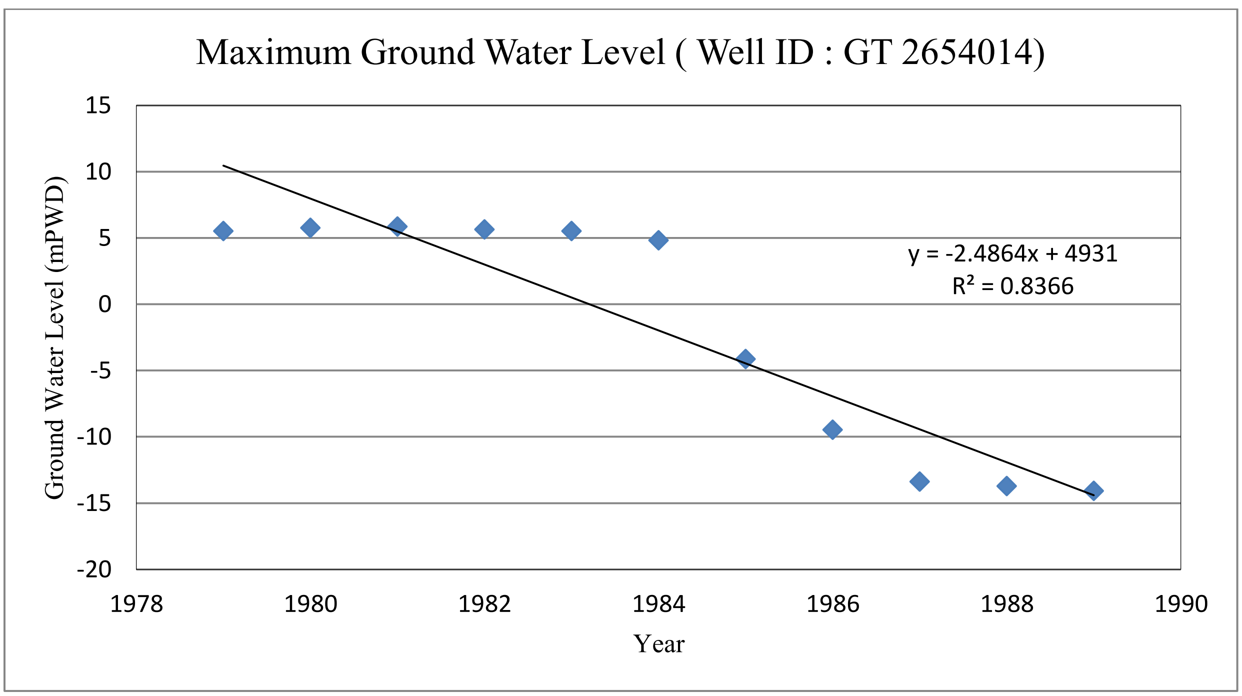

Figure B.52: Annual Maximum Groundwater Level Hydrograph (Location: Well ID GT 2654014, South Khilgaon, Motijheel)

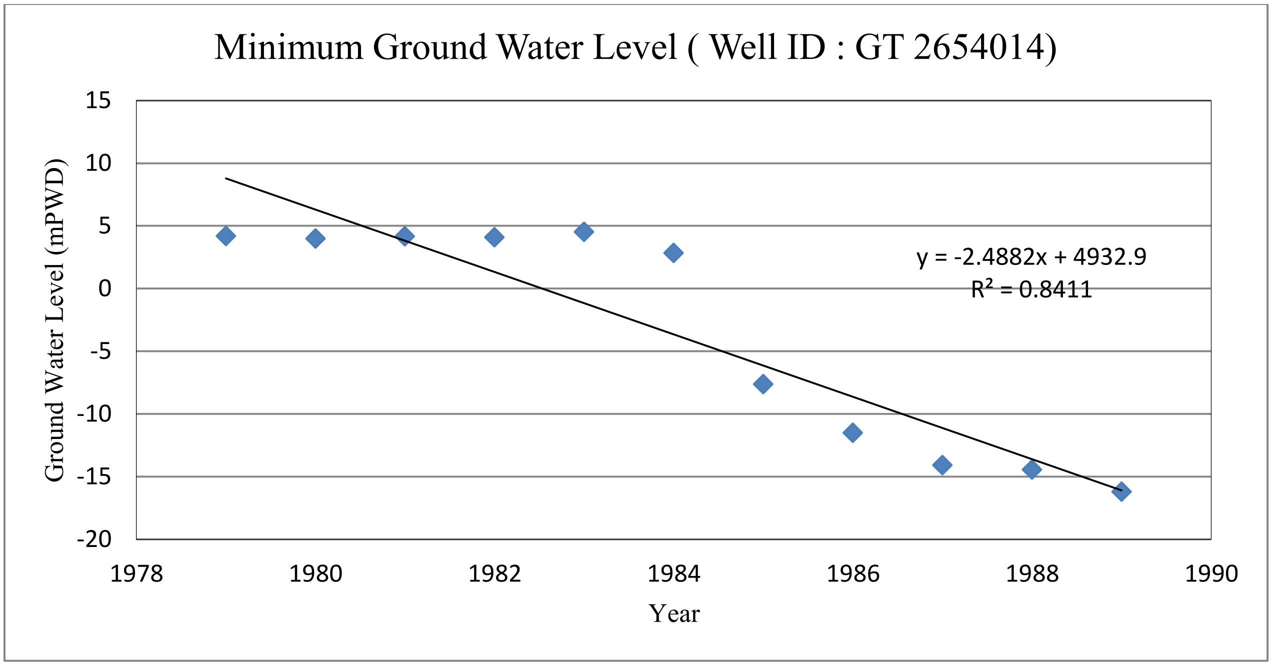

Figure B.53: Annual Minimum Groundwater Level Hydrograph (Location: Well ID GT 2654014, South Khilgaon, Motijheel)

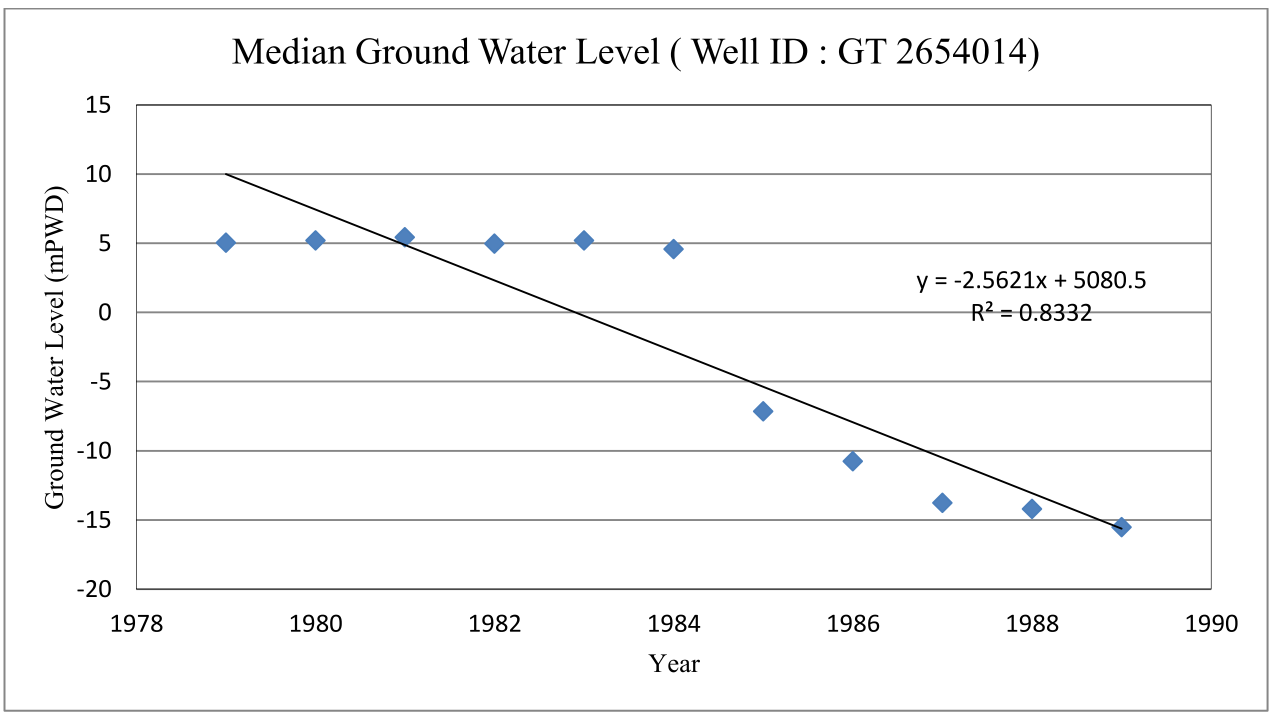

Figure B.54: Annual Median Groundwater Level Hydrograph (Location: Well ID GT 2654014, South Khilgaon, Motijheel)

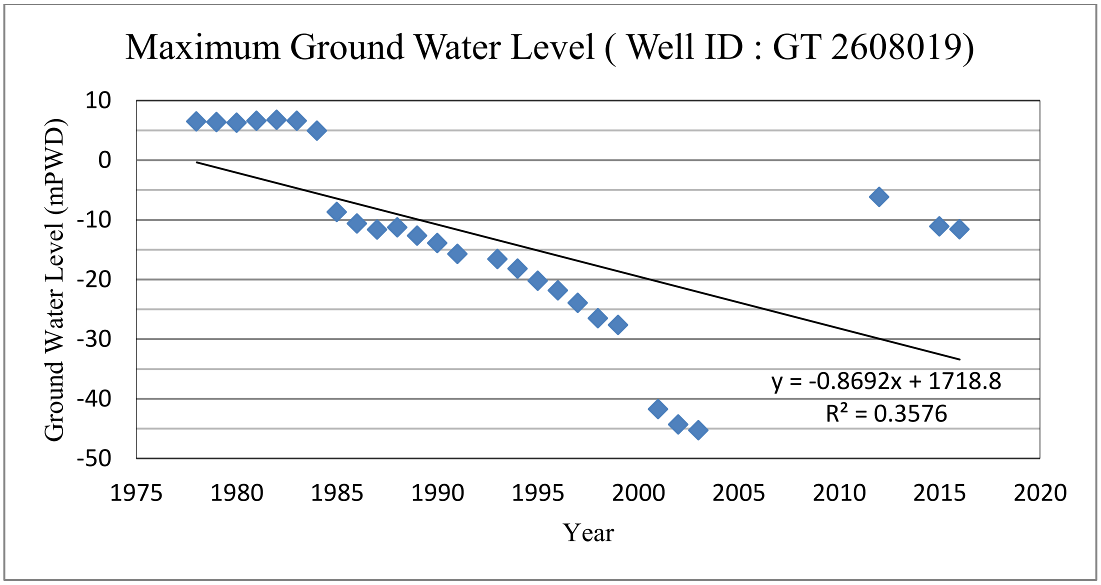

Figure B.55: Annual Maximum Groundwater Level Hydrograph (Location: Well ID GT 2668019, Khilgaon, Sobujbag)

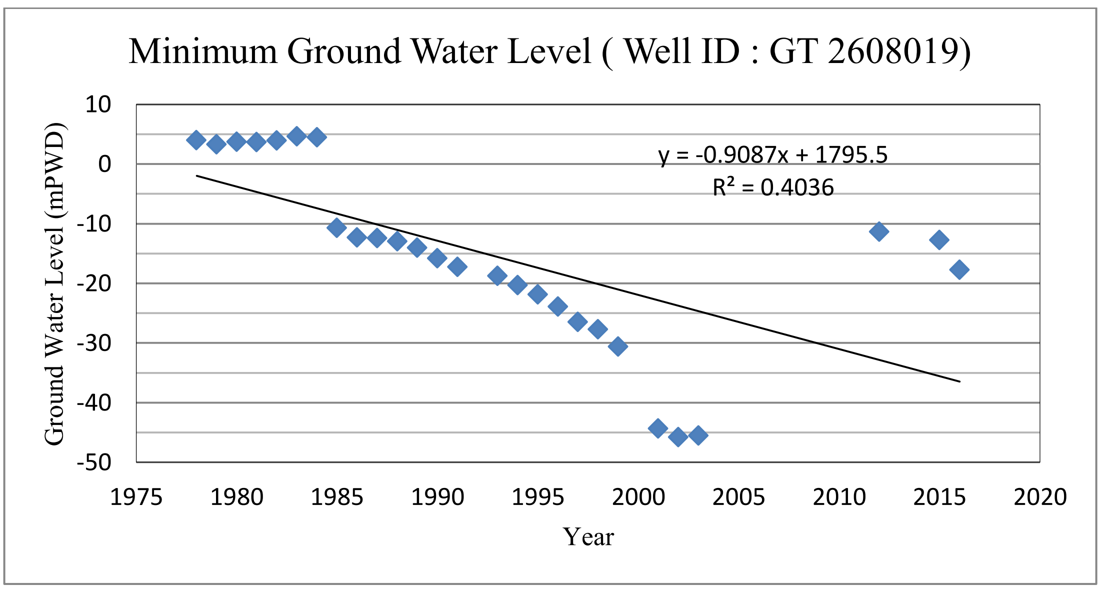

Figure B.56: Annual Minimum Groundwater Level Hydrograph (Location: Well ID GT 2668019, Khilgaon, Sobujbag)

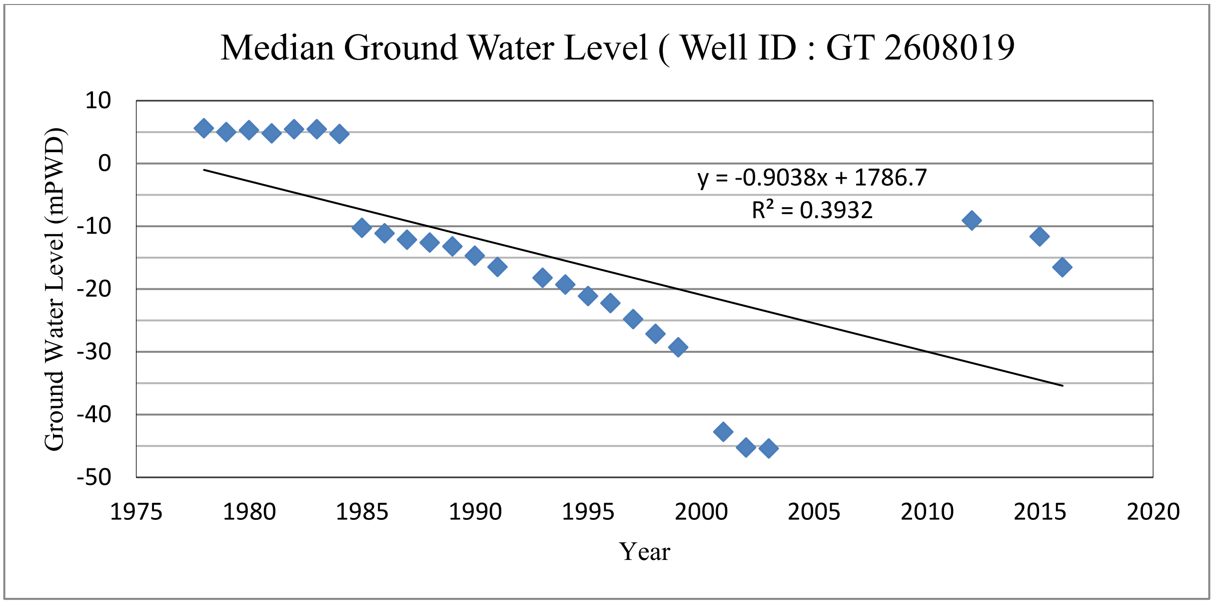

Figure B.57: Annual Median Groundwater Level Hydrograph (Location: Well ID GT 2668019, Khilgaon, Sobujbag)

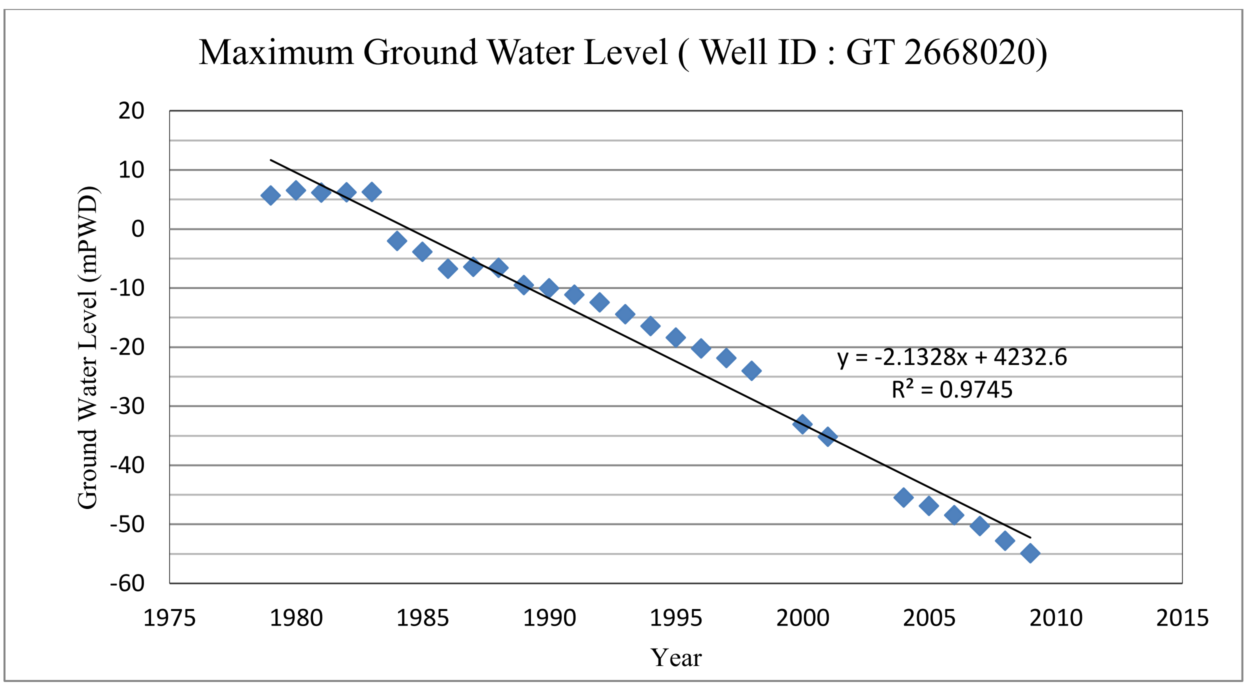

Figure B.58: Annual Maximum Groundwater Level Hydrograph (Location: Well ID GT 2668020, South Basabo, Sobujbag)

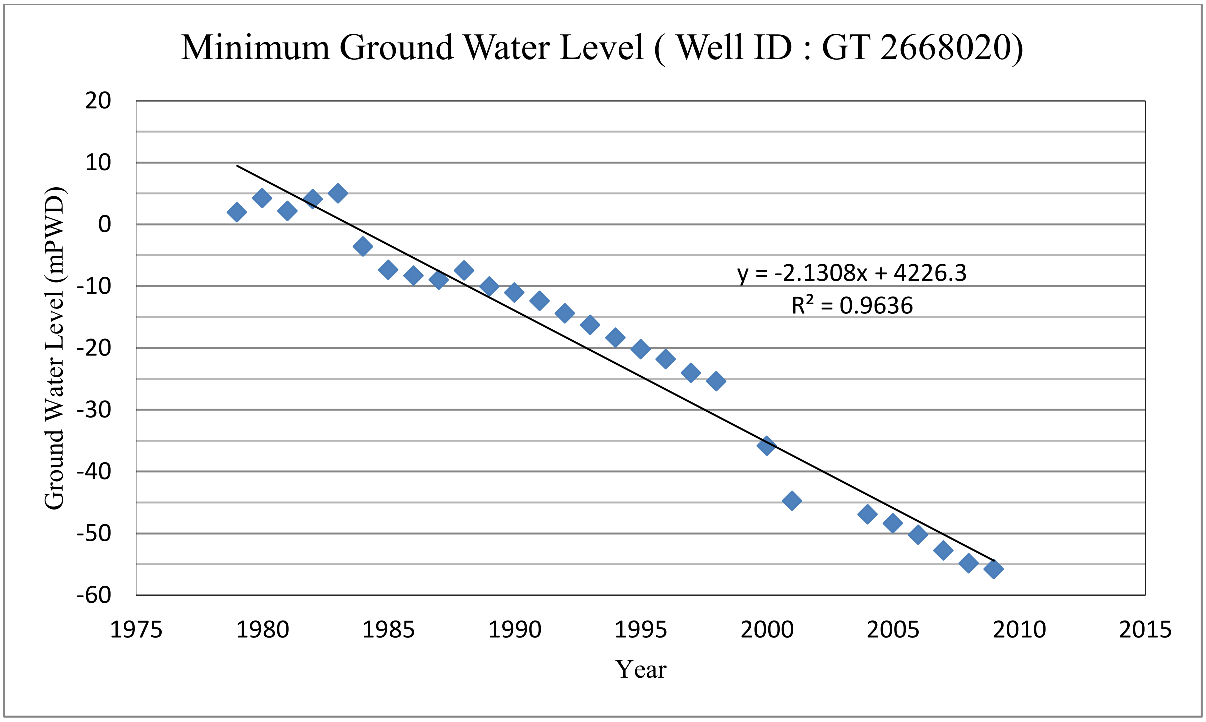

Figure B.59: Annual Minimum Groundwater Level Hydrograph (Location: Well ID GT 2668020, South Basabo, Sobujbag)

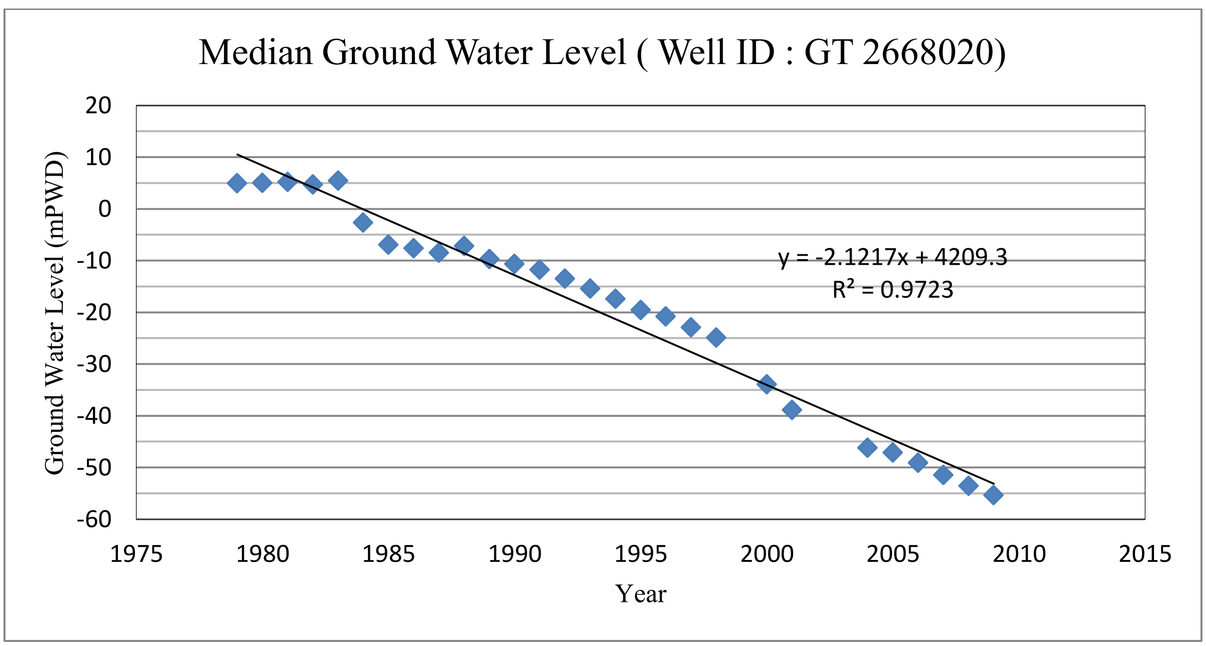

Figure B.60: Annual Median Groundwater Level Hydrograph (Location: Well ID GT 2668020, South Basabo, Sobujbag)

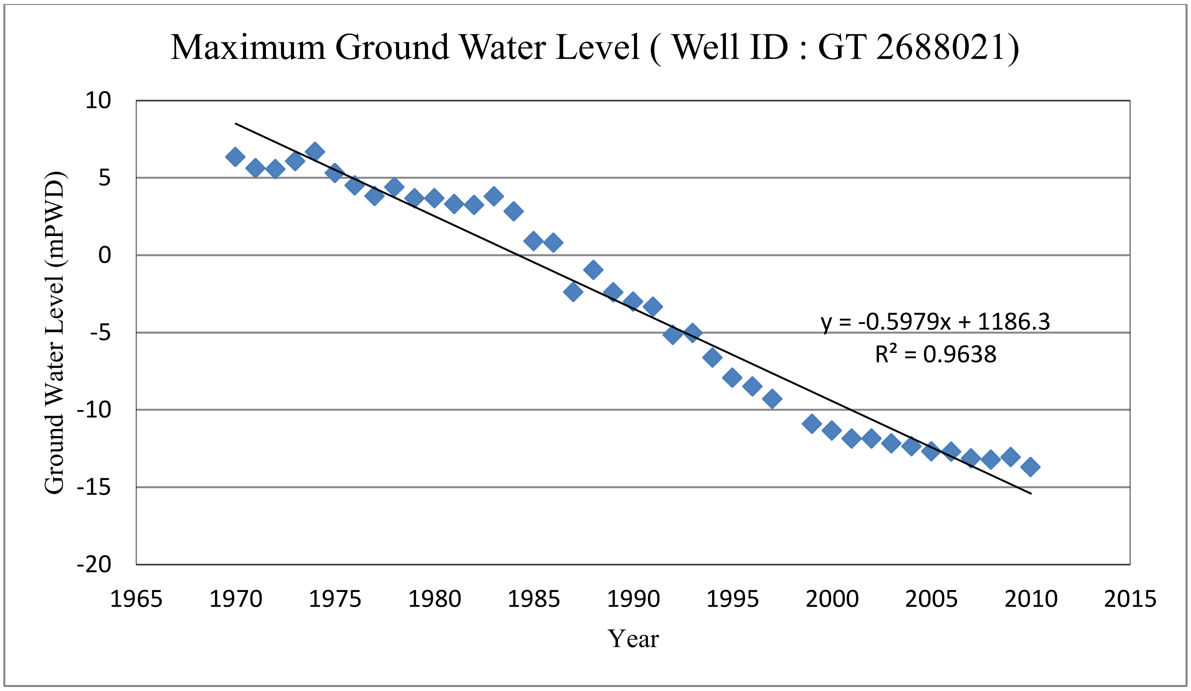

Figure B.61: Annual Maximum Groundwater Level Hydrograph (Location: Well ID GT 2668021, Jagannath University,Sutrapur)

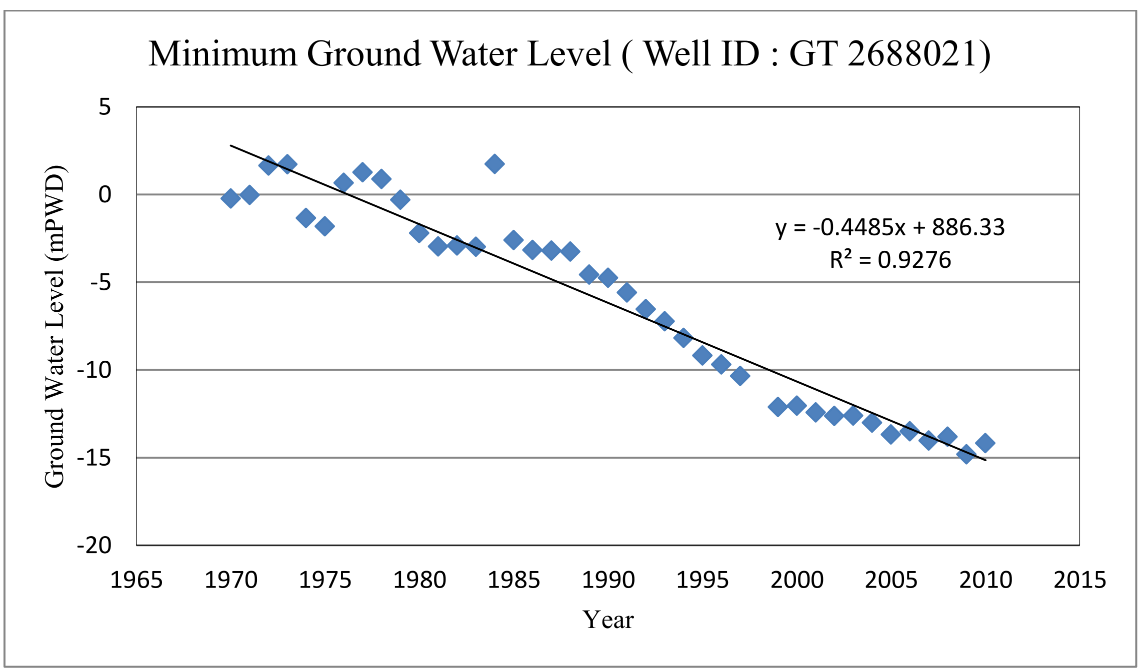

Figure B.62: Annual Minimum Groundwater Level Hydrograph (Location: Well ID GT 2668021, Jagannath University,Sutrapur)

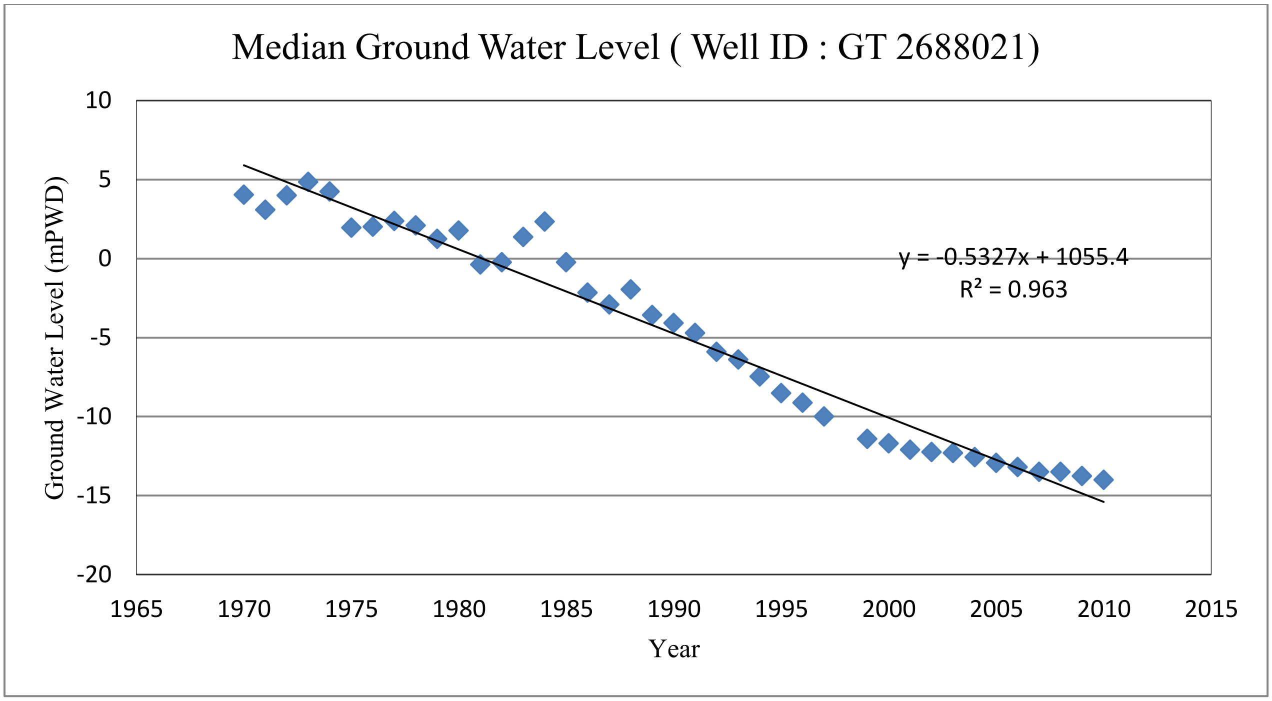

Figure B.63: Annual Median Groundwater Level Hydrograph (Location: Well ID GT 2668021, Jagannath University,Sutrapur)

Appendix C

Groundwater Level Hydrographs of Monitoring Wells from DWASA

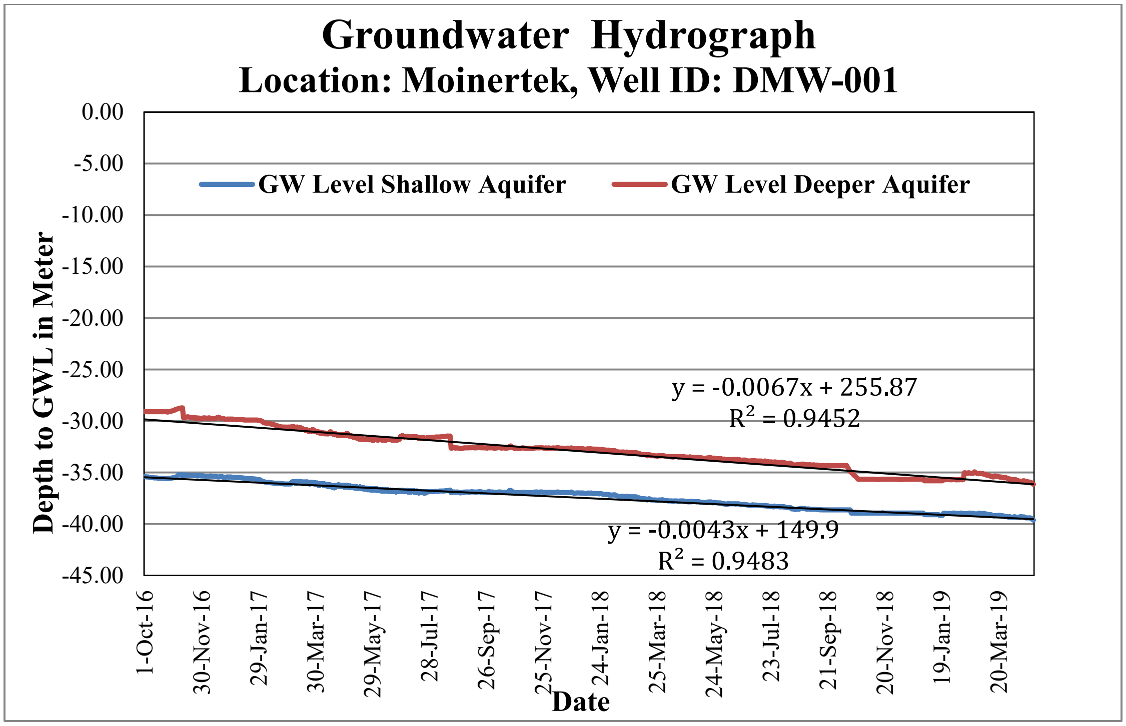

Figure C.1: Groundwater level hydrograph (Location: Well ID: DMW-001, Moinertek)

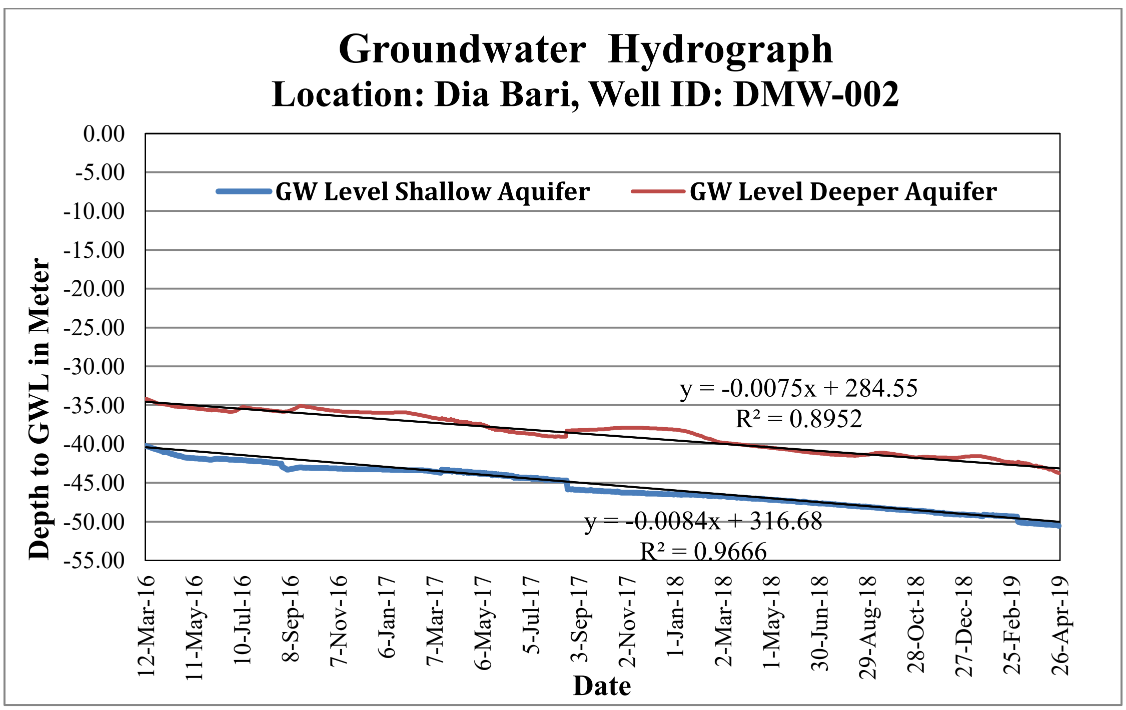

Figure C.2: Groundwater level hydrograph (Location: Well ID: DMW-002, Dia Bari)

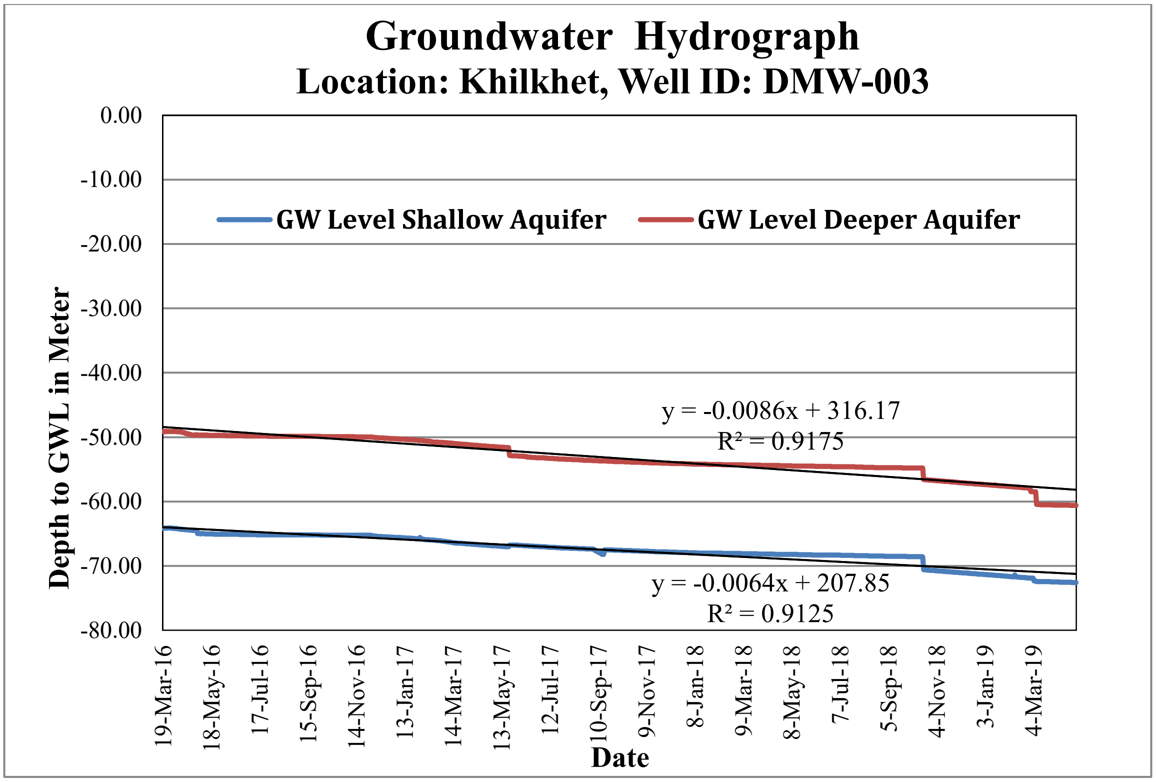

Figure C.3: Groundwater level hydrograph (Location: Well ID: DMW-003, Khilkhet)

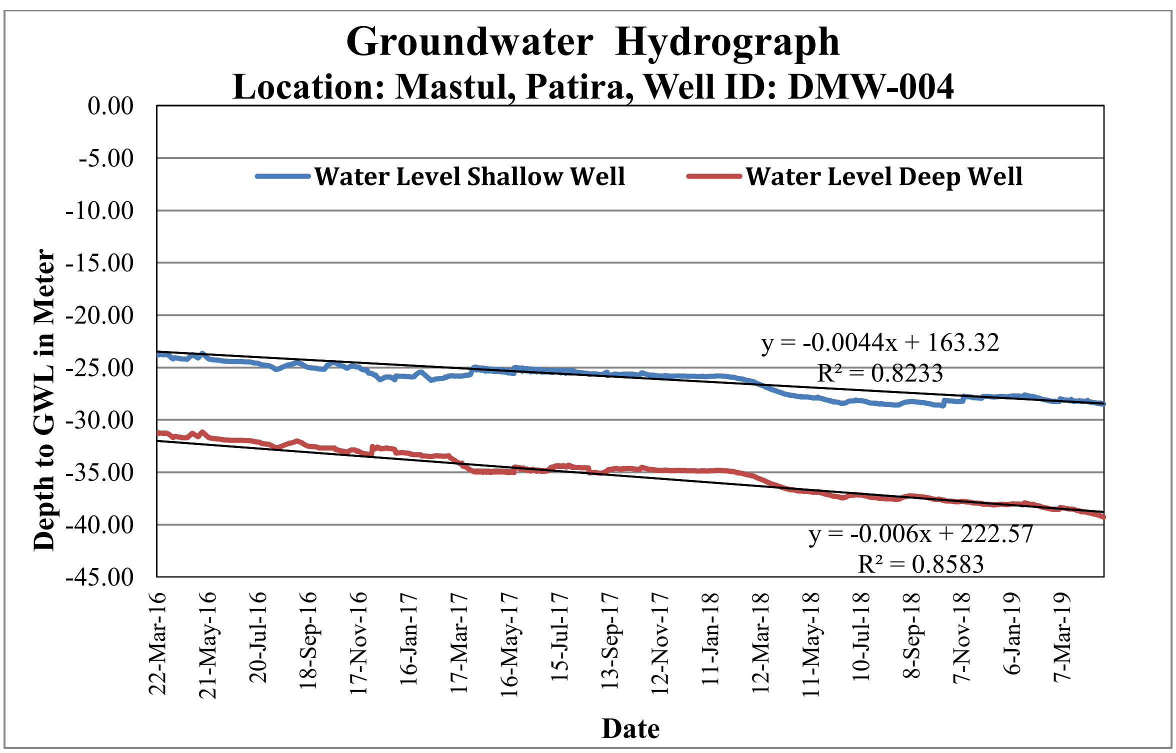

Figure C.4: Groundwater level hydrograph (Location: Well ID: DMW-004, Mastul,Patira)

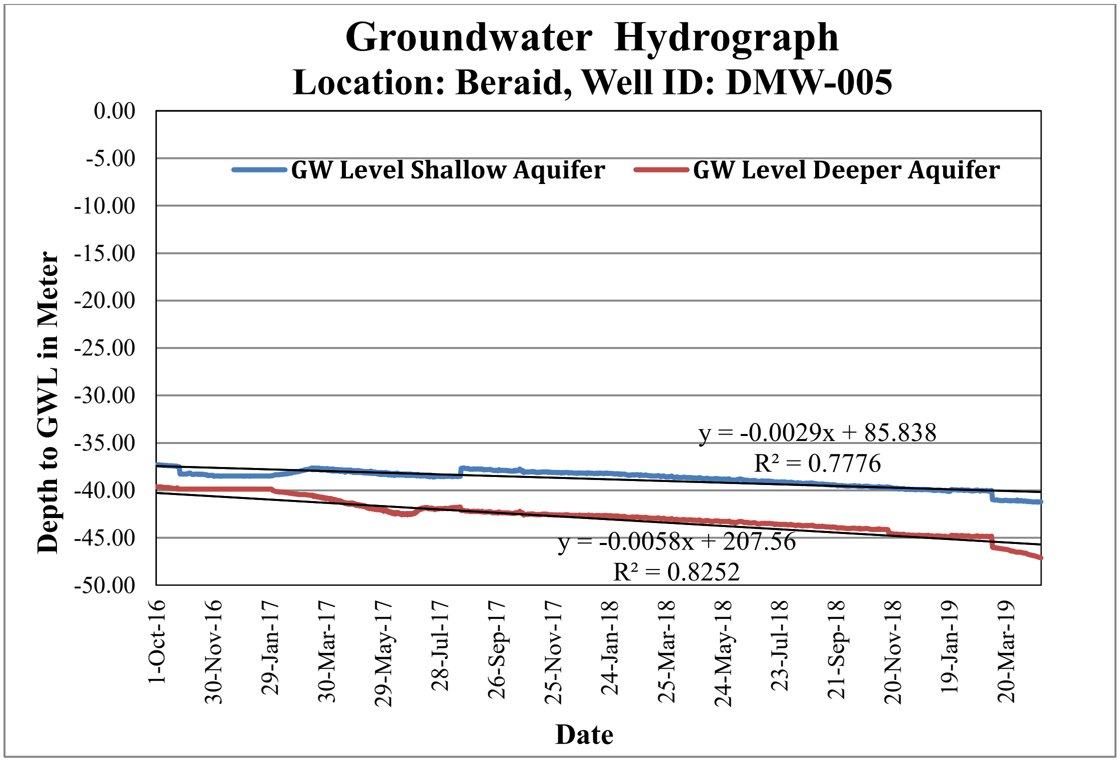

Figure C.5: Groundwater level hydrograph (Location: Well ID: DMW-005, Beraid)

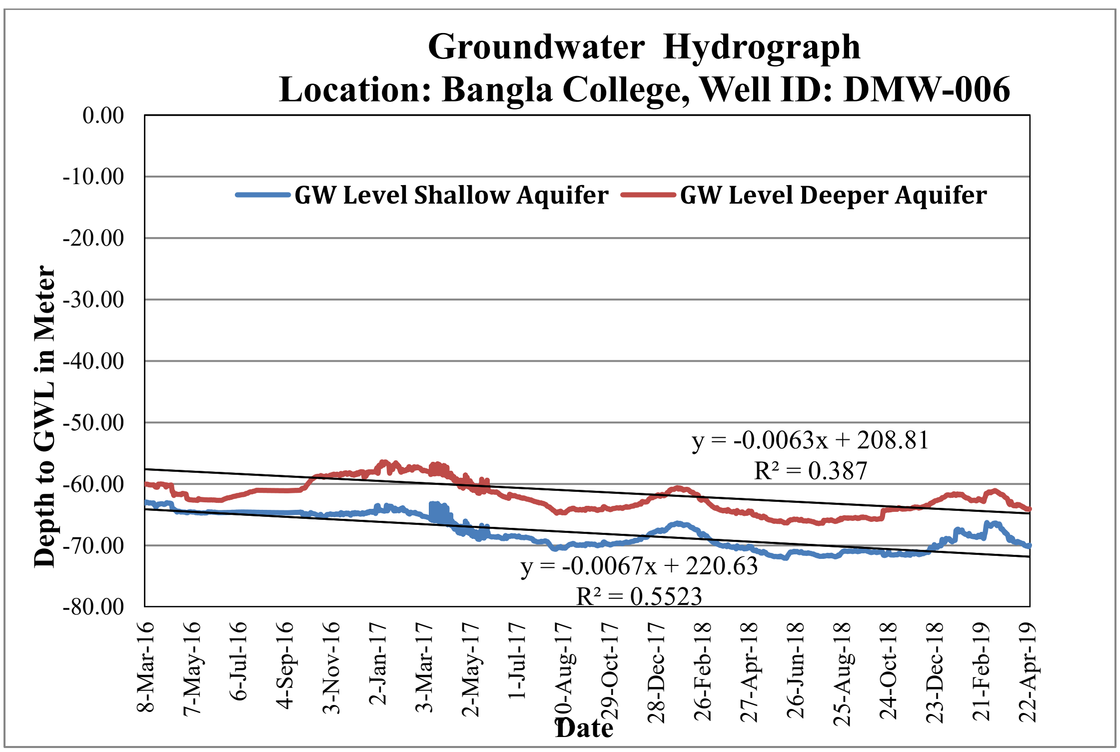

Figure C.6: Groundwater level hydrograph (Location: Well ID: DMW-006, Bangla College)

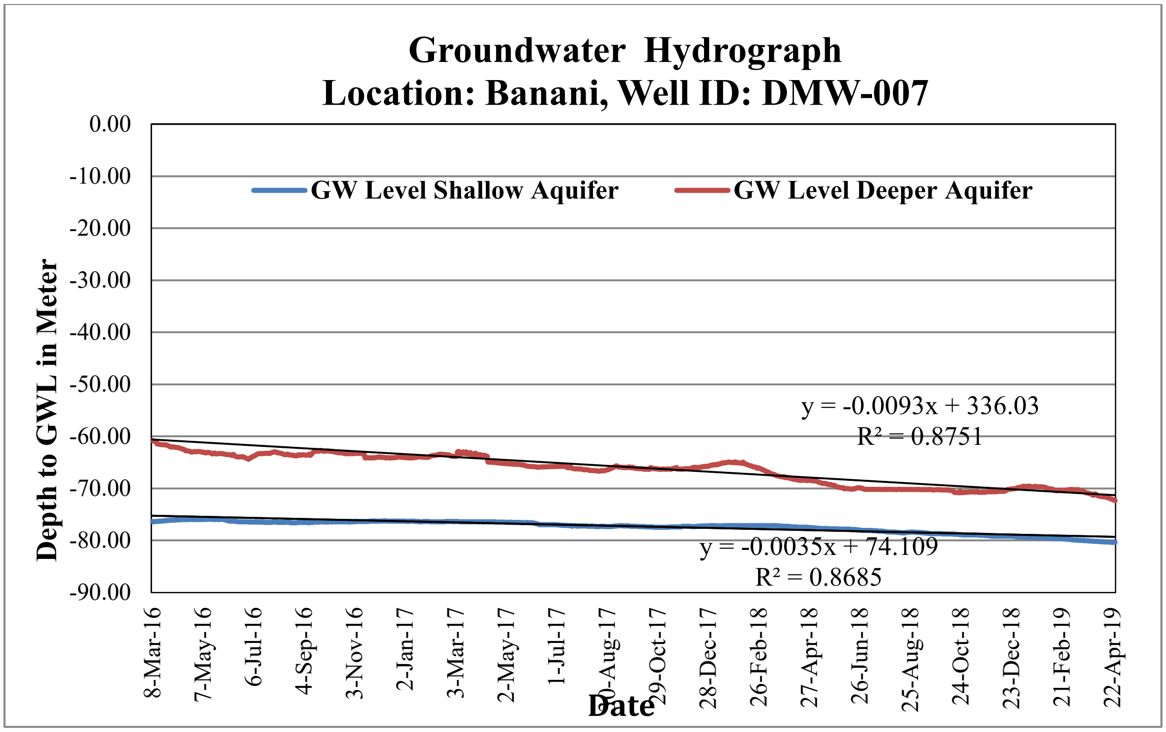

Figure C.7: Groundwater level hydrograph (Location: Well ID: DMW-007, Banani)

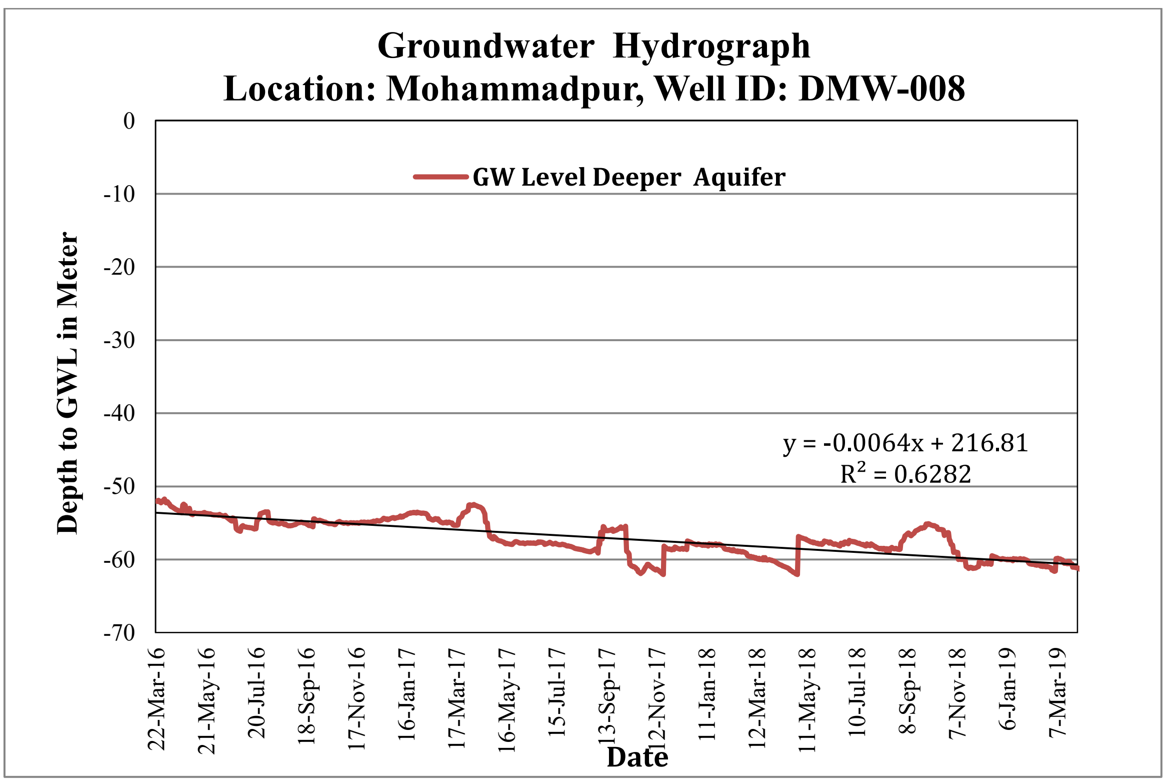

Figure C.8: Groundwater level hydrograph (Location: Well ID: DMW-008, Mohammadpur)

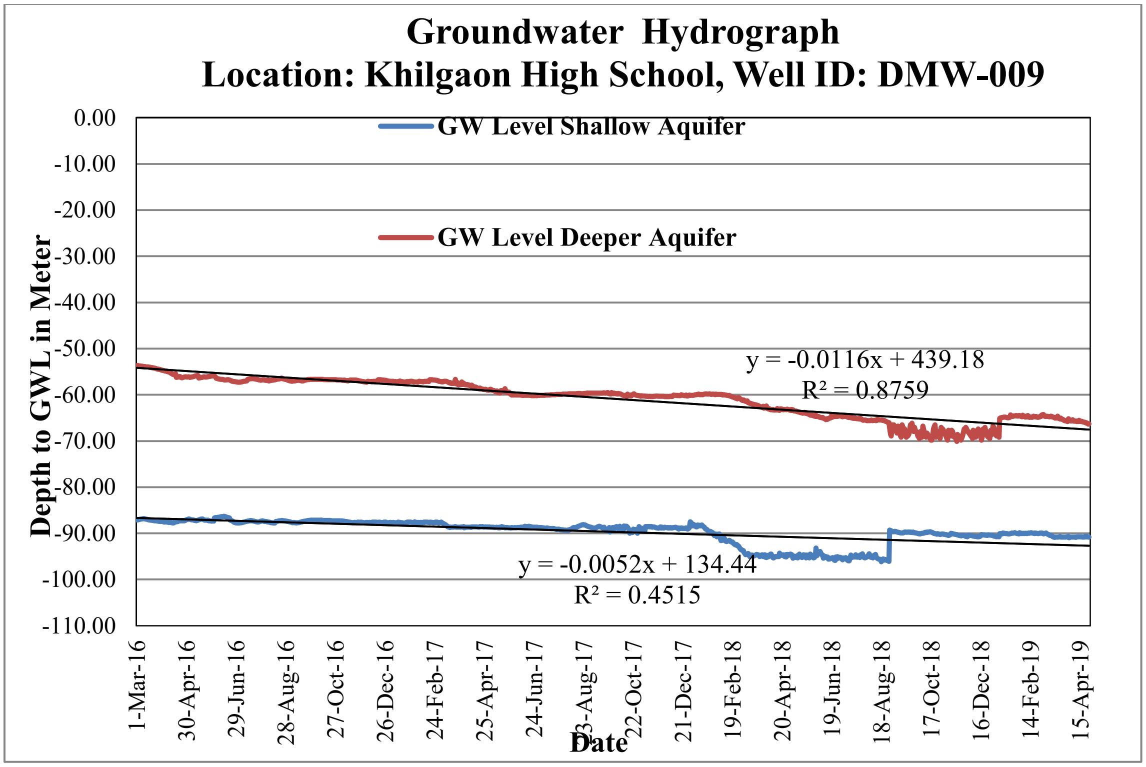

Figure C.9: Groundwater level hydrograph (Location: Well ID: DMW-009, Khilgaon High School)

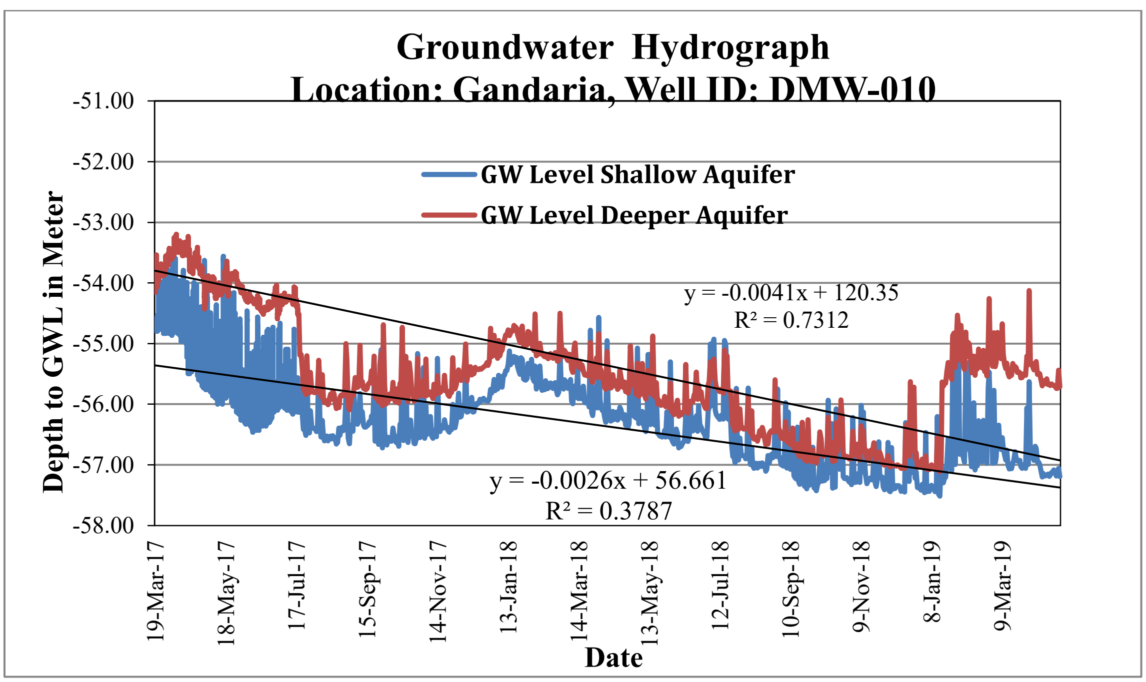

Figure C.10: Groundwater level hydrograph (Location: Well ID: DMW-010, Gandaria)

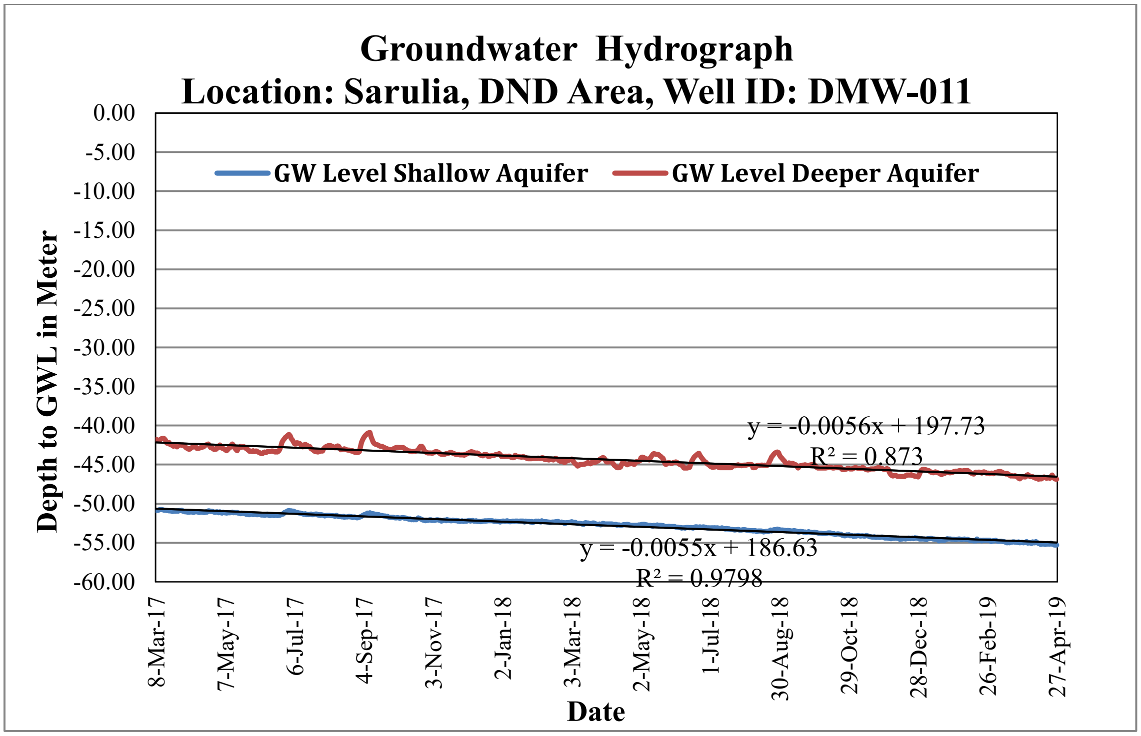

Figure C.11: Groundwater level hydrograph (Location: Well ID: DMW-011, Sarulia, DND Area)

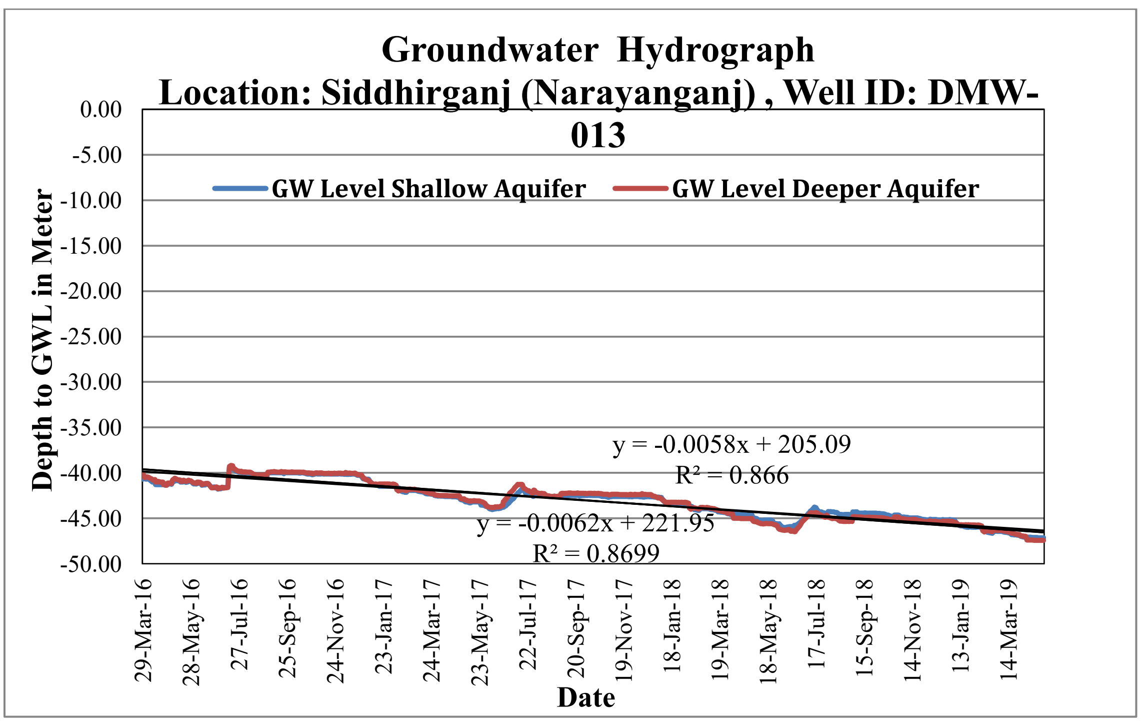

Figure C.12: Groundwater level hydrograph (Location: Well ID: DMW-013,Siddhirganj, Narayanganj)

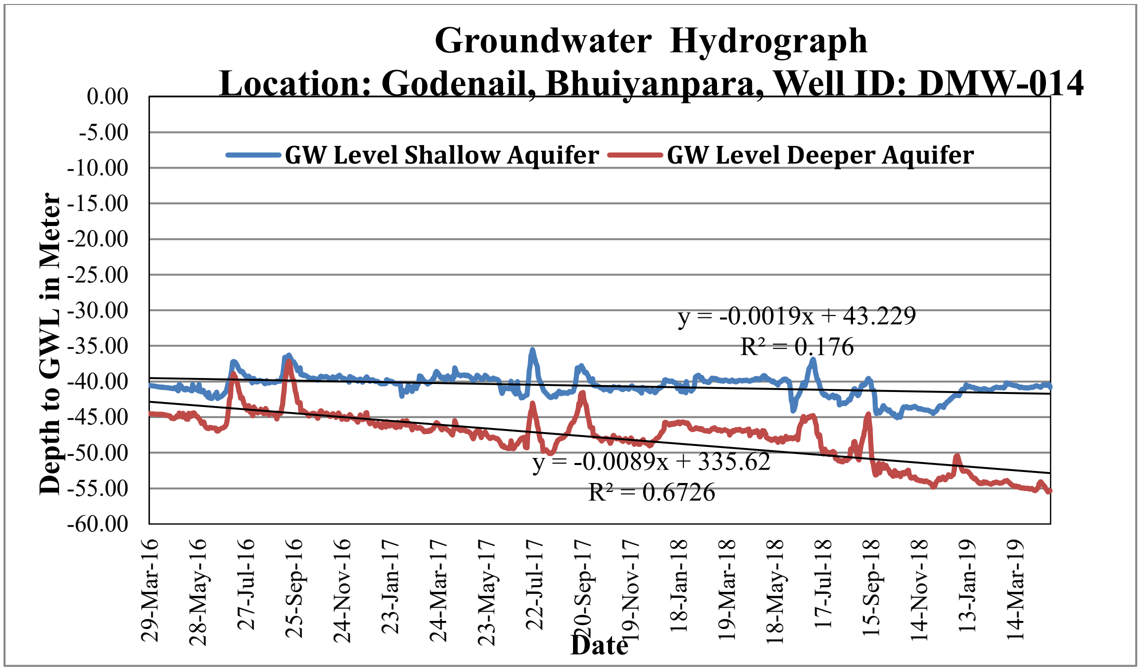

Figure C.13: Groundwater level hydrograph (Location: Well ID: DMW-014,Godenail, Bhuiyanpara)

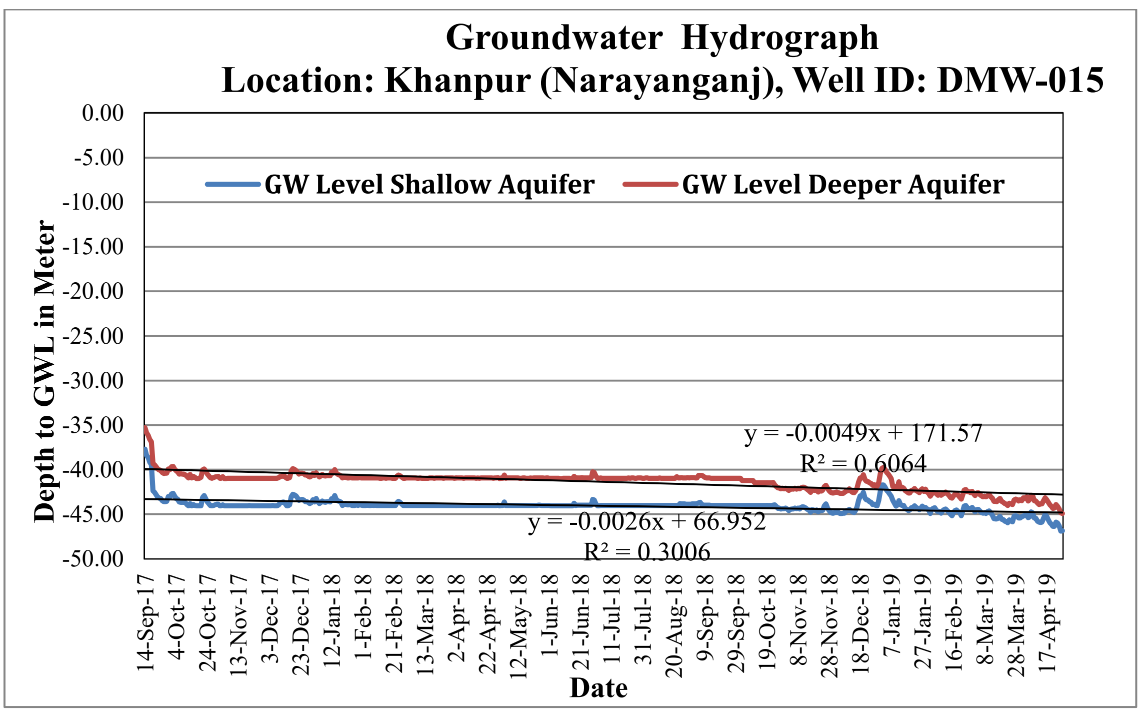

Figure C.14: Groundwater level hydrograph (Location: Well ID: DMW-015,Khanpur, Narayanganj)

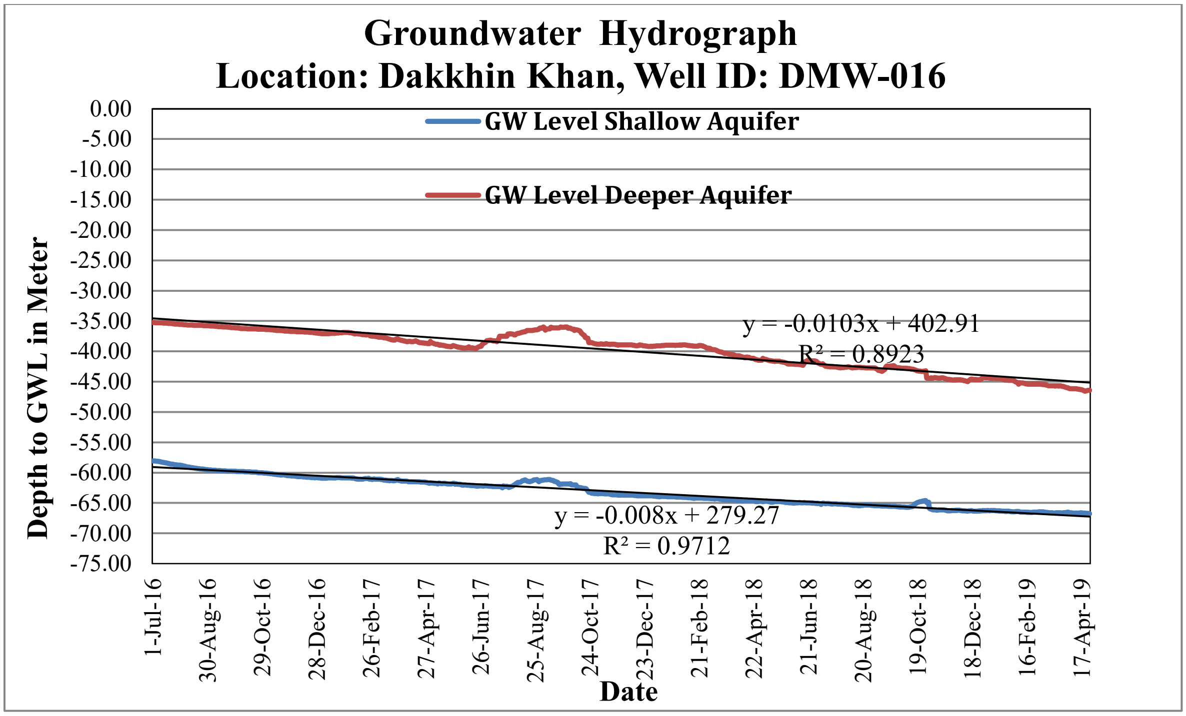

Figure C.15: Groundwater level hydrograph (Location: Well ID: DMW-016, Dakkhin Khan)

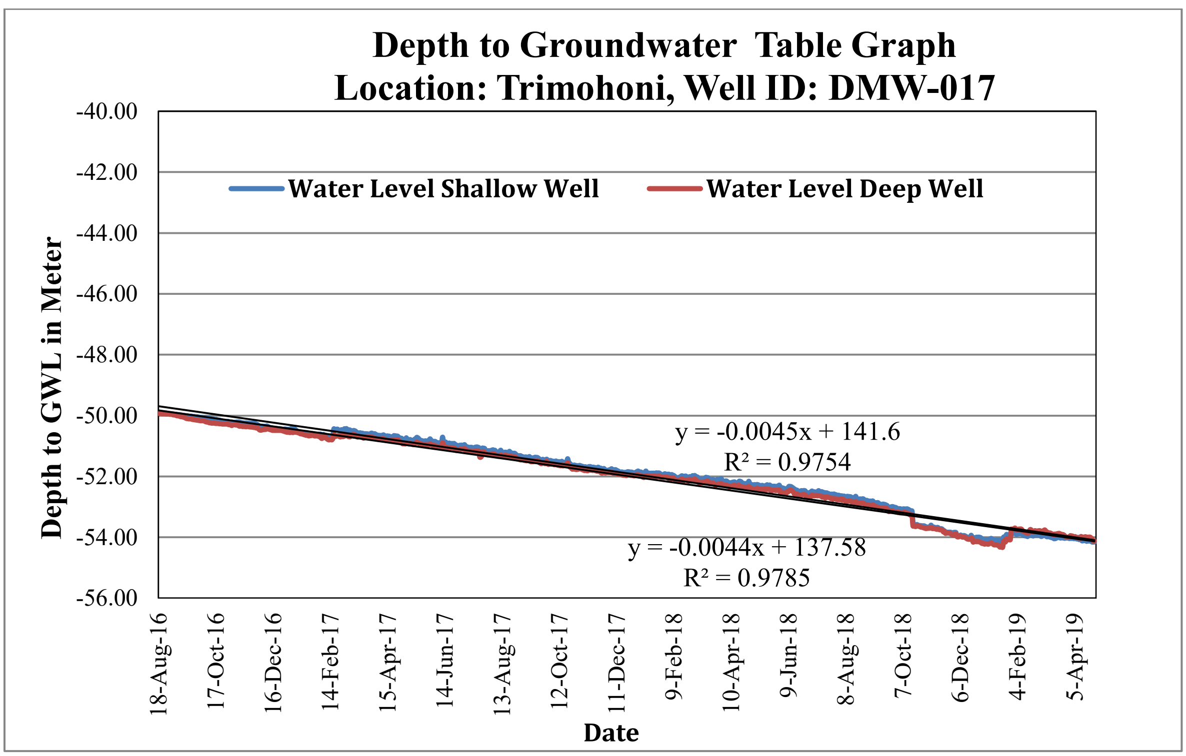

Figure C.16: Groundwater level hydrograph (Location: Well ID: DMW-017, Trimohoni)

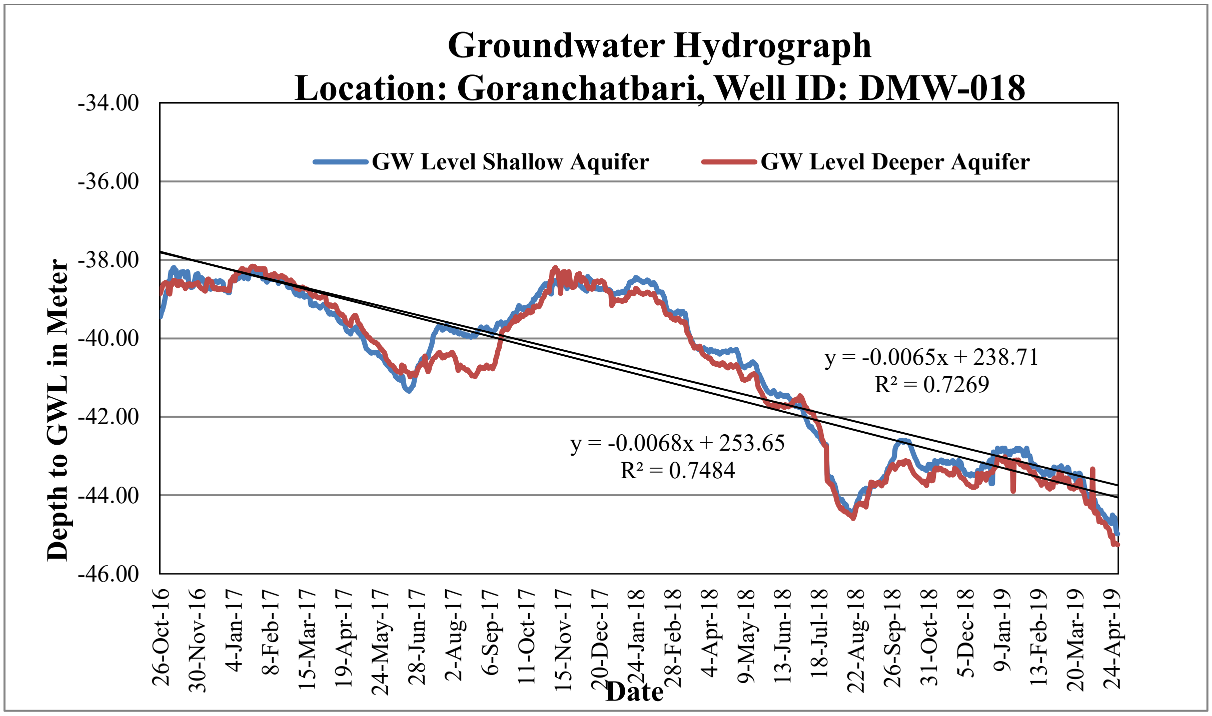

Figure C.17: Groundwater level hydrograph (Location: Well ID: DMW-018,Goranchatbari)

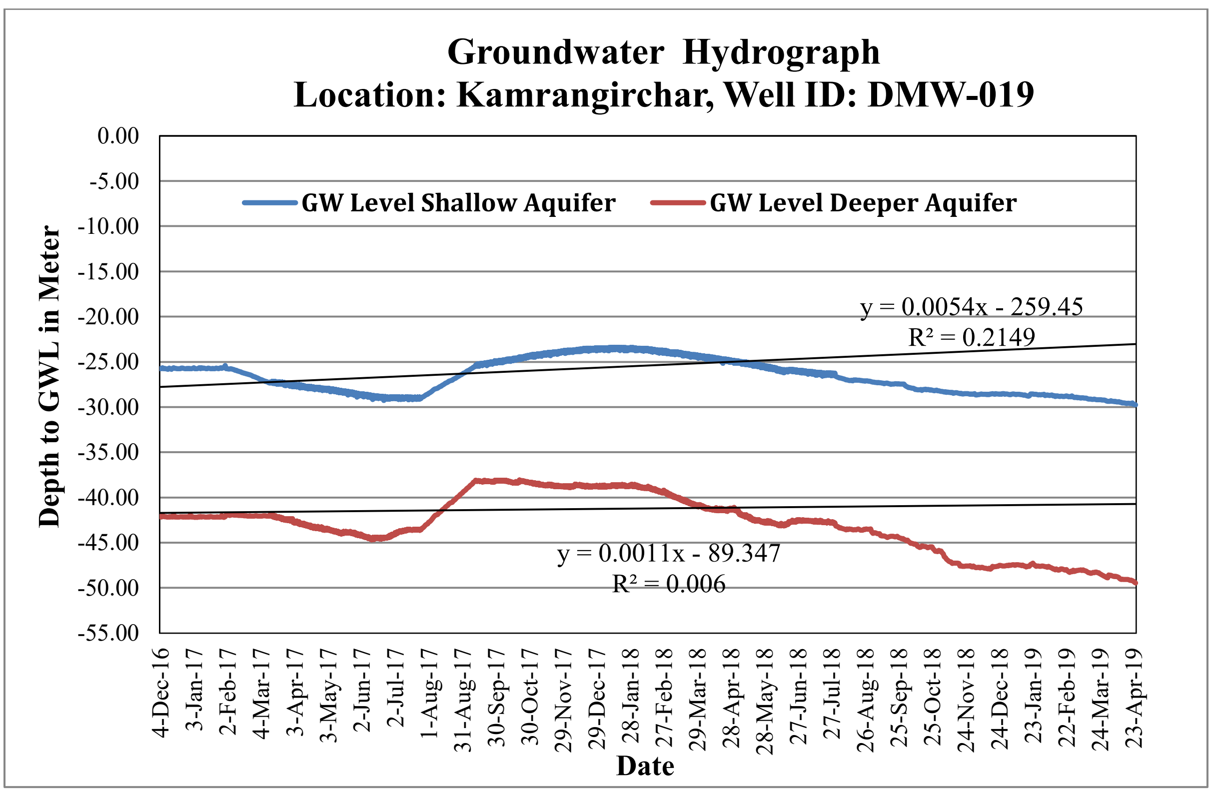

Figure C.18: Groundwater level hydrograph (Location: Well ID: DMW-019, Kamrangirchar)

Appendix D

Checklist for KII and Semi Structured Interview

Checklist for KII and Semi structured interview:

1. GWL is declining 2-3 m/yr এরজন্য DWASA কি step নিচ্ছে GW declination কমানোরজন্য?

2. SWTP Plant গুলো Design করারসময় Intake Water Quality যেমনছিলএখনআরঅদূরভবিষ্যতেতেমনথাকবেবলেকিআপনিমনেকরেন?

3. SW Quality Maintain করারজন্য DWASA, অন্যান্য Govt Organization এরসাথেকোনকাজকরবেকি?নাকি Intake Location টাই DWASA maintain করবে।

4. DWASA Master Plan অনুযায়ীযে Step গুলোনিচ্ছে GW Declination কমানোর জন্যআপনিকিযথেষ্টমনেকরেন?

5. DWASA-য় 900 এরওবেশি DTW আছে। Dhaka-র aquifer দেখলেআমরাবুঝতেপারিএখানে 4 টা aquifer আছে।

	Aug.Bottom (Depth)
Upper Aquifer -1	118m = 448.4ft
Upper Aquifer -2	116m = 544.48ft
Lower Aquifer -1	285m = 934.8ft
Lower Aquifer -2	337m = 1105.36ft

আমরাএখনযে DTW Install করছিতারবেশিরভাগই lower Aquifer-এপ্রায় 100 ft এরবেশি।
Upper Aquifer rechargeable Lower Aquifer ততটুকুনা।এটাকতটুকু Sustainable বলেআপনিমনেকরেন ?

7. কাগজেকলমে deficit নাথাকলেও Dry Season এ পানির crisisএ নগরবাসীপড়ে থাকেন।পত্রিকায়লেখালিখিহয়।এব্যাপারেআপনারঅভিমত?

8.Master Plan এ Block Tarrift System নিয়েউল্লেখআছে।এখনকার্যকরকেনকরাযায়নি,এবিষয়েআপনারঅভিমত?

9.DWASA Water Supply খুবনিষ্ঠারসাথেকরলেও Consumer Level এখুবএকটানিয়ন্ত্রনআনতেপারেনি।পানিরঅপচয়রোধকরাএবং Water Quality Maintain করারজন্য Underground Reservoir এর Cleaning এরক্ষেত্রে DWASA এরপদক্ষেপকি?

-Low water flushing commode
-Low Pressure faucets

এসবেরব্যাপারে WASA কিকোন rule জারিকরতেপারে?
কিংবা Advertisement?

10.ব্যাক্তিগতভাবে Master Plan এরবাইরেআরকিকি Adaptation Strategy DWASA নিতেপারে to reduce GW declination.

- অন্যান্য Watersectoral institute গুলোকিকিপদক্ষেপনিতেপারে GW Declination কমানোরজন্য।
-Water sector এরসবপ্রতিষ্ঠানকিএকসাথেকোন plan করতেপারে to reduce GW declination?

11. আমার study থেকেবেরকরছি contour map করেযে, Dhaka-রসবচেয়েবেশি GW declination হচ্ছে Khilgaon Area-তে।এব্যাপারে DWASA কিকরছে? After all কিছুদিনপরএইসবএলাকায় DTW গুলো inoperable or low production দেবে।

12.SWTP গুলোএকযোগেচালুহলেআস্তেআস্তে DTW গুলোকি বন্ধকরেদেয়াহবে?
13. RWH নিয়ে আপনার মন্তব্য।
14. ETP, Greywater recycling, wastewater treatment নিয়ে DWASA কোন পদক্ষেপ নিয়েছে কি?