EXECUTIVE SUMMARY

The Department of Bangladesh Haor & Wetland Development (DBHWD) is mandated to ensure overall coordination and monitoring for integrated development of haors and wetlands that will holistically address the problems related to water resources, agriculture, fisheries, livestocks, ecology and biodiversity. A large number of inhabitants are dependent for their livelihoods on diverse activities around wetlands which influence the socio-economic condition of the country. Moreover, following the recommended strategy of the Haor Master Plan, DBHWD is now giving emphasis on promoting investigation and expansion of groundwater irrigation which has been formulated to facilitate improved and sustainable management of surface water and groundwater resources for agricultural use in haor area through an integrated mathematical modelling study. DBHWD also giving emphasis on assessment of interaction between Haor and river ecosystem. As a result, a study covered Habiganj, Maulvibazar, Sylhet, Kishoreganj, Netrokona and Sunamganj districts is proposed to explore the availability of both surface water as well as groundwater resources to develop future irrigation expansion plan for proper management of water resources in an integrated manner.

The study was formulated with a view to explore the availability of both surface water as well as groundwater resources for developing a future irrigation expansion plan for proper management of water resources in an integrated manner. The study also addressed the zoning of the areas for future irrigation expansion based on the quantity as well as quality of surface water and groundwater resources.

The major activities that have been furnished to accomplish the study objectives are hydrogeological investigations, assessment of water resources using mathematical modelling and development of an Interactive Information System (IIS) using the state of art technology. Hydrogeological investigations include exploratory drilling, construction of production tubewells, long term aquifer tests, installation and monitoring of groundwater level, geophysical survey, seepage and percolation measurements and water quality sampling and analysis. The modelling activities include development, calibration and validation of surface water and groundwater interaction model for the study area and simulations of model for likely scenarious.

The major study findings from hydrogeological investigations are illustrated below:

- The data collected from the secondary sources as well as from field investigations reveals that three major aquifers encountered upto 200m depth throughout the study area with some exception in Sylhet, Maulvibazar and Sunamganj districts. Tthickness of the first aquifer ranges from 9-115m, second aquifer ranges from 13-152m and third aquifer ranges from 11-88m. The thickness of the aquifers is thicker in Netrokona, Sunamganj, Kishoreganj and Habiganj district rather than that of Sylhet and Maulvibazar districts. The aquifers are mostly composed of fine sand, medium sand and coarse sand materials with a semi confined in nature.

- Depth to groundwater level/table from ground surface for the project installed observation wells in the study area reveals that the minimum depth of water level is observed during August and maximum during March or April. Groundwater level starts to decline in September and reaches to the maximum depth in March-April and then moves upward again in monsoon to regain the static water level in July-August. The maximum and minimum depth to groundwater table along with fluctuation for different districts is presented below:

District	Depth to Groundwater Table		
	Minimum	Maximum	Fluctuation
Kishoreganj	1.5 to 5.0m	4.5 to 11.0m	2.5 and 7.0m
Netrokona	1.5 to 4.5m	4.5 to 11.0m	4.0 and 19.0 m
Sylhet	3.5 m	5.5 m	2.0m
Maulavibazar	1.0 to 1.5 m	2.5 to 3.5 m	1.0 and 1.5 m
Habiganj	1.5 to 5.0 m	6.0 to 10.5 m	4.5 and 5.5 m
Sunamganj	2.0 to 8.0 m	6.5 to 9.0 m	1.0 and 8.0 m

- The geophysical investigations revealed that in the study area 3 nos. of aquifers separated by aquitard exist upto the depth of 200m which is similar to the borelog data.
- The top geological unit is aquitard shows resistivity range from 11Ωm to about 24Ωm which is clay or silty clay.
- The next unit is Aquifer-1 also termed to be shallow aquifer shows resistivity variation in the range of 25Ωm to 164Ωm. Thicknes of this unit varies from 4m to 104m. Maximum thickness of Aquifer-1 is about 104m at Atpara, Kishoreganj and minimum thickness is about 4m at Madan, Netrokona.
- Aquifer-2 also shows the same resistivity range. Thicknes of this unit varies from 3m to 135m. Maximum thickness of Aquifer-2 is about 134m at Madhabpur, Habiganj and minimum thickness is about 3m at Bajitpur, Kishoreganj.

Maximum depth of the lower boundary of Aquifer-3 is about 171m at Madhabpur. Habiganj and minimum depth is about 100m at Mohanganj, Netrokona.

- Hydraulic properties obtained from aquifer tests conducted in installing production wells are given below:

SL No.	District	Upazila	Latitude	Longitude	Well Depth (m)	Strainer Position (m)	Transmissivity (m^2/day)
1	Habiganj	Bahubal	24.32082	91.529585	60.98	35.67-53.35	380
2	Sylhet	Balaganj	24.750651	91.826652	145.43	123.78-143.90	347
3	Sunamganj	Bishwambarpur	25.109018	91.331422	100	79.87-96.95	70.86
4	Sunamganj	Chhatak	24.959974	91.674454	80.49	60.37-77.44	1241.76
5	Sunamganj	Dowarabazar	25.061507	91.513586	79.27	54.88-76.21	996.7
6	Netrokona	Kendua	24.650789	90.73543	121.95	99.09-119.51	2697.28

SL No.	District	Upazila	Latitude	Longitude	Well Depth (m)	Strainer Position (m)	Transmissivity (m^2/day)
7	Habiganj	Madhabpur	24.133174	91.317786	132.93	117.07-131.71	982.7
8	Netrokona	Netrokona Sadar	24.92976	90.78699	146.74	126.02-143.7	1090.03
9	Kishoreganj	Pakundia	24.33247	90.68894	94.88	68.67-91.84	1059.86
10	Kishoreganj	Kuliar Char	24.151159	90.931561	118.9	92.68-115.85	1128.90
11	Maulvibazar	Kamalganj	24.431566	91.842153	108.23	78.96-104.57	270.68
12	Maulvibazar	Kulaura	24.531552	92.035999	150.3	128.0-148.0	853.06

- Hydraulic properties from aquifer tests conducted by IWM using existing production wells are given in table below:

SL No.	District	Upazila	Latitude	Longitude	Well Depth (m)	Strainer Position (m)	Transmissivity (m^2/day)
1	Kishoreganj	Hossainpur	24.384963	90.670189	24.39	9.45-24.39	976.33
2	Kishoreganj	Pakundai	24.347127	90.680394	18.29	9.45-18.29	2906.00
3	Kishoreganj	Hossainpur	24.431675	90.686672	27.44	16.77-27.44	381.33
4	Kishoreganj	Pakundai	24.317144	90.714931	18.29	4.87-18.29	1268.33
5	Kishoreganj	Katiadi	24.244321	90.824074	18.29	8.17-18.29	1116.33
6	Kishoreganj	Katiadi	24.338581	90.830665	19.81	9.14-19.81	452.67
7	Kishoreganj	Kishoreganj	24.42832	90.743163	28.96	12.07-28.96	673.33
8	Netrokona	Kendua	24.659028	90.83409	21.34	5.18-21.34	988.33
9	Kishoreganj	Kuliar Char	24.150566	90.902424	21.34	14.33-21.34	647.00
10	Netrokona	Purbadhala	24.847156	90.624749	17.37	3.65-17.37	3093.00
11	Netrokona	Barhatta	24.88526	90.888705	20.42	4.57-20.42	1120.67
12	Netrokona	Barhatta	24.902348	90.82222	26.82	10.36-26.82	498.33
13	Netrokona	Atpara	24.793216	90.805503	21.34	15.24-21.34	263.67

- The maximum and minimum S&P rate for different districts is presented as bellows:

District	S&P Rate (mm/day)	
	Minimum	Maximum
Kishoreganj	3.6	13.0
Netrokona	3.0	11.0
Sylhet	7.1	11.4
Maulavibazar	5.3	10.9
Habiganj	5.1	12.0
Sunamganj	8.6	14.6

Major findings from water quality sampling and analysis based on 40 nos. samples collected under study are as bellows:

- pH values range from 5.68 to 6.96, indicating neutral to slightly acidic conditions. Ec values ranges from 110 µs/cm to 1537µs/cm, TDS values range from 55mg/l to 578mg/l and salinity value varies from 0.0 to 0.7 ppt and temperature of groundwater samples ranges from 23.5^{0}C to 29^{0}C. But in Dowarabazar upazila of Sunamganj district, the groundwater possesses slightly higher temperature and found 34.2^{0}C.

- Manganese concentrations vary from 0.01mg/l to 2.65mg/l. The maximum concentration (2.65mg/l) found at Kendua upazila. There are 32 samples (80%) that exceed Bangladesh Drinking Water Standards 1997 guideline limit of Manganese. Therefore, the study area has a potential threat of groundwater Manganese contamination.
- Calcium concentrations vary from 156.80mg/l to 2.88mg/l. Only 1 sample at Kendua upazila of Netrokona district exceeds Bangladesh Drinking Standard guideline.
- Iron concentrations vary between 0.09mg/l to 30.05mg/l with mean, median and standard deviation of 4.29mg/l, 2.65mg/l and 5.14mg/l, respectively. Bangladesh Drinking Water Standard is from 0.3mg/l to 1.0mg/l. Maximum Iron concentration is found in Kanaighat upazila of Sylhet district. Considering the Bangladesh Drinking Water Standard 83% samples show concentrations above taste limit.
- Phosphate concentrations vary between 0mg/l and 12.67mg/l. Bangladesh Standard follows 6mg/l maximum allowable concentration based on the taste threshold. All the samples except Balaganj and Golapganj upazila of Sylhet district are within safe limit.
- Salinity index for irrigation water quality found that all the samples collected is categorized under medium to low salinity classes except the groundwater from Jahangirpur and Chandigor union of Netrokona districts.
- The Sodium Adsorption Ratio (SAR) values of 98% of the samples are found to be less than 10. Groundwater classified based on SAR as being excellent for irrigation (i.e., S1 category) except the groundwater from Mannargaon union of Doarabazar upazila in Sunamganj District which is fall in good category.
- The classification of groundwater samples with respect to percent sodium for irrigation uses is found that 70% samples belong to permissible category. Maximum Na% found for the groundwater from Mannargaon union of Doarabazar upazila in Sunamganj District which is unsuitable for irrigation.
- In the study area, the magnesium hazard (MH) values for irrigation water quality analysis have been calculated in the range of 17.27% to 70.71%. 88% of the samples showed magnesium index value below 50%, suggesting their suitability, while 12% fall in the unsuitable category with MH more than 50%, indicating their adverse effect on crop yield.
- Surface water quality analysis indicates the presence of E-coli in river water whereas it is free from heavy metal (Mercury, Cadmium, and Lead).

Major Findings from the Mathematical Modelling Study:

- Available groundwater resource has been calculated based on useable recharge which is 75% of potential recharge. The estimated potential recharge for different upazila is given below:

SL No	District	Upazilla	Potential Recharge (mm)
1	Habiganj	Baniachong	1219
2	Habiganj	Nabiganj	612
3	Habiganj	Ajmiriganj	1101
4	Habiganj	Bahubal	689
5	Habiganj	Habiganj Sadar	426
6	Habiganj	Lakhai	893
7	Habiganj	Chunarughat	679
8	Habiganj	Madhabpur	855
9	Kishoreganj	Itna	1234
10	Kishoreganj	Tarail	1126
11	Kishoreganj	Karimganj	1086
12	Kishoreganj	Kishoreganj Sadar	970
13	Kishoreganj	Hossainpur	914
14	Kishoreganj	Mithamain	1250
15	Kishoreganj	Nikli	1090
16	Kishoreganj	Austagram	1186
17	Kishoreganj	Pakundia	609
18	Kishoreganj	Katiadi	1108
19	Kishoreganj	Bajitpur	770
20	Kishoreganj	Kuliar Char	995
21	Kishoreganj	Bhairab	1097
22	Maulvibazar	Barlekha	568
23	Maulvibazar	Kulaura	718
24	Maulvibazar	Rajnagar	642
25	Maulvibazar	Maulvi Bazar Sadar	690
26	Maulvibazar	Kamalganj	490
27	Maulvibazar	Sreemangal	860
28	Netrakona	Durgapur	897
29	Netrakona	Kalmakanda	458
30	Netrakona	Purbadhala	865
31	Netrakona	Netrokona Sadar	973
32	Netrakona	Barhatta	932
33	Netrakona	Mohanganj	938
34	Netrakona	Atpara	1013
35	Netrakona	Khaliajuri	1043
36	Netrakona	Kendua	713
37	Netrakona	Madan	958
38	Sunamganj	Tahirpur	606
39	Sunamganj	Dharampasha	932
40	Sunamganj	Bishwambarpur	554
41	Sunamganj	Dowarabazar	543
42	Sunamganj	Sunamganj Sadar	1042
43	Sunamganj	Chhatak	582
44	Sunamganj	Jamalganj	961
45	Sunamganj	Derai	1199

SL No	District	Upazilla	Potential Recharge (mm)
46	Sunamganj	Jagannathpur	973
47	Sunamganj	Sulla	1022
48	Sylhet	Jaintiapur	577
49	Sylhet	Gowainghat	635
50	Sylhet	Companiganj	584
51	Sylhet	Kanaighat	687
52	Sylhet	Kotwali	705
53	Sylhet	Zakiganj	626
54	Sylhet	Beani Bazar	600
55	Sylhet	Bishwanath	520
56	Sylhet	Golabganj	462
57	Sylhet	Balaganj	658

- Due to the future abstraction considering 80% area of cultivable land under HYV Boro, it is observed that in most of the areas, groundwater table drops down by about 0.1m to 1.0m compared to the groundwater table of present condition. However, groundwater table drops down upto 6m in Habiganj and Bahubal Upazilla where most probably abstraction has been imposed for industries.
- The study reveals that due to extreme drought condition most of the areas of Netrokona and Kishoreganj districts, groundwater table drop down from 0.5m to 2m in comparison with the base condition.
- Due to the increment of abstraction the groundwater recharges also increase which implies that aquifer has potential for receiving more recharge if provision is made.
- Available surface water resources in the selected khals after controlling the water by water control structure is given below:

District	Haor Name	Khal Name	Length of Khal (Km)	Volume (m^3) of Water to be Irrigated
Kishoreganj	Boro Haor	Digha Nadi	6	504500
		Baniajan Gang	7	122000
		Singua Khal	12	178000
	Noapara Haor	Pania Khal	3	341000
	Naogaon Haor	Khaiyar Khal	7	351000
		Markhali Khal	5	900000
		Nandir Khal	6	299000
	Dakhshiner Haor	Shankir Khal	6	242500
	Sunair Haor	Suti Khal	16	1590000
	Chatal Haor	Noaparakhali	1.8	324000
Netrokona	Khaliajuri-4	Putia Khal	5	165000
	Khaliajuri-2	Naiyari Khal	8	889000
Sunamganj	Jaliar Haor	Rauli Khal	6	71500
		Dora Nadi	8	42500
	Dhakua Haor	Muktakhai Khal	12	670000
	Dharmapasha Haor	Manai Khal	16	680000

District	Haor Name	Khal Name	Length of Khal (Km)	Volume (m^3) of Water to be Irrigated
		Dahar Gang	7	132500
		Agunia Khal	8	221500
Moulvibazar	Hail Haor	Lunglabijna	24	2145000
	Kawardighi Haor	Lash Gang	12	525000
		Sampad Khal	9	630000
		Udna Gang	12	531000
Habiganj	Mokhar Haor	Medhabeel Khal	5	304500
		Old Kushiyara-2	18	948000
		Rajendrapur Khal	5	118500
	Gangajuri	Teli Khal	6	214000
		Shashya Nadi	10	118000

- Sufficient surface water resources are available in Dhanu, Baulai, Ghorautra rivers for round the year irrigation while limited resources are available in Saidulbaruni, Mogra, Kangsha rivers in dry period but sufficient water is available in October for supplemental irrigation.
- Based on the surface water availability and its development constraints, the maximum possible irrigation area expansion has been determined and future water demand has been estimated. Areas under HYV Boro have been estimated to be about 87500 ha for surface water based irrigation.

An Interactive Information System (IIS) for storing, visualizing, manipulating, maintaining and managing a huge volume of hydrological, hydro-geological, meteorological hydro-geochemical, topographical, physiographical, soils and agricultural data for both spatial and spatio-temporal for the project area has been developed which enables users to support for data management, visualization, data analysis, data retrieval and reporting

Recommendation from the Study

- Crop diversification is recommended i.e cultivation of crop with less crop water requirement can be increased instead of HYV Boro crop for improve water management and crop yield.
- Coordination among the different stakeholders working in the haor area should be well established. There should have a strong coordination among different organizations, departments such as DBHWD, BIWTA, BWDB, BADC, LGED, DPHE, DAE etc.
- During infrastructure development in hoar area, there should have navigation facilities. For any infrastructure related project, coordination among different organizations/departments is highly recommended.
- Re-excavation of major khals is highly desirable. Large scale dredging through technical study and monitoring is recommended.

- Water is limited, and its uses should be appropriate and efficiently. As per government policy surface water-based irrigation is encouraged. As such, to reduce the dependency on groundwater, surface water-based irrigation is recommended under this study. To reduce the conveyance and other losses, buried pipe system using LLP is highly recommended.
- During stakeholder's consultation and field workshops, the beneficiaries asked for the rehabilitation of pumps and other infrastructure of Manu Irrigation project. So, steps should be taken to rehabilitate the existing pumps.
- The transportation system of haor area during rainy season is not good enough to bring the crops from field to high lands. As such the combined harvester is recommended here to reduce time and the cost of labor as well as reduce the risk of crop damage.
- Regulatory structures have to be constructed for ensuring the proper drainage and navigation.
- Regular monitoring of water quality in Haor region is recommended.
- Natural reservoir may be used to store excess rainwater during rainy season.
- Plan wise groundwater abstraction considering water act is recommended.
- The future climate change scenarios need to be addressed since due to changing of rainfall pattern, more complicated flooding situation may arise.
- As per ToR, this study covers only the technical part. So detailed feasibility study considering environmental viability, economic feasibility and social acceptability needs to be addressed before implementation of the project.
- In the stakeholder's consultation, PIC meeting, local level workshops and final workshop at Dhaka for several study projects have been suggested to take for the sake of the improvement of haor livelihood. As such a comprehensive integrated study considering the following issues is highly recommended under this study:
  - ✓ The quality of the model can further be improved undertaking a comprehensive study on geological formation, aquifer properties, recharge pattern and groundwater abstraction rate. A further study is needed to formulate different land and water management options for a long-term planning.
  - ✓ Assessment of detailed water quality for drinking and irrigation purpose.
  - ✓ Protection of fish sanctuary as well as establishment of new sanctuary in the haor area is also recomanded.
  - ✓ Solid waste management for reducing the risk of contamination of surface water.

- ✓ Industrial waste management specially for Habiganj, Sayestaganj and Madhbpur industrial area.
- ✓ Update existing Haor Master Plan considering climate change scenarios and other human interventions for the duration of next 100 years in line with Bangladesh Delta Plan 2100.
- ✓ Address the Social, Environmental and Ecological factors holistically.
- ✓ Identification of changes of bio-diversity before and after the re-excavation of haor/beel.
- ✓ Investigation of the long-term impact of iron on land fertility and its remedial measures.
- ✓ Assessment of the sanitation, education, health and livelihood of haor region.
- ✓ Establishment of draining out of water from upstream of Kawa Digi Haor.
- ✓ Study for assessment of groundwater flow from Meghalaya hill tracts to understand the groundwater flow direction as well as flow volume.
- ✓ Study for assessment of the impact on ecosystem due to surface water irrigation.
- ✓ Research on irrigation efficiency and environmental flow analysis of major rivers.
- ✓ Study to assess the morphological changes in the river system of haor region in Bangladesh.
- ✓ A study on establishment of linkage between Agricultural/Livestocks and others with haor ecosystem.
- ✓ A study on wise use of wetlands and best wetland management practices for restoration of ecosystem in haor area.
- ✓ Research on sedimentation and sink for haor area.
- ✓ A hydrogeological study to determine the spacing of tubewells and aquifer mapping.
- ✓ Assessment of volume of water comes from transboundary river in hoar region.
- ✓ Study to improve the navigation facilities for transportation of paddy by boat during dry season.

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ACCRONYMS AND ABBREVIATION

AWWA	American Water Works Association
BADC	Bangladesh Agricultural Development Corporation
BBS	Bangladesh Bureau of Statistics
BM	Bench Mark
BTM	Bangladesh Transverse Mercator
BUET	Bangladesh University of Engineering & Technology
BMD	Bangladesh Meteorological Department
BWDB	Bangladesh Water Development Board
CNRS	National Center for Scientific Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CWR	Crop Water Requirement
DAE	Department of Agricultural Extension
DBHWD	Department of Bangladesh Haor & Wetland Development
DEM	Digital Elevation Model
DFR	Draft Final Report
DPHE	Department of Public Health Engineering
DTW	Deep Tube Well
EC	Electrical Conductivity
EOI	Expression of Interest
ET	Evapotranspiration
FGD	Focal Group Discussion
FR	Final Report
FIWR	Field Irrigation Water Requirement
GIS	Geographical Information System
GPS	Global Position System
GPRS	General Packet Radio Service
GoB	Government of Bangladesh
GWL	Groundwater Level
HD	Hydrodynamic
HTW	Hand Tube Well
HTS	Hunting Technical Services
IIS	Interactive Information System

IDA	International Development Association
IMED	Implementation Monitoring and Evaluation Division
IR	Inception Report
ISO	International Standards Organization
IUCN	International Union for Conservation of Nature
IWRM	Irrigation Water Resources Management
IWM	Institute of Water Modelling
Kc	Crop Coefficient
LAI	Leaf Area Index
LLP	Low Lift Pump
MIS	Management Information System
MoWR	Ministry of Water Resources
MOA	Ministry of Agriculture
MMIL	Mott MacDonald International Limited
MPO	Master Plan Organization
MSL	Mean Sea Level
NAM	Nedbor Afstroming Model
NEMIP	North East Minor Irrigation Project
NERM	North East Regional Model
NMIDP	National Minor Irrigation Development Project
OL	Overland Flow
PR	Progress Report
PWD	Public Works Datum
QPR	Quarterly Progress Report
RDF	Root Depth Function
RL	Reference Level
SDLC	Software Development Life Cycle
SoB	Survey of Bangladesh
SWR	Scheme Water Requirement
SRDI	Soil Resources Development Institute
STW	Shallow Tube Well
S&P	Seepage and Percolation
SZ	Saturated Zone
TDS	Total Dissolved Soilds

TOR	Terms of Reference
UNICEF	United Nations International Children's Emergency Fund
UZ	Unsaturated Zone
VES	Vertical Electrical Sounding
WARPO	Water Resources Planning Organization
WBRP	Wetlands Biodiversity Rehabilitation Project
WRE	Water Resources Engineering

1 INTRODUCTION

1.1 Background

Haors are large saucer-shaped flood plain depressions located mostly in north-eastern region of Bangladesh covering about 25% of the entire region. There are altogether 411 haors comprising an area of about 8000 km^2 dispersed in the districts of Sunamganj, Sylhet, Maulvibazar, Habiganj, Netrokona and Kishorganj. These haors are subject to very peculiar conditions and suffers from extensive annual flooding. This makes livelihoods extremely vulnerable and limits the potential for agriculture production and rural enterprise growth.

Boro rice is the main dry season crop grown in the haor areas requiring irrigation for cultivation. The total cultivated area in those haor districts is about 1.26 million hectares of which 0.68 million ha (nearly 66%) is under haor. Almost 80% of this area (i.e. 0.68 million ha) is covered by Boro rice, while only about 10% area is covered by T. Aman production (Huda, 2004).

In the districts of Habiganj, Maulvibazar and Sylhet, as per the master plan study, irrigation coverage during dry season is about 62% of net cultivated area. In Rabi season, about 83% of Boro crop area is irrigated and the rest of the area is irrigated by traditional methods or remain under rainfed condition. Other dry land Rabi crops are grown under fully rainfed condition. In kharif-II season, major crops Aus and Aman are mostly cultivated under the rainfed condition. Total irrigation coverage during dry season is about 8.17 lakh ha. Irrigation coverage by groundwater is about 3.45 lakh ha of where coverage of deep tube well (DTW) is about 0.37 lakh ha and STW is about 3.08 lakh ha of land. The remaining 4.72 lakh ha area is irrigated by surface water.

The Department of Bangladesh Haor & Wetland Development (DBHWD) is mandated to ensure overall coordination and monitoring for integrated development of haors and wetlands that will holistically address the problems related to water resources, agriculture, fisheries, livestocks, ecology and biodiversity as a large number of inhabitants are dependent for their livelihoods on diverse activities around wetlands which influence the socio- economic condition of the country. Moreover, following the recommended strategy of the Haor Master Plan, DBHWD is now giving emphasis on promoting investigation and expansion of groundwater irrigation which has been formulated to facilitate improved and sustainable management of surface water and groundwater resources for agricultural use in haor area through an integrated mathematical modelling study. DBHWD also emphasis on assessment of interaction between Haor and river ecosystem. As a result, a study area located in Bahubal, Chunarughat, Madhabpur, Nabiganj and Sadar upazilas of Habiganj district; Barlekha, Kamalganj, Kulaura, Rajnagar, Sreemangal and Sadar upazilas of Maulvibazar district; Balaganj, Beani Bazaar, Bishwanath, Fenchuganj, Gopalganj, Gowainghat, Jaintapur, Kanaighat, Zakiganj and Sadar upazila of Sylhet districts; Itna, Tarail, Karimganj, Kishoreganj Sadar, Hossainpur, Mithamain, Nikli, Austagram, Pakundia, Katiadi, Bajitpur, Kuliarchar, Bhairab upazillas of Kishoreganj districts; Durgapur, Kalmakanda, Purbadhala, Netrokona Sadar, Barhatta, Mohanganj, Atpara, Khaliajuri, Kendua and Madan upazillas of Netrokona districts; Tahirpur, Dharampasha, Bishwambarpur, Dowarabazar, Sunamganj Sadar, Chhatak, Jamalganj, Derai, Jagannathpur and Sulla Upazila of Sunamganj districts Figure 1-1 is proposed to explore the availability of both surface water as well as groundwater resources to develop future irrigation expansion plan for proper management of water resources in an integrated manner.

Groundwater is the key source of water supply to the crops in high and medium high land where surface water is not readily available. However, the availability of groundwater varies throughout the region and its extent is not well known. Also, there is no comprehensive study on data collection and surface water & groundwater resources assessment in an integrated manner in the study area. Groundwater tapping occurs mainly in the private sector; its rate of extraction is uncertain. Also, unplanned way of abstraction of groundwater may cause depletion of groundwater level. It is making extraction of groundwater rather difficult and renders it unavailability for drawing by pumps. Therefore, it is of paramount importance to undertake a study to explore the availability of both the surface water as well as groundwater resources to develop future irrigation expansion plan for proper management of water resources in a sustainable way.

1.2 Engagement of Institute of Water Modelling (IWM)

Department of Bangladesh Haor and Wetland Development (DBHWD) called for EoI for engagement of consulting organization to conduct "Study for Investigation of Groundwater and Surface Water Irrigation in Habiganj, Maulavibazar, Sylhet, Sunamganj, Netrokona and Kishorganj Districts" on March 17, 2016. In response, IWM submitted the EoI vide memo no. 42.07.018.01.03.1713.2016/1056, Dated April 07, 2016. A 'Request for Proposal' was issued by DBHWD vide the memo No. 42.04.0000.003.14.390.16.272, Dated May 12, 2016, for the submission of technical and financial proposal to conduct the study.

In response, IWM submitted Technical and Financial proposal to DBHWD on June 20, 2016. The proposal was duly evaluated by DBHWD and the study was awarded to IWM accordingly. A contract agreement has been signed on November 10, 2016 between DBHWD and IWM to conduct the study as presented in Figure 1-2. IWM mobilized the study team on November 13, 2016 for preparatory works, necessary primary and secondary data collection. Primary data collection program comprises mainly exploratory drilling (upto 200m) and installation of monitoring well, groundwater level monitoring, construction of production well, aquifer test, geophysical survey, seepage and percolation (S&P) measurement, water quality measurement etc. The secondary data collection includes collection of reports and relevant data from related organizations.

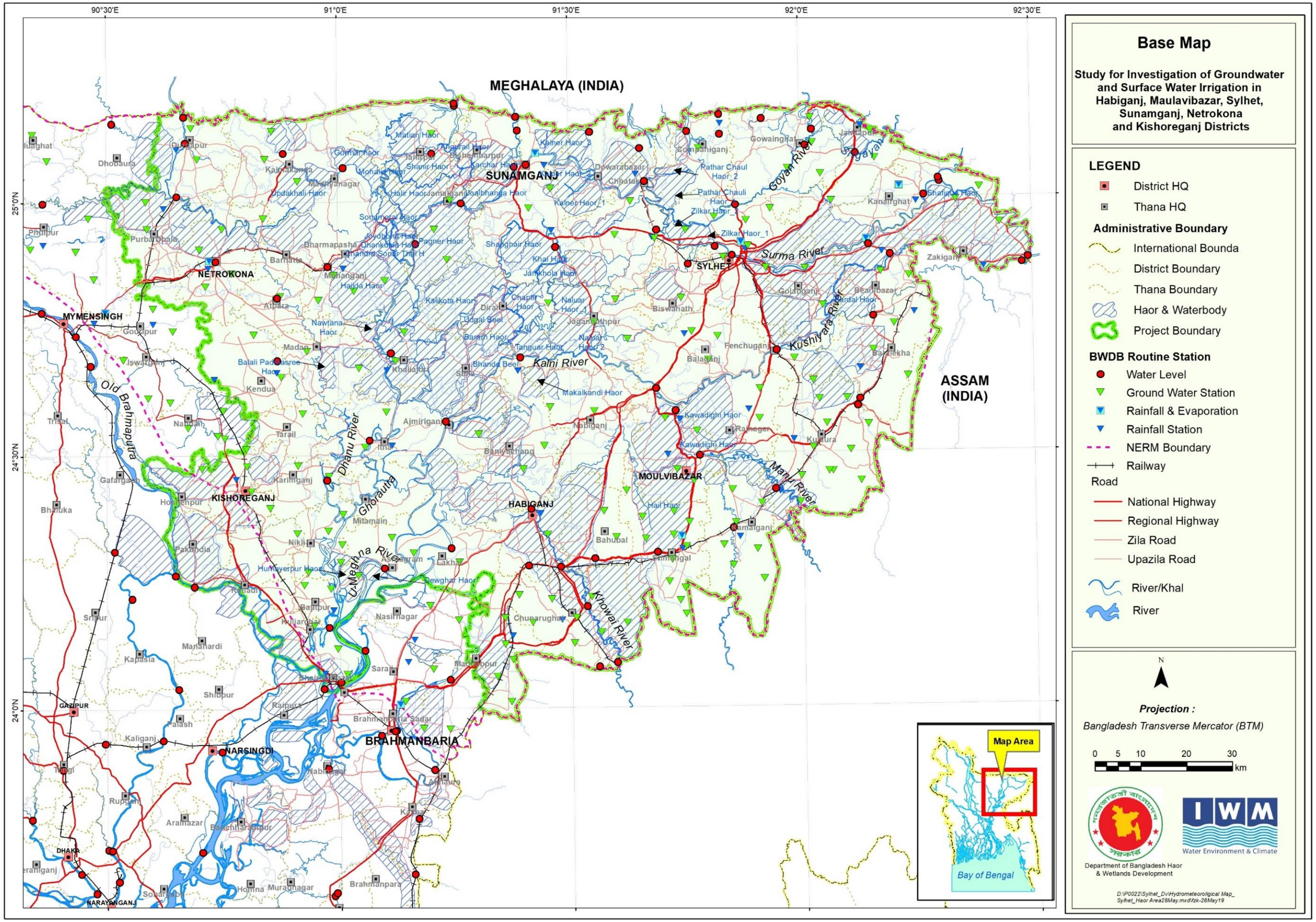


Figure 1-1: Base Map of the Study Area

Figure 1-2: Contract Signing Ceremony between DBHWD and IWM.

As per contract and ToR of the study, the Draft Final Report was submitted on May 30, 2019. A workshop on the DFR was held participated by representatives of Planning Commission, MoWR, MoA, BWDB, BADC and other concerned organizations. This Final Report has been prepared incorporating necessary corrections and improvements as per comments and as well as recommendations of the workshop.

1.3 Objectives of the Study

The study is formulated with a view to explore the availability of both the surface water as well as groundwater to develop future irrigation expansion plan for proper management of water resources in an integrated manner. The objectives of the study are as follows:

- Assessment of groundwater resources through integrated surface water-groundwater interaction modelling and analysis.
- Determine the overall irrigation development opportunities that can be achieved through sustainable uses of water resources.
- Assessment of the impact on groundwater table due to increased abstraction.
- Identification of both surface water and groundwater sources through surface water-groundwater interaction modelling.
- Zoning of the area for future irrigation expansion based on the suitability of surface water and groundwater resources.
- Assessment of surface water and groundwater quality.
- Development of future agricultural expansion plan.

- Design an appropriate groundwater monitoring system to understand and assess the future impacts of abstraction.
- Development of comprehensive Interactive Information System (IIS).

1.4 Scope of the Works

The following activities were envisaged in achieving the study objectives:

- Collection of related maps, reports and data
- Exploratory drilling (upto 200m depth) at 40 selected locations
- Construction of production tubewells at 12 locations
- Long term (3 days) aquifer tests at 13 selected locations using existing shallow tubewells or deep tubewells.
- Long term (3 days) aquifer tests at 12 selected locations in newly installed production wells.
- Installation and monitoring of 40 groundwater observation wells including BM connection.
- Water quality sampling and analysis at 50 locations.
- Seepage and percolation measurements at 50 selected locations.
- Geophysical survey at 60 locations.
- Assessment of present and future water demands.
- Lithological characterization and delineation of aquifer system in the study area.
- Development, calibration and validation of surface water and groundwater interaction model.
- Assessment of surface water and groundwater resources.
- Assessment of present and future groundwater status through mathematical model study.
- Zoning of irrigation expansion areas for various mode of irrigation.
- Development of IIS for the project.
- Design a sustainable groundwater monitoring system.
- Transfer of technology through training program.
- Six numbers of consecutive workshops at 6 districts to disseminate the draft findings from the study to beneficiaries and stakeholders before finalization of Draft Final Report (DFR). Another one workshop has been held after submission of DFR at Dhaka to disseminate the study outcomes to the decision makers.
- Reporting: Inception, Progress, Technical, Draft Final and Final Reports.

1.5 Structure of the Report

This report is the Final Report of “Study for Investigation of Groundwater and Surface Water Irrigation in Habiganj, Maulavibazar, Sylhet, Sunamganj, Netrokona and Kishorganj Districts”. This report contains the technical works carried out during the study period, findings, conclusions and recommendations. The report is presented in two volumes for sake of clarity and ease of comprehending the issues addressed during the study. The volumes are as follows:

Volume	Title of the Report
Volume-I	Main Report Annex-A: Terms of Reference (ToR) of the Study
Volume-II	Appendix A: Details of Borelogs Appendix B: Groundwater Level Data Appendix C: Detail Design of Production Well Appendix D: Water Depth Status for Seepage and Percolation (S&P) Measurement Appendix E: Water Quality Analysis Appendix F: Details of Geophysical Survey Appendix G: Analysis of Aquifer Test Data Appendix H: Field Irrigation Water Requirement (FIWR) and Surface Irrigation Water Requirement (SIWR) for Aus Appendix J: Calibration and Validation Plot of Mathematical Model Appendix K: Sensitivity Analysis of Mathematical Model Appendix L: List of Participants Attended in the Workshop

This is Volume-I: Main Report which comprises 14 chapters including a list of references mentioned in the report. A list of acronyms and abbreviations used in the report has been presented following the table of contents.

Chapter 1 focuses on the project background, study objectives and scope of works.

Chapter 2 Collection and review of reports of the previous studies and findings related to this study.

Chapter 3 provides the physical setting of the project that includes the project area description, its climate and topography, groundwater and hydrogeological setting, river system and surface water, physiography and soil condition, agricultural practices, existing irrigation system and coverage.

Chapter 4 focuses on the major data collection issues. It deals with the data requirements, data collection program from both the primary and secondary sources of different types of data such as hydrometric and hydrometeriological data, hydrologic and hydrogeological data etc., review of data availability and methodology for data quality control.

Chapter 5 represents the aquifer system of the project area. The analysis of geophysical survey and bore log also described in this chapter.

Chapter 6 focuses the analysis of aquifer properties within the study area. The trend of groundwater tables is also described in this chapter.

Chapter 7 describes the computation of irrigation, domestic and industrial water demand.

Chapter 8 describes the development, calibration and validation of surface water and groundwater flow models.

Chapter 9 presents the prospects of future surface water development.

Chapter 10 illustrates the application of groundwater model which includes resources assessment, option formulation and analysis.

Chapter 11 describes the details of design and development of Interactive Information System (IIS).

Chapter 12 gives a brief on technology transfer to the project authority. It also includes the findings and recommendation of the workshop that have been conducted under the study at the field level and national level.

Chapter 13 lays the conclusions on various issues by which the project has been studied and analyzed. The recommendations of the study have also been provided in this chapter.

Chapter 14 cited the References of the reports and manuals consulted for the preparation of the report.

Annex-A: Terms of Reference (ToR)

2 REWIEW OF PREVIOUS STUDY

Since the inception of the study, IWM collected various reports, data, maps and related documents from relevant organizations. To obtain a preliminary idea on hydrological and hydrogeological issues pertaining the study and to identify information and data gaps for formulation of primary data collection program as well as to utilize judiciously the existing information, the review of relevant previous studies has been conducted. Some of the important study findings are briefly presented in the following sections.

2.1 Studies Carried out by NEMIP, Ministry of Agriculture

Ministry of Agriculture (MoA) designed a project entitled "North East Minor Irrigation Project (NEMIP)" to popularize the use of various minor irrigation equipments for extraction of groundwater resource in the greater Sylhet area. The NEMIP has been executed under the financial assistance of Asian Development Bank for the period from 1992-93 to 2001-02. As per NEMIP provision, two studies were undertaken to prepare a database on the availability of the aquifer conditions as well as to determine the aquifer characteristics for the area.

2.1.1 Aquifer Parameters Study by NEMIP (1997)

North East Minor Irrigation Project conducted pumping tests to determine the aquifer parameters for designing and planning management of minor irrigation system through installation of shallow tubewells and other mode of minor irrigation. Twenty-eight numbers of aquifer tests were conducted in the year of 1997 in the greater Sylhet area. The aquifer test conducted for 48 hours by continuous pumping and observing the changes in hydraulic head in the piezometers. The results obtained from the 28 pumping test sites in the greater Sylhet area has been presented in Table 2-1 .

Table 2-1: Aquifer Properties in the Districts of Sylhet, Maulavibazar, Sunamganj and Habiganj (MOA, 1997)

District: Sylhet

Upazila	Union, Mouza (JL. No., Plot No.)	Well Number	KD, S, S_y and Adopted Method	C, L, R and Adopted Method	Aquifer Type	Remark
Beanibazar	Beanibazar, Dasura (JL: 116, Plot: 4292	SYL/BEA /ST-01	KD=304 HCF S=1.8X10^{-2} HCF S_Y=1.6X10^{-2} NCF	C=2792 Walton L=742 Walton R=833 Walton	Leaky	
Fenchugonj	Ghilachara, Dharon (JL: 21, Plot: 4151)	SYL/FEN /ST-02	KD=180 HCF S=1.5X10^{-2} HCF SY=1.6X10^{-2} NCF	C=19,879 Walton L=1530 Walton R=1718 Walton	Leaky	SY = S
	Ghilachara, Sultanpur	SYL/FEN /ST-06	KD=370 HCF S=7.4X10^{-4} HCF S_Y=0.1 NCF	C=220,000 H-J L=10,341 H-J R=11,582 H-J	Leaky	

Upazila	Union, Mouza (JL. No., Plot No.)	Well Number	KD, S, S_y and Adopted Method	C, L, R and Adopted Method	Aquifer Type	Remark
	(JL: 25, Plot: 930)					
Golapgonj	Bodeshwar, Fatehpur (JL: 36, Plot: 229	SYL/GOL/ST-03	KD=358 HCF S=1.9X10^{-4} HCF S_Y=5.1X10^{-2} NCF	C=39,000 H-J L=3619 H-J R=3962 H-J	Leaky	
Gowainghat	Nandirgaon, Angarjore (JL: 200, Plot: 87)	SYL/GOW/ST-01	KD=684 Walton S=1.7X10^{-4} Walton S_Y=3.3X10^{-3} NCF	C=8181 Walton L=2286 Walton R=2567 Walton	Leaky	
Jaintapur	Nizpat, Laxiprasad (JL: 328, Plot: 39)	SYL/JAI/ST-01	KD=1266 HCF S_Y=0.16 NCF	C=1140 H-J L=939 H-J R=1052 H-J	Un-confined	S value omitted
Sylhet	Sitam, Rustompur (JL: 143, Plot: 818)	SYL/SAD/ST-01	KD=153 Walton S=2.9X10^{-4} Walton S_Y=4.9X10^{-4} NCF	C=606 Walton L=305 Walton R=342 Walton	Leaky	
Zakigonj	Zakigonj, Madhudatta (JL: 73, Plot: 94)	SYL/ZAK/ST-04	KD=442 Walton S=1.6X10^{-3} Walton S_Y=5.3X10^{-2} NCF	C=1814 Walton L=742 Walton R=833 Walton		

District: Maulavibazar

Upazila	Union, Mouza (JL. No., Plot No.)	Well Number	KD, S, S_y and Adopted Method	C, L, R and Adopted Method	Aquifer Type	Remark
Baralekha	Dasherbazar Gulua (JL: 15, Plot: 646)	MOU/BAR/ST-01	KD=416 HCF S=6.4X10^{-3} HCF S_Y=8.4X10^{-2} NCF	C=18,182 Walton L=3048 Walton R=3423 Walton	Leaky	
Kamalgonj	Kamalgonj, Kumrakapon (JL: 79, Plot: 1579)	MOU/KAM/ST-06	KD=365 Thesis S=1.1X10^{-3} Thesis	C=1471 H-J L=729 H-J R=817 H-J	Confined	S value omitted
	Adampur, Tilokpur (JL: 84, Plot: 9776)	MOU/KAM/ST-17	KD=527 HCF S=3.1X10^{-4} HCF S_Y= 0.22 NCF	C=492 H-J L=408 H-J R=457 H-J	Leaky	
Kulaura	Hajipur, Chandgaon (JL: 135, Plot: 445)	MOU/KUL/ST-02	KD=285 HCF S=6.3X10^{-4} HCF S_Y= 0.59 NCF	C=686 H-J L=436 H-J R=488 H-J	Leaky	
Rajnagar	Tengra, Admabad	MOU/RAJ/ST-03	KD=605 HCF S=1.5X10^{-3} HCF S_Y= 0.92 NCF	C=653 H-J L=653 H-J R=731 H-J	Leaky	

Upazila	Union, Mouza (JL. No., Plot No.)	Well Number	KD, S, S_y and Adopted Method	C, L, R and Adopted Method	Aquifer Type	Remark
	(JL: 161, Plot: 116)					
	Tengra, Tengra (JL: 111, Plot: 786)	MOU/RAJ/ST-02	KD=185 HCF S=3.7X10^{-4} HCF S_Y= 0.12 NCF	C=69 H-J L=106 H-J R=119 H-J	Leaky	
Maulavibazar	Chandighat, Borshigora (JL: 205, Plot: 400)	MOU/SAD/ST-02	KD=384 HCF S=2.0X10^{-3} HCF S_Y= 0.21 NCF	C=9189 Walton L=1554 Walton R=2438 H-J	Leaky	

District: Sunamganj

Upazila	Union, Mouza (JI. No. Plot No.)	Well Number	KD, S, S_y and Adopted Method	C, L, R and Adopted Method	Aquifer Type	Remark
Biswambarpur	Polash, Kacirhate (JL: 5, Plot: 413)	SUN/BIS/ST -04	KD=582 HCF S=2.6X10^{-3} HCF Sy=8.0X10^{-2} NCF	C=240 Walton L=335 Walton R=376 Walton	Leaky	
Dhannapasha	Picorte, Alapuchar (JL: 76, Plot: 3502)	SUN/DHA/ST -01	KD=507 HCF S=8.7X10^{-3} HCF Sy=8.8 X10^{-2} NCF	C=1544 H-J L=925 H-J R=1036 H-J	Leaky	
Doarabazar	Banglabazar, Paeicpara (JL: 07, Plot:)	SUN/DWA/ST-	KD=672 HCF S=5.0X10^{-3} HCF Sy=5.1X10^{-2} NCF	C=3515 Walton L=1554 Walton R=1746 Walton	Leaky	
Jagannathpur	Patly, Kasapur (JL: 48, Plot: 467)	SUN/ JAG/ST - 01	KD=577 Walton S=2.7 X10^{-2} Walton Sy=O.22 NCF	C=387 H-J L=408 H-J R=457 H-J	Leaky	
Sunamgonj	Rangerchor, Fatergaon (JL: 45 Plot:144)	SUN/SUN/ST -03	KD=295 Walton S=2.0X10^{-3} Walton Sy=1.l2 NCF	C=407 Walton L=311 Walton R=349 Walton	Leaky	
Tahirpur	Badagat, Jaspratap (JL: 159, Plot: 455)	SUN/TAH/ST-03	KD=331 Walton S=2.3X10^{-3} Walton Sy=4.6X10^{-2} NCF	C=194 Walton L=234 Walton R=262 Walton	Leaky	

District: Habiganj

Upazila	Union, Mouza (JI. No. Plot No.)	Well Number	KD, S, S_y and Adopted Method	C, L, R and Adopted Method	Aquifer Type	Remark
Ajmirigonj	Jalshuka, Atpara (JL: 30, Plot: 4610)	HOB/AJM/ST-03	KD=274 HCF S=2.6X10^{-2} HCF Sy=4.7X10^{-2} NCF	C=12,586 Walton L=1555 Walton R=1746 Walton	Leaky	
Bahubal	7 No. Badeshar, Kandarapur	HOB/BAH/ST-05	KD=558 HCF S=6.0X10^{-3} HCF Sy=5.6X10^{-3} NCF	C=87 H-J L=190 H-J R=213 H-J	Leaky	

Upazila	Union, Mouza (JI. No. Plot No.)	Well Number	KD, S, S_y and Adopted Method	C, L, R and Adopted Method	Aquifer Type	Remark
	(JL: 130, Plot: 516)					
Baniachong	Baniachong, Tarashal (JL: 125, Plot: 155)	HOB/BAN/ST-05	KD=476 Jacob(r=C) S=9.5X10^{-2} Sy=0.26 NCF	C=7338 Walton L=1554 Walton R=1745 Walton	Leaky	
Chunarughat	Deorgach, Sararkhona (JL: 108, Plot: 134)	HOB/CHU/ST-05	KD=301 HCF S=1.4X10^{-3} HCF Sy=9.0X10^{-2} NCF	C=12,000 H-J L=1905 H-J R=2134 H-J	Leaky	
Hobigonj	Shaestagonj, Jagatpur (JL: 129, Plot: 134)	HOB/ HOB/ST-05	KD=324 HCF S=4.6X10^{-2} HCF Sy=0.29 NCF	C=163 Walton L=198 Walton R=223 Walton	Leaky	
Lakhai	Carab, Carab (JL: 29, Plot: 2934)	HOB/ LAK/ST-05	KD= 852 Thesis S=208X10^{-4} Thesis	C=5566 H-J L=2177 H-J R=2438 H-J	Confined	
Nabigonj	Showodpur, (JL: 45, Plot: 144)	HOB/NAB/ST-	KD=277 Walton S=8.4X10^{-2} Walton Sy=0.1 NCF			

Note: HCF : Hantush Curve Fitting Method
H-J : Hantush-Jacob Method
NCF : Neuman Curve-Fitting Method

KD : Transmissivity (m^2/ day); *S: Storativity (dimensionless);*
Sy : Specific Yeild ((dimensionless); *C: Hydraulic Resistence (days);*
L : Leakage Factor (m); *R: Radius of Pumping Influence (m)*

From Table 2-1 it is observed that calculated aquifer parameters vary considerably among different methods. The transmissivity value varies from 153m^2/day to 1266m^2/day, 185m^2/day to 605m^2/day, 295m^2/day to 672m^2/day and 277m^2/day to 852m^2/day in Sylhet, Maulvibazar, Sunamganj and Habiganj districts respectively. The study revealed that the study area encounter mostly of highly discontinuous aquifer. It has been observed that the storativity and specific yield values vary widely in the area without following any trend. The leakage factors and radius of influences for all the test sites have very wide variation and follow no trend. High leakage factors indicate the confining layer is relatively impervious and the influence of leakage is small. The study indicated that the Sylhet, Maulavibazar and Sunamganj districts have relatively less aquifer volumes, so, high capacity STWs may not be suitable at places and it may happen that STWs might dry up after prolonged pumping. It has been recommended in this study, as the aquifer conditions are very complicated in this region; at least one pumping test is necessary for each of the union in the future.

2.1.2 Aquifer Availability Study by Ahmed (1997)

This report was prepared under the groundwater development component of NEMIP based on the data obtained from test drilling to focus on the aquifer availability and deep setting requirements for shallow tubewells in the project area.

Ahmed (1997) collected and analyzed 1000 bore logs drilled by NEMIP, and 606 bore logs from NMIDP, BADC, BWDB and DPHE sources. The data analyzed by Ahmed related to lithology of an upazila are weighted averaged and assigned at the centroid of the upazila for preparing district wise zoning of different parameters. The average thickness of top silt/clay layers and average thickness of screenable aquifer as obtained from the analysis of Ahmed (1997) is given in Table 2-2.

Table 2-2 show that the average thickness of the top aquitard is less than 30m in the northern and southeastern piedmont areas. The average thickness of the top aquitard, in a closed sub-region consisting parts of Sunamganj and Habiganj districts is greater than 45m. In the remaining areas forming a wide central band extending from this deeper zone to the eastern boarders, the average thickness varies from 30m to 45m. Average thickness of the aquifer layers varying from less than 3m to greater than 12m in different zones of the area. Thickness and extent of the aquifer layers are highly variable and unpredictable in the greater Sylhet area.

Table 2-2: Upazila Wise Average Aquifer Condition (Ahmed 1997)

District	Upazila	Average Thickness of Top Silt/Clay Layers (m)	Average Thickness of Screenable Aquifer (m)	Aquifer Condition
Sylhet	Balaganj	43	7	Relatively extensive but discontinuous single layer, have poor yield
	Beanibazar	30	8	Relatively extensive but discontinuous single layer
	Biswanath	38	7	Multiple; both layers discontinuous, less extensive
	Companiganj	37	5	Relatively extensive but discontinuous single layer, have poor yield
	Fenchuganj	32	8	Multiple; both layers discontinuous, less extensive
	Golapgonj	36	6	Less extensive discontinuous single layer, have poor yield
	Gowainghat	30	15	Relatively extensive but discontinuous single layer
	Jaintapur	34	7	Multiple, both layers discontinuous, less extensive, poor yield
	Kaniaghat	44	6	Relatively extensive but discontinuous single layer
	Sylhet	35	5	Less extensive, discontinuous single layer, poor yield

District	Upazila	Average Thickness of Top Silt/Clay Layers (m)	Average Thickness of Screenable Aquifer (m)	Aquifer Condition
	Zakigonj	42	10	Relatively extensive but discontinuous single layer
Maulavibazar	Baralekha	34	8	Less extensive, discontinuous single layer, poor yield
	Kamalgonj	18	21	Relatively extensive but discontinuous single layer
	Kulaura	25	11	Multiple, both layers discontinuous, lower one more extensive
	Rajnagar	25	15	Multiple, both layers discontinuous, lower one more extensive
	Maulvibazar	31	9	Multiple, both layers thin, discontinuous, less extensive
	Srimongal	26	7	Less extensive, discontinuous single layer, poor yield
Sunamganj	Biswambharpur	28	10	Multiple, both layers discontinuous, upper one more extensive
	Chhatak	48	10	Less extensive, discontinuous single layer
	Derai	72	2	No aquifer
	Dharmapasha	28	12	Relatively extensive but discontinuous single layer
	Dwarabazar	33	8	Less extensive, highly discontinuous single layer
	Jagannathpur	44	10	Less extensive, discontinuous single layer
	Jalamgonj	62	3	Less extensive, highly discontinuous single layer
	Sunamganj	43	9	Less extensive, discontinuous single layer
	Sulla	59	29	Less extensive, discontinuous single layer
	Tahirpur	19	12	Multiple, both layers discontinuous, upper one more extensive
Habiganj	Ajmirigonj	52	9	Extensive single layer
	Bahubal	32	14	Less extensive, discontinuous single layer
	Baniachong	43	11	Extensive single layer
	Chunarughat	23	15	Multiple, both layers discontinuous, upper layer more extensive
	Habiganj	31	12	Less extensive, discontinuous single layer
	Lakhai	41	12	Extensive single layer
	Madhabpur	41	28	Extensive single layer
	Nabigonj	40	12	Extensive single layer

According to Ahmed (1997), it may be concluded that:

- Some of the main aquifers are divided into two or more separate aquifers, have high to low hydraulic connections and are suitable for installation of tubewells.
- Almost all the upazilas in Habiganj district have good lithological conditions for shallow tubewells.
- In Maulvibazar district, Kamalgonj is the most promising upazila in terms of suitable lithology for STWs. Rajnagar & Kulaura upazila also have fairly good prospects.
- In Sylhet district, Fenchugonj, Zakigonj, Goainghat, Kanairghat and Beanibazar upazilas are the promising upazila
- In Sunamganj district, Dharmapasha, Tahirpur and Biswamvarpur upazilas have comparatively more favorable lithological conditions than other upazila. Doarabazar, Jagannatpur and Chatak upazilas also have fairly good aquifers.

However, since in most of the upazila of Maulvibazar, Sylhet and Sunamganj districts, relative volumes of aquifer materials in the aquifer zones are small, high capacity STWs in these aquifers may not be suitable and at many places, it may happen that STWs will dry up after prolonged pumping.

2.2 The UNICEF-DPHE Study (1994)

The study was done nationwide to plan for installation of TARA pumps according to the requirement of the area. They have used the same suit of models as developed by MPO (1991) during the preparation of National Water Plan.

UNICEF-DPHE (1994) was needed to know the areas where the dry season water table is falling at various levels of development. The study also assessed the groundwater development potential for irrigation and water supply. The groundwater resources assessment was made from the UNICEF-DPHE report to show the upazila wise groundwater resources available along with the basic land and hydrogeological parameters. The groundwater resource assessment by UNICEF-DPHE (1994) for the area of greater Sylhet is presented here in Table 2-3.

Table 2-3: Groundwater Resource Assessment by UNICEF-DPHE (1994)

District	Upazila	Transmissivity (m^2/day)	Deep Percolation (mm/d)	Potential Recharge (mm)
Maulvibazar	Baralekha	500	3.3	1397
	Kamalgonj	500	3.3	1183
	Kulaura	500	3.3	1124
	Rajnagar	500	3.3	859
	Maulvibazar	500	3.3	1032
	Srimongal	500	3.3	999
Sylhet	Balaganj	400	3.3	1327
	Beanibazar	500	3.3	1511

District	Upazila	Transmissivity (m^2/day)	Deep Percolation (mm/d)	Potential Recharge (mm)
	Biswanath	500	3.3	751
	Companiganj	500	3.3	1531
	Fenchuganj	500	3.3	1003
	Golapgonj	500	3.3	1343
	Gowainghat	500	3.3	1447
	Jaintapur	500	3.3	1241
	Kaniaghat	500	3.3	1271
	Shylet	500	3.3	1332
	Zakigonj	500	3.3	1175
Habiganj	Ajmirigonj	500	3.5	2029
	Bahubal	500	3.5	832
	Baniachong	500	3.5	2479
	Chunarughat	500	3.5	763
	Habiganj	650	3.5	967
	Lakhai	500	3	1819
	Madhabpur	850	3	787
	Nabigonj	500	3.3	1419
Sunamganj	Biswambharpur	700	3.3	2112
	Chatak	650	3.3	1041
	Derai	500	3.3	1587
	Dharmapasha	500	3.3	1087
	Dwarabazar	500	3.3	1923
	Jagannathpur	500	3.3	1373
	Jalamgonj	500	3.3	1503
	Sunamganj	500	3.3	1609
	Sulla	600	3.3	1297
	Tahirpur	500	3.3	1695

2.3 The Study of Groundwater Resources Potential by BADC, 1990

The study was done under IDA Deep Tubewell II Project on the greater Sylhet area. The study made a preliminary assessment of groundwater potential of greater Sylhet area based mainly on a program of exploratory drilling and testing carried out in 15 upazila where little or no drilling had been carried out previously. In addition, an autographic water level recorder was installed at Sylhet upazila in 1986 and was being operated by BADC and an inventory of deep and shallow tubewells was completed under the study.

According to this report the screenable aquifers were most likely between 46m and 70m, and between 107m and 119m, but the probability hardly exceeded 50% at any depth. Also, aquifer samples contained higher proportions of silt and clay. The very low probabilities of encountering screenable aquifers in the top 46m indicated that the small numbers of STWs were operating in Sylhet area. Pumping tests were carried out at 12 exploration sites as summarized in Table 2-4. The pumping test results shows that many of the tubewells are hydraulically inefficient when pumping at 2 cusec.

Table 2-4: Summary of Pumping Test Analyses (BADC, 1990)

Upazila	Mouza	Tested Discharge (l/s)	Duration (hrs.)	Specific Drawdown (ft/cs)	Transmissivity (m^2/d)	Permeability (m/d)	Storage Co-efficient	Leakage Factor (m)
Jagannathpur	Jatrapasha	59	50	19.08	479	19.6		
Biswanath	Singerkach	54	53	27.2	456	16.6	0.00056	
Sylhet Sadar	Hassanpur	54	34	14.13	692	25.2	0.00029	812
Gowainghat	Uparatlihai	40	28	30.8	478	26.1	0.00052	475
Kanaighat	Durgapur	60	50	17.5	800	26.2	0.0007	1360
Zakiganj	Kazalsar	58	48	1587	631	20.7	0.0007	680
Beanibazar	Alipur	45	48	34.75	278	9.1	0.0007	881
Golapganj	Tikorpara	36	48	42.93	280	10.2	0.0007	
Kulaura	Hajipur	35	46	43.39	316	13.0	0.00035	700
Maulavibazar	Barbag	18	2	36.05	285	11.7	0.00035	
Lakhai	Zarunda	48	44	22.49	707	29.0	0.00002	

Water samples for laboratory analysis were collected during ten of the pumping tests. The water was found anaerobic, and this was reflected in the significant concentrations of iron and perhaps also the low concentrations of sulphate and nitrate. Although there was no oxygen, there were very high concentrations of carbon dioxide at some sites, and methane was encountered at Maulavibazar.

The high concentrations of bicarbonate were matched by very low concentrations of calcium and magnesium and consequently the water is extremely under saturated with respect to the common carbonate minerals calcite and dolomite.

2.4 Economic Design of Deep Tubewells by MMIL, 1990

This study was undertaken to make an economic evaluation of the various well design options for greater Sylhet area. In determining economically justified discharge, the optimum well design and the scope for adjusting the balance of capital and operating costs, Mott MacDonald International Limited (MMIL) carried out the study under the IDA Deep Tubewell II Project. In preparing this report it was assumed that a deep tubewell project would be followed.

The objective was to produce a "What if " model for the economic design of the tubewells incorporating capital and operating costs, variations in depth and aquifer conditions, and well components. The model was based on the Jacob equation, the Logan approximation and actual head loss characteristics for casing and screen. The critical hydrogeological parameters for the model were the depths, thickness and permeability of the aquifers, static water level and the irrigation water requirement.

The activities included three distinct stages such as construction of a technical economic model for well design, definition of the economic costs and benefits, and finally use of the model to examine the sensitivity to all relevant parameters.

According to this study, the optimum tubewell design would have approximately 21.5m of PVC screen. The top 9m, at least, of this screen should be 15cm in diameter while the lower part could be usefully replaced by 10cm screen. However, the best overall result will be obtained if screen lengths are kept within the range of 15.2-24.4m. Screen lengths of less than 15.2m are not recommended because of high screen entrance velocities and definitely not less than 12.2m because of excessive approach velocities at the pack - aquifer interface. In areas where the average hydraulic conductivity is lower it would be advantageous to increase the screen length, if practical. In areas of very low hydraulic conductivity, but otherwise screenable, aquifer screen lengths could be to about 30.4m. However, in areas where the hydraulic conductivity is the same but proportion of screenable material is less, screen lengths should be kept as short as possible (but not less than 15.2m).

As per the study, for the average conditions in Sylhet the optimum 14 l/s DTW design would have 12.2m of 10cm diameter PVC screen, although there would be a little extra overall cost if this were increased to 15.2m. The optimum 14 l/s DTW would be much less profitable than the optimum 28 l/s DTW with benefit - cost ratios of 1.69 and 2.53 respectively. In areas where the hydraulic conductivity is lower, the optimum screen length increases. For 50% reduction in hydraulic conductivity the optimum length is 15.2 - 18.2m, given that 14 l/s wells are most likely used in poor aquifers areas. However, screen lengths of less than 12.2m are not recommended, also because of excessive approach velocities at the pack - aquifer interface.

The study indicated that 14 l/s DTW designs do not stand up to the same worst case analysis used to test 28 l/s designs. A relatively efficient use (i.e. pumping hours and discharge) and productivity (crop yield and price) is needed to ensure their economic viability.

The study was carried out on the basis of the "model aquifer configuration" made from the lithological logs of only 15 numbers of drilling of exploratory boreholes in the greater Sylhet area. As the aquifer condition is complicated and changeable within a very few kilometers in the area, the drilling sites considered in this study are very limited. In the model, it was considered that the screenable layers are situated between 30.4m and 137.2m below ground surface and unscreened layers make no contribution to the yield of the tubewell. But, it is experienced that the study area has screenable layers within 30.5m from ground surface in many places where 14 l/s wells can be installed successfully.

2.5 Groundwater Recharge Study by Karim, M.A., 1987

In this study the actual recharge was computed based on the maximum water table fluctuation of the area for a period 1978-1983 multiplied by specific yield. The fluctuation of groundwater level for each upazila was worked out from the difference between the smallest depth of groundwater level in the months of August to October and the maximum depth of groundwater level in the months of April to May. The available recharge was estimated after deducting the loss of groundwater, which varies from 10% to 40% of the annual recharge before the first week of November when groundwater discharge starts. The specific yield values for different physiographic units considered in this study were taken from different BWDB Technical and Water Supply Papers, UNDP (1982), Water Balance Studies of BWDB/UNDP (1983), MPO (1987) and others. Maximum fluctuation of groundwater level was multiplied by specific yield of water table fluctuation zone to estimate the annual recharge to groundwater. The actual and available recharge and future groundwater development potential in the project area as calculated by Karim (1987) are shown in Table 2-5.

For the greater Sylhet area, the table shows that the average annual recharge is 81.5mm with a range from 20mm to 212mm. The available recharge varies from 14mm to 159mm in the area. It has been observed in this study that about 26% of total annual recharge is being lost by discharges through evapotranspiration and into the khals, streams and rivers before the start of the irrigation seasons in the month of November. In determining the groundwater level, only 80 observation wells were used to develop hydro graphs for all over the study area, which is not sufficient. In calculating the available recharge, different quantities of groundwater losses

(10% - 40% of the annual recharge) for different upazila were considered in this study. No basis is found in considering the quantity of groundwater losses for an Upazila.

Table 2-5: Upazila Wise Groundwater Recharge (Karim 1987)

District	Upazila	Maximum Fluctuation of GWL (m)	Specific Yield %	Actual Recharge (mm)	Loss of GW %	Available Recharge (mm)
Sylhet	Gowainghat	3.88	3	116	25	87
	Katwali	2.02	5	101	20	81
	Biswarath	2.74	2	55	20	44
	Balagonj	2.21	3	66	20	53
	Fenchugonj	2.41	3	72	25	54
	Golapgonj	2.02	5	101	20	81
	Beanibazar	2.63	5	132	20	106
	Zakigonj	2.21	5	111	20	89
	Kanaighat	1.74	5	87	20	70
	Jaintapur	4.24	5	212	2	159
	Companigonj	3.93	5	197	2	158
Maulvibazar	Maulvibazar	1.87	1	20	30	14
	Srimangal	4.06	2	81	25	61
	Kamalgonj	3.1	2	62	25	47
	Rajnagar	2.21	3	66	20	53
	Kulaura	3.25	2	65	20	52
	Baralakha	3.42	2	68	20	54
Sunamganj	Taherpur	3.93	2	79	30	55
	Derai	2.39	2	48	35	31
	Jagnnathpur	2.74	2	55	30	39
	Sunamganj	1.54	2	31	25	23
	Chatok	3.38	2	68	25	51
	Jamalgonj	2.12	2	42	20	34
	Sullah	2.39	2	48	20	38
	Dharmapasha	5.26	2	105	20	84
	Dewarabazar	3.26	3	98	25	74
Habiganj	Ajmerigonj	3.12	1	31	30	22
	Baniachong	3.1	3	93	30	65
	Lakhai	3.68	3	110	30	77
	Madhabpur	3.46	2	69	30	48
	Chunarughat	3.12	3	94	35	71
	Habiganj	3.38	2	68	25	51
	Bahubal	3.4	2	68	25	51
	Nabigonj	1.87	2	37	20	30

2.6 Study on Hydrogeology of Greater Sylhet Area by BWDB, 1986

This is a technical report, which is one of the series of such type of reports prepared as a part of the project of groundwater survey and investigation in Bangladesh. It is an area wise specific study for quantitative and qualitative evaluation of groundwater to plan the future water resources development schemes. The main objective was to study the recharge and discharge condition of the area and to evaluate the groundwater potential of the area for further development. To evaluate the role of groundwater in regional development for irrigation planning the hydrogeological condition of the study area was investigated. For the systematic potential development of the groundwater resources study was under taken.

According to the study, the actual annual recharge of the area has been estimated to be about 1404.21Mm^3. The potential recharge has been calculated by lowering the groundwater table from 2.5 meter to 12 meter from the highest groundwater table and it has been estimated about 1896.69Mm^3. The available recharge has been calculated by subtracting 40% of the potential recharge and is about 1137.98Mm^3.

The study show that the sediments of the area mainly comprises of little consolidated sand stones and shales and unconsolidated sandy sediments in the hills. The topsoil is not favorable for infiltration of rainwater. Below this layer a water bearing zone exists consisting of fine to medium sand, in some places the main aquifer is interbedded with clay layer. In some area, the thickness of main aquifer ranges from 20 meter to 98 meter and may be considered as moderately good aquifer for tubewell development. It has been indicated that the hydrogeological condition of the area is not promising for utilization of groundwater for irrigation.

According to the study, the groundwater flow of greater Sylhet area study area is mainly centralized in haor areas and the hydraulic gradient varies from 0.27 meter to 0.29 meter per kilometer. The maximum depth to groundwater table of the study area varies from 0.77 meter to 9 meter from land surface and it is observed during the month of March and April. Groundwater fluctuation of the area varies from 0.19 meter to 6 meter. The transmissivity of the main aquifer varies from 146.90 m^2/day to 825.45 m^2/day and storage co-efficient from 1.5xl0^{-3} to 3.48xl0^{-2}. The actual annual groundwater recharge varies from 66.53mm to 294.00mm estimated based on groundwater table fluctuation. The average potential recharge varies from 91.45mm to 376.35mm estimated based on lowering of groundwater table up to potential recharge limit as estimated from hydrographs. The available recharge is about 60 percent of the potential recharge. It was observed that there was some rejected recharge and on these assumption potential recharges was calculated.

2.7 Tea Irrigation Report by Pakistan Tea Board, 1967

In 1967, Government of Pakistan investigated surface water and groundwater resources with the help of consulting Engineers Sir M. Macdonald and Partners in cooperation with Hunting Technical Services (HTS) Limited for irrigating tea in the greater Sylhet area. The HTS Limited assessed the potential for groundwater irrigation in the tea estates. The study included 13 exploratory boreholes, 8 pumping tests and an inventory of tube wells on the tea estates. The HTS (1967) obtained an average specific drawdown of 41ft/cusec with a range between 24 and 63ft/cusec. The average hydraulic conductivity of 2.1ft/sec was found in this study. Storage coefficients were determined for three tests and ranged from $1.0x10^{-5}$ to $1.6xl0^{-5}$, and it was noted that most tests showed a leaky aquifer response.

The study also included chemical analysis of groundwater from both private and the test wells. The study concluded that there would be negligible risk of crop damage from salinity, alkalinity or boron.

2.8 Study Carried by Ahmed et al 2015

Ahmed et al 2015 conducted a study to improve the understanding of groundwater recharge, age, inter-aquifer connectivity, mixing pattern and hydrogeochemical processes within the Holocene and Pleistocene aquifers in the Surma Basin – Sylhet. Topographically driven flow, free convection and tectonically driven flow are the main geological process that control the reginal groundwater flow in the Surma basin. An isotopic and hydrogeochemical approach has been used in this purpose. 91 nos. groundwater and 12 nos. of surface water samples has been analyzed in this study. Groundwater sample has been taken from shallow depth (30-70m), intermediate depth (71-145m) and deep well (146-270m). Water quality analyses revealed that groundwater type in shallow aquifer is Na-Mg-Ca-HCO_3 whereas groundwater in intermediate and deep aquifer is Na-HCO_3 type. But groundwater in intermediate aquifer in Sylhet City Corporation area is Ca-Mg-Na-HCO_3 and deep aquifer water in Gowainghat and Fenchuganj area is Na-Ca-Mg-HCO_3.

Seven & three samples of intermediate & deeper depth (Balaganj) are found with higher Arsenic concentration respectively. The likely reason of this may be the migration of shallow arsenic contaminated water to intermediate and deeper depth of the aquifers may be due to improper well construction or because of intensive groundwater pumping (over last 20 – 30 yrs). The aquifers in this case are in mid Holocene stage where the aquitard or clay lenses are absent. These cases do not necessarily imply the Arsenic contamination of intermediate and deep aquifers.

Spatial distribution of 14C shows that low concentration in northern part and high concentration in southern part of the basin. Low 14C activity in the northern part GW represents the old age recharged water. The presence of high 14C activity in the southern part groundwater reflects an open system unconfined aquifer and thus represents sub-modern to modern recharge. Plots of Oxygen-18 vs. Tritium indicates that in monsoon, the Surma river shows some connectivity with the adjacent shallow aquifers. With the higher C-14 and depleted C-13 values indicated some mixing trend in the groundwater.

2.9 Arsenic Contamination in Groundwater in North-Eastern Bangladesh, Badruzzaman et al, 1998

In this study, arsenic contamination of the north-eastern region of Bangladesh has been assessed based on analysis of 1,210 groundwater samples from six districts in that region. The districts are Kishorganj, Netrokona, Sylhet, Maulavibazar, Sunamganj and Habiganj. It has been found that about 61.1% of the tubewells in the north-eastern region contain arsenic exceeding the acceptable limit set by the WHO (0.01mg/L) for drinking water and about 33.2% of the tubewells exceed the Bangladesh EQS (0.05 mg/L). Of the tubewells exceeding the Bangladesh EQS about 42.8% contain arsenic over 0.100 mg/L posing a potential threat to human health. Among the six districts arsenic contamination in Sunamganj appears to be the worst with 74.1% of the wells exceeding the Bangladesh EQS. In a upazila-wise perspective the Karirngonj, Nikli, Itna and Kuliarchar upazila in Kishorganj district appears to be the worst affected. Similarly, in Netrokona district Mohongonj, Khaliajuri and Madan than as have the higher percentages of tubewells contaminated with arsenic. In Habiganj district the Bahubal, Ajmirigonj and Madhabpur thanas have the larger shares of tubewells affected with arsenic. This study clearly shows that the north-eastern region of the country is severely affected by arsenic contamination of groundwater.

2.10 Groundwater Management and Feasibility Study for 148 Pourashavas having no Piped Water Supply, IWM 2013

In this study several aquifer tests have been conducted to determine the performance characteristics of a well and hydraulic parameters of the aquifer in different Pourashavas all over the Bangladesh. The summary of the aquifer test results with in the present study area has been presented in Table 2-6.

Table 2-6: Aquifer Test Results (IWM 2013)

District	Upazila	Pourashava	Aquifer Materials	Screen Position (m)	Discharge Rate (l/s)	KD (m^2/d)	S	K (m/d)	Area of Influence (m)
Netrokona	Durgapur	Durgapur	Fine to Medium Sand	48.77 to 76.21	42.47	3848.78	0.00105	106	580
Netrokona	Madan	Madan	Fine to Medium Sand	204.27 to 228.66	28.31	986	0.0000734		330
Netrokona	Kendua	Kendua	Fine to Medium Sand/Medium Sand	185.67 to 209.76	37.85	439	0.000113	13	400
Moulvibazar	Kamalganj	Kamalganj	Medium Sand	106.71 to 121.95 and 141.77 to 150.91	28.26	566	0.0002472	8.84	160
Kishoreganj	Karimganj	Karimganj	Fine to Medium Sand, Medium Sand & Coarse Sand	79.27 to 125	42.47	2318.33	0.0027305	30.41	390
Kishoreganj	Pakundia	Pakundia				864	0.014440	7	

2.11 Assessment of State of Water Resources, IWM 2016

In this study upazila wise lithostratigraphy has been constructed using a number of borelogs of the Upazila. This probability diagram represents vertical and lateral variation of lithology upto 33 meter depth, which helps to assess the upper aquifer characteristics. The summary of the analysis has been presented in Table 2-7 .

Table 2-7: Summary of Stratigraphy (IWM 2016)

Upazila	Top Layer Description	Upper Aquifer Description
Ajmiriganj	The top most clay layer exists in about 90% of area upto 1.5m	✓ Fine sand, very find sand and silt ✓ Confined in nature
Bahubal	The top most clay layer exists in about 90% of area upto 21.5 m	✓ Fine sand, however some very find sand and silt lenses are observed ✓ Semi-confined to confined in nature
Baniachong	The top most clay layer exists in about 90% of area upto 6m	✓ Very fine sand aquifer, fine and medium sand aquifer ✓ Confined in nature
Chunarughat	The top most clay layer exists in about 70% of area upto 6m	✓ Fine sand, fine to very fine sand and medium sand aquifer ✓ Semi-confined in nature
Habiganj Sadar	The top most clay layer exists in about 80% of area upto 3m and 70% of area upto 9 meter	✓ Fine sand and medium and coarse and aquifer is present ✓ Semi-confined to unconfined
Lakhai	The top most clay layer exists in about 100% of area upto 15m	✓ The top most clay layer exists in about 100% of area upto 15m ✓ Confined in nature
Madhabpur	The top most clay layer exists in about 90% of area upto 3m	✓ Very fine sand to fine sand and medium sand aquifer is present ✓ Confined to semi-confined
Nabiganj	The top most clay layer exists in about 90% of area upto 6m.	✓ Very fine sand and fine sand aquifer is present ✓ Confined in nature
Barlekha	The top most clay layer exists in about 80% of area upto 10.50m.	✓ Very fine sand, fine sand and medium sand aquifer is present ✓ Semi-confined to unconfined in nature
Kamalganj	The top most clay layer exists in about 90% of area upto 7.50m	✓ Very fine sand, fine sand and medium and coarse sand aquifer is present ✓ Confined in nature
Kulaura	The top most clay layer exists in about 90% of area upto 9m	✓ Very fine sand and fine sand aquifer is present ✓ Confined in nature
Maulvibazar Sadar	The top most clay layer exists in about 80% of area upto full study depth	✓ Very fine sand and fine sand aquifer is present ✓ Semi-confined in nature
Rajnagar	The top most clay layer exists in about 70% of study area upto 9m depth	✓ Very fine sand and fine sand aquifer is present ✓ Semi-confined in nature
Sreemangal	The top most clay layer exists in about 90% of area upto study depth	✓ Very fine sand and silty aquifer is present ✓ Confined in nature
Balaganj	The top most clay layer exists in about 90% of area upto 6m.	✓ Very fine sand and fine sand aquifer is present ✓ Confined in nature

Upazila	Top Layer Description	Upper Aquifer Description
Beani Bazar	The top most clay layer exists in about 90% of area upto 6m	✓ Very fine sand and fine sand aquifer is present ✓ Confined in nature
Bishwanath	The top most clay layer exists in about 100% of area upto 12m	✓ Very fine sand, fine sand and medium sand aquifer is present ✓ Confined in nature
Copaniganj	The top most clay layer exists in about 80% of area upto 3m	✓ Clay and fine sand aquifer is present ✓ Confined in nature
Fenchuganj	The top most clay layer exists in about 70% of area upto 18m	✓ Very fine sand, and fine sand aquifer is present ✓ Semi-confined in nature
Golapganj	The top most clay layer exists in about 90% of area at the top and 70% upto study depth.	✓ Mainly composed of very fine sand, fine sand and silt but medium sand is present ✓ Confined in nature
Jaintiapur	The top most clay layer exists in about 100% of area upto 2m	✓ Fine sand and medium and coarse sand aquifer is present ✓ Confined in nature
Kanaighat	The top most clay layer exists in about 100% of area upto 3m	✓ Fine sand aquifer, fine and medium sand aquifer exist ✓ Confined in nature
Sylhet Sadar	The top most clay layer exists in about 100% of area upto 6m	✓ Very fine to fine sand and medium sand aquifer is present ✓ Confined in nature
Zakiganj	The top most clay layer exists in about 90% of area upto 6m.	✓ Composed of fine sand medium sand and very fine sand ✓ Unconfined in nature
Chhatak	The top most clay layer exists in about 100% of area upto 18m	✓ Very fine sand, fine sand and medium sand aquifer is present ✓ Confined in nature

2.12 Water Supply Sanitation and Drainage Project in Sylhet & Barisal City, BETS-IWM (2009)

The overall objective of the project is to ensure safe and adequate water supply in Sylhet and Barisal cities. The study revealed that the layered hydro-stratigraphy of the area is not homogeneous and assemblage of sands, silts and clays. The aquifer layer of Sylhet city corporation area consists primary of medium sand and occasional presence of fine sands with intercalation of clay and silt layers.

Two number of aquifer tests were conducted to know the aquifer properties in Sylhet city area. The aquifer test at Balur Char area revealed that the drawdown after 72 hours of pumping at production well, observation well-1 (30m distance from production well), observation well-2 (90m distance from production well) and observation well-3 (300m distance from production well) is 10.22m, 2.91m, 1.68m and 0m respectively. The rate of pumping was 3168m^3/day. The average hydraulic conductivity found 16.69m/day.

Another aquifer test was conducted at Ansar Training Center with a pumping rate 2592m^3/day. The drawdown at observation well-2 (200m distance from production well) found 0.03m. Analysis showed that average hydraulic conductivity found 13.296m/day.

Modelling study also conducted under this study to assess the potentiality of subsurface aquifer system of Sylhet city and surrounding areas to fulfill the projected future demand of 2010, 2020 and 2030. For abstraction of 101470m^3/day of water in 2030 from aquifer water level will decline in the city area. It was observed from the model predicted groundwater level that a cone of depression develops around the city area. In the central part of the cone the water level might fall to about -2.0m.

From the model study, groundwater recharge and aquifer storage volume was stand as 14.89Mm^3 and 5.92Mm^3 respectively. The available groundwater storage volume up to 8m rated drawdown depth in aquifer was estimated using saturated thickness of the aquifer, area and the specific yield of the aquifer material for the city area and estimated volume of water was about 35.78Mm^3.

Water quality of Surma River was analyzed under the study. The test results have been presented in Table 2-8 and Table 2-9.

Table 2-8: Water Quality Analysis Surma River, Sylhet during December, 2008

Location	**Unit**	**Masimpur, Sylhet**	**Gashitola, Sylhet**
Calcium, Ca	mg/L	21	20
Magnesium, Mg	mg/L	6.5	6.51
Sodium, Na	mg/L	11.95	12.22
Potassium, K	mg/L	1.71	2.21
Iron, Fe	mg/L	0.8	0.72
Manganese, Mn	mg/L	0.008	<0.08
Lead, Pb	mg/L	0.015	0.012
Zinc, Zn	mg/L	0.02	<0.02
Cadmium, Cd	mg/L	<0.001	<0.001
Arsenic, As	mg/L	0.001	<0.001
Boron, B	mg/L	2.9	2.7
Ammonia, NH3-N	mg/L	<0.017	<0.017
Ammonium, NH4-N	mg/L	0.03	0.03
Nitrate, NO3-N	mg/L	0.8	1.8
Nitrite, NO2-N	mg/L	0.256	0.008
Silica, SiO2	mg/L	6.1	7.4
Iodine, I2	mg/L	0.04	0.05
Fluoride, F	mg/L	0.13	0.09
Orthophosphate, PO4	mg/L	<.04	0.184
Carbon-dioxide, CO2	mg/L	6	9
Chloride, Cl-	mg/L	6	8
Sulphate, SO4	mg/L	47.7	46.9
Carbonate, CO3	mg/L	0.03	0.03
Bi-Carbonate, HCO3	mg/L	56.1	57.3
Total Coliform, TC	CFU/100mL	500	350
Fecal Coliform, FC	CFU/100mL	400	200

Table 2-9: Water Quality Analysis of Surma River, Sylhet during March, 2009

Location	Topkhana (near existing WTP site), Sylhet	Naya Bazar, Kushi Ghat, (near prposed WTP site), Sylhet
GPS Position	24 53 14.2	24 52 35.5
	91 51 51.6	91 53 39.4
Time/Date	8:40 (06/04/09)	10:45 (06/04/09)
Temp(^{0}c)	27.6	27.4
pH	8.22	8.35
DO (mg/l)	6.52	6.54
BOD (mg/l)	2.25	2.28
COD (mg/l)	143	139
TSS (mg/l)	4.82	5.2
Fe (mg/l)	1.85	1.68
Cl_2 (mg/l)	0	0
NH_3 (mg/l)	1.2	1
NO_3 (mg/l)	0.65	0.75
Mn (mg/l)	<0.01	<0.01
Turbidity (NTU)	22	18

2.13 Feasibility Study with Detail Design of Surface Water Treatment Plant for Sylhet City Corporation (IWM 2017)

Sylhet City Corporation (SCC) carried out a feasibility study with detail design for a 50 MLD capacity water treatment plant withdrawing water from a suitable location of Sari-Gowain River. Details of the sampling campaigns carried out during both wet season and dry seasons are given below:

Sampling Date & Time	Sampling Location	GPS Position		Weather Condition
		Latitude	Longitude	
26/07/2016, 17:15	Salutikor Bridge on Sari-Gowain River	24 59 18.50	91 50 57.20	Sunny
26/07/2016 16:30	Badha Ghat Bridge on Sari-Gowain River	24 57 00.00	91 48 07.00	Sunny
24/08/2016, 10:10	Badha Ghat Bridge on Sari-Gowain River	24 56 54.20	91 47 58.80	Sunny
27/09/2016, 09:30	Chamura Kandi on Sari-Gowain River	24 57 39.60	91 49 24.20	Sunny
24/12/2016, 08:50	Chamura Kandi on Sari-Gowain River	24 57 41.3	91 49 26.8	Sunny
14/02/2017, 08:20	Chamura Kandi on Sari-Gowain River	24 57 42.4	91 49 28.8	Sunny
19/03/2017	Chamura Kandi on Sari-Gowain River	24 57 43.6	91 49 31.3	Sunny
24/04/2017	Chamura Kandi on Sari-Gowain River	24 57 42.4	91 49 29.1	Sunny

The results of the in-situ testing and laboratory analysis of water samples collected from the Sari Gowain River during both wet and dry seasons are presented in Table 2-10 and Table 2-11.

Table 2-10: Characteristics of Raw Water Collected during Wet Season (July – September 2016) from Sari Gowain River

Water Quality Parameter	Unit	Concentration Present				Bangladesh Drinking Water Standard
		Salutikor Bridge	Badha Ghat	Badha Ghat	Chamura Kandi	
pH	-	6.76	6.87	6.47	6.54	6.5-8.5
Color (Apparent)	Pt-Co	**37**	**38**	**175**	**72**	15
Color (True)	Pt-Co	6	12	**53**	**42**	15
Turbidity	NTU	5	5	**34.4**	**30.8**	10
TDS	mg/L	--	--	--	--	1000
Iron (Fe)	mg/L	0.18	0.12	0.60	0.70	0.3-1.0
Total Coliform (TC)	cfu/100 mL	**660**	**390**	**TNTC**	**1520**	0
Fecal Coliform (FC)	cfu/100 mL	**250**	**190**	**TNTC**	**690**	0
EC at 25ºC	µS/cm	36	55	58	59	--
Dissolved Oxygen (DO)	mg/L	**4.39**	**4.65**	**3.56**	**4.01**	6
Ammonium (NH_4-N)	mg/L	0.060	0.070	0.290	**0.556**	0.5
Ammonia (NH_3-N)	mg/L	0.000	0.000	0.000	0.001	--
TSS	mg/L	10	**12**	**25**	**39**	10
Temperature	ºC	27.1	26.9	30.4	30.3	20-30
COD	mg/L	4	3	2.5	**19**	4
BOD_5	mg/L	**0.8**	**0.4**	**0.4**	**0.8**	0.2
Chlorophyll-a	µg/L	0.7	0.7	2.4	3.0	--
Lead (Pb)	mg/L	0.005	0.002	Not tested	Not tested	0.05
Cadmium (Cd)	mg/L	<0.001	<0.001	Not tested	Not tested	0.005
Chromium (Cr)	mg/L	<0.001	<0.001	Not tested	Not tested	0.05
Zinc (Zn)	mg/L	<0.001	<0.001	Not tested	Not tested	5.0
Mercury (Hg)	mg/L	<0.0001	<0.0001	Not tested	Not tested	0.001

Table 2-11: Characteristics of Raw Water Collected during Dry Season (December 2016 – April 2017) from Sari Gowain River

Water Quality Parameter	Unit	Concentration Present				Bangladesh Drinking Water Standard
		Chamura Kandi	Chamura Kandi	Chamura Kandi	Chamura Kandi	
pH	-	7.76	7.34	6.90	6.36	6.5-8.5
Color (Apparent)	Pt-Co	**112**	**20**	**90**	**15**	15
Color (True)	Pt-Co	**52**	8	**57**	**14**	15
Turbidity	NTU	**31.6**	**34**	**31.3**	**32.0**	10

Water Quality Parameter	**Unit**	**Concentration Present**				**Bangladesh Drinking Water Standard**
		Chamura Kandi	**Chamura Kandi**	**Chamura Kandi**	**Chamura Kandi**	
TDS	mg/L	57	81	77	33	1000
Iron (Fe)	mg/L	--	1.25	0.90	1.24	0.3-1.0
Total Coliform (TC)	cfu/100 mL	**500**	**1380**	**582**	**TNTC**	0
Fecal Coliform (FC)	cfu/100 mL	**258**	**840**	**278**	**TNTC**	0
EC at 25ºC	µS/cm	82	112	101	56	--
Dissolved Oxygen (DO)	mg/L	**7.61**	**5.46**	**5.17**	**5.60**	6
Ammonium (NH_4-N)	mg/L	0.31	0.324	**0.546**	**0.567**	0.5
Ammonia (NH_3-N)	mg/L	0.001	0.004	0.002	0.001	--
TSS	mg/L	**30**	**28**	**27**	**21**	10
Temperature	ºC	28.4	22.6	22.3	23.4	20-30
COD	mg/L	**9**	**23**	**5**	**7**	4
BOD_5	mg/L	1.4	**1.2**	0.2	**0.4**	0.2
Chlorophyll-a	µg/L	Not tested	4.1	1.4	0.6	--
Lead (Pb)	mg/L	Not tested	0.032	Not tested	Not tested	0.05
Cadmium (Cd)	mg/L	Not tested	<0.001	Not tested	Not tested	0.005
Chromium (Cr)	mg/L	Not tested	0.007	Not tested	Not tested	0.05
Zinc (Zn)	mg/L	Not tested	0.047	Not tested	Not tested	5.0
Mercury (Hg)	mg/L	Not tested	<0.0001	Not tested	Not tested	0.001

3 DESCRIPTION OF THE STUDY AREA

3.1 Location of the Study Area

The study area is located in the North-East region of Bangladesh. The gross area of the study area is about 17747sq. km which is 85% of North-East region of Bangladesh. The study area is located in Bahubal, Chunarughat, Madhabpur, Nabiganj, Ajmiriganj, Baniachong, Lakhai and Sadar upazilas of Habiganj district; Barlekha, Kamalganj, Kulaura, Rajnagar, Sreemangal, Juri and Sadar upazila of Maulvibazar district; Balaganj, Beani Bazaar, Bishwanath, Fenchuganj, Gopalganj, Gowainghat, Jaintapur, Kanaighat, Zakiganj, Companiganj, South Surma and Sadar upazila of Sylhet district; Itna, Tarail, Karimganj, Kishoreganj Sadar, Hossainpur, Mithamain, Nikli, Austagram, Pakundia, Katiadi, Bajitpur, Kuliarchar, Bhairab upazila of Kishoreganj districts; Durgapur, Kalmakanda, Purbadhala, Netrokona Sadar, Barhatta, Mohanganj, Atpara, Khaliajuri, Kendua and Madan upazila of Netrokona districts; Tahirpur, Dharampasha, Bishwambarpur, Dowarabazar, Sunamganj Sadar, Chhatak, Jamalganj, Derai, Jagannathpur, Dakshin Sunamganj and Sulla upazila of Sunamganj districts as shown in Figure 1-1. The north and east side of the study area is bounded by Indian boarder, Brahmanbaria and Narsingdi districts in the south side of the study area whereas the west side is bounded by Mymensingh district.

3.2 Topography

The topography map of the study area has been shown in Figure 3-1, which reveals that topography of the study area varies from 0.7mPWD to 219mPWD. Central part of the study area is mainly low laying area. There are two very low areas in the central basin, one near Sulla and other along the north central rim. The low area near Sulla and Khaliajuri has large tracts below 3mPWD. The basin itself is a succession of Bills and Haors, interspersed with river cutoffs, scours, swales and long higher levees. From the central low area, the basin rises on all sides but imperceptibly. The rise is fairly sharp on the west and very gradual in the east. The rise is gradual at first and then fairly steep in the southeast. In the north, there is a fairly high rim of land.

Small hills, locally known as tilas are found scattered at many places along the Sylhet city up to Srimangal and Maulavibazar. The Central Sylhet Low Land contains the Hakaluki Haor and the low lands to its northwest and southeast. Sylhet Hills include Meghalaya foothills and Tila ranges. Area elevation curve of the study area has been presented in Figure 3-2 which reveals that about 76% of the study area the elevation is within 10mPWD.

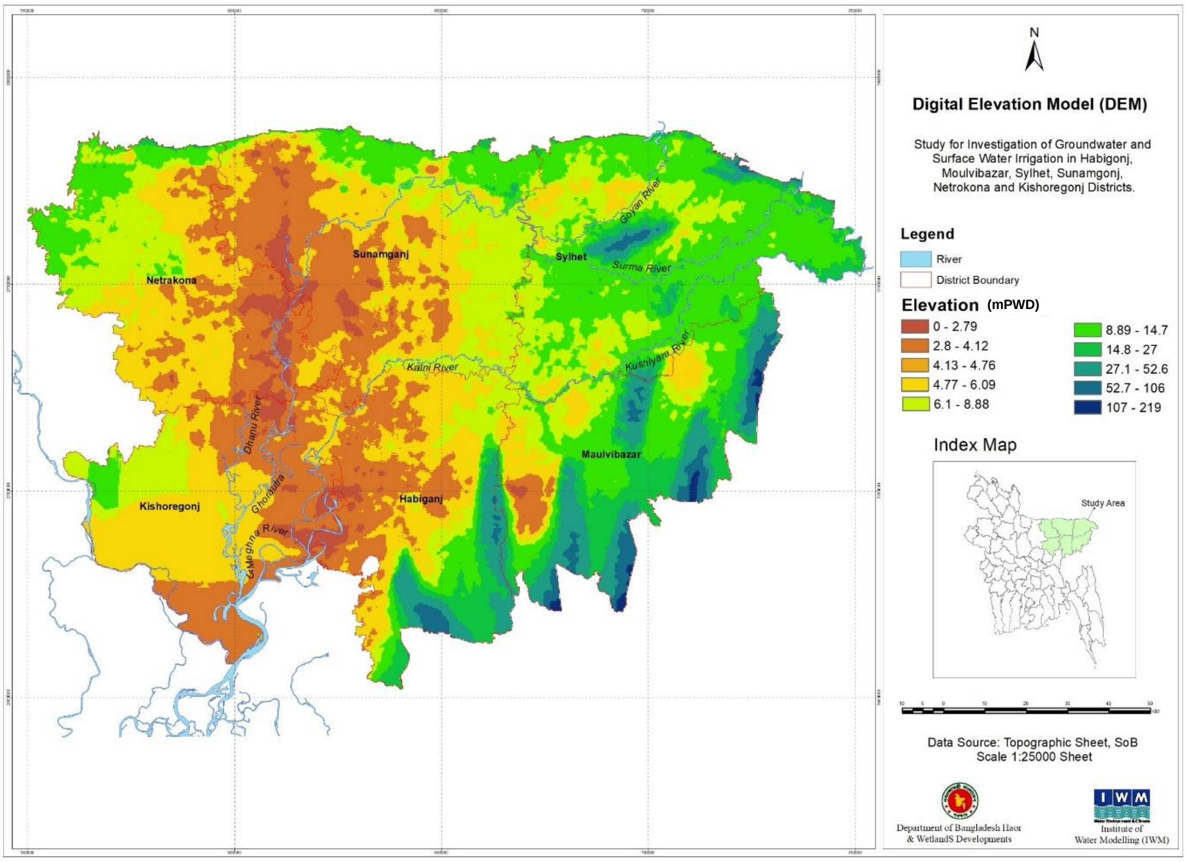


Figure 3-1: Topographic Map of the Study Area

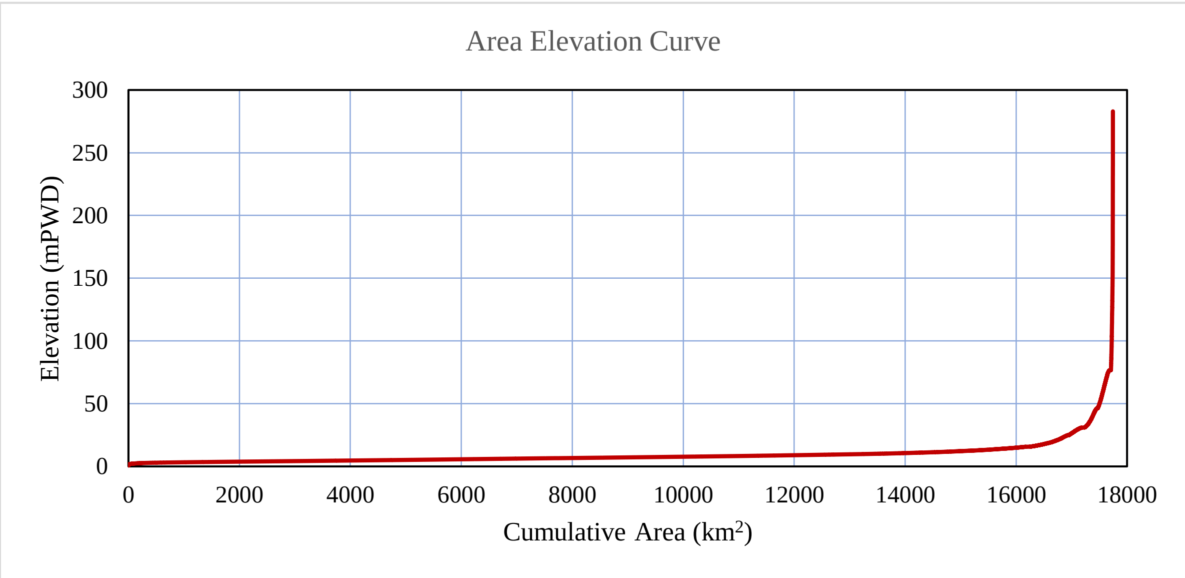


Figure 3-2: Area Elevation Curve of the Study Area

3.3 Climate

Rainfall: Rainfall is the most distinctive component of climate in the study area. On the other hand, the climate is dominated by distinctive geographical characteristics of the region which ultimately plays a main role in determining the spatial and temporal distribution of rainfall, evapotranspiration and hydrology of surface and groundwater. The climatic factors of the region are sub-tropical monsoon in nature with three prominent seasons, viz. summer, monsoon and winter.

Summer begins in April through to June. The monsoon is the rainy season, extending from June to September. Winter is the following season with the peak cold weather in December and January. The study area is characterized by highest rainfall and relatively low temperature compared to annual average of the country. There is a huge variation of rainfall pattern in the study area. The average annual rainfall of the study area varies from 2150mm to 5600mm (IWM 2016). The spatial distribution of annual rainfall pattern is shown in Figure 3-3. The annual rainfall totals show a slight decline (20mm/year) on average from 1985 to 2009 in north east region of Bangladesh (CSIRO 2014).

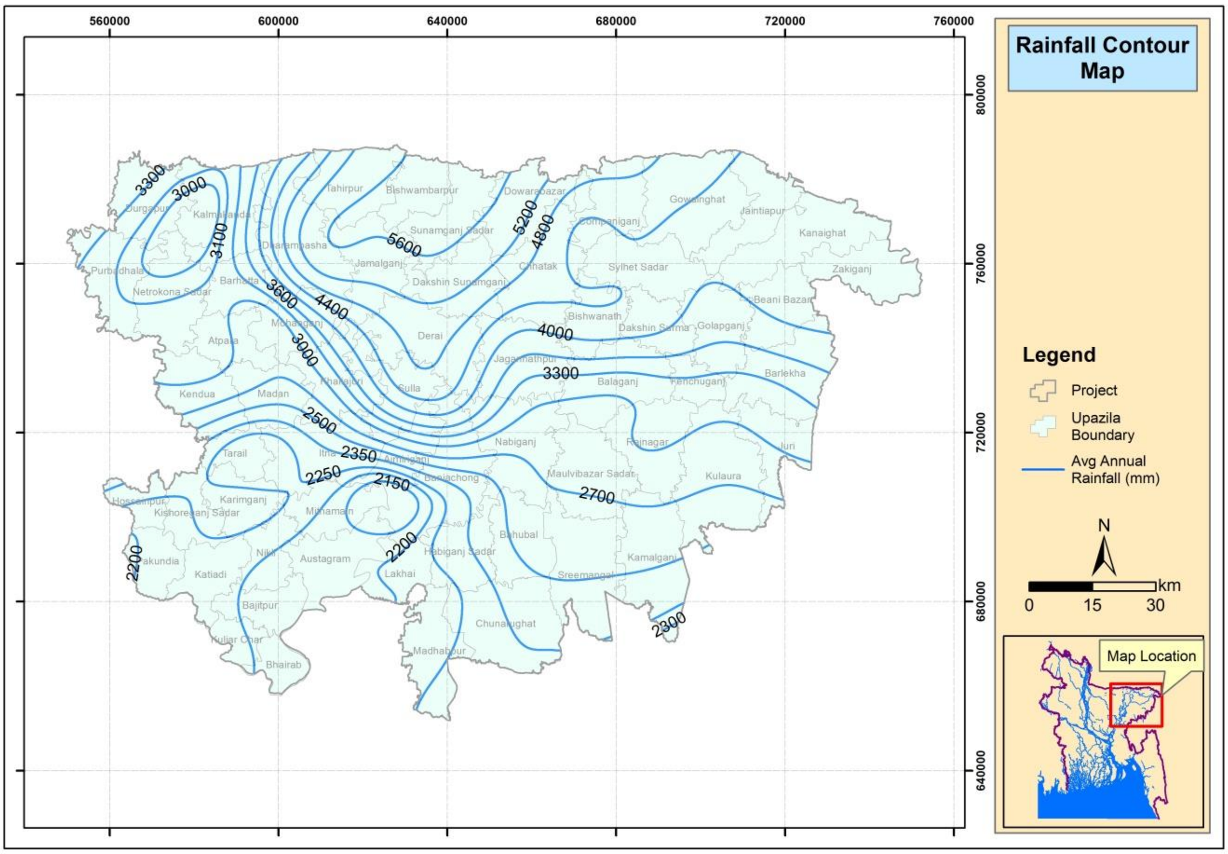


Figure 3-3: Spatial Distribution of Rainfall in the Study Area

Evapotranspiration: Evapotranspiration has been found to be the highest in April in most part of the study areas whereas it has been found minimum in December. The average monthly evapotranspiration varies from 2.00-3.40mm/day during dry period and from 3.90-4.80mm/day during wet period throughout the haor region (Haor Master Plan 2012). Long-term annual evaporation of the study area varies from 1200mm to 1345mm (IWM 2016). The spatial distribution of annual evaporation pattern is shown in Figure 3-4.

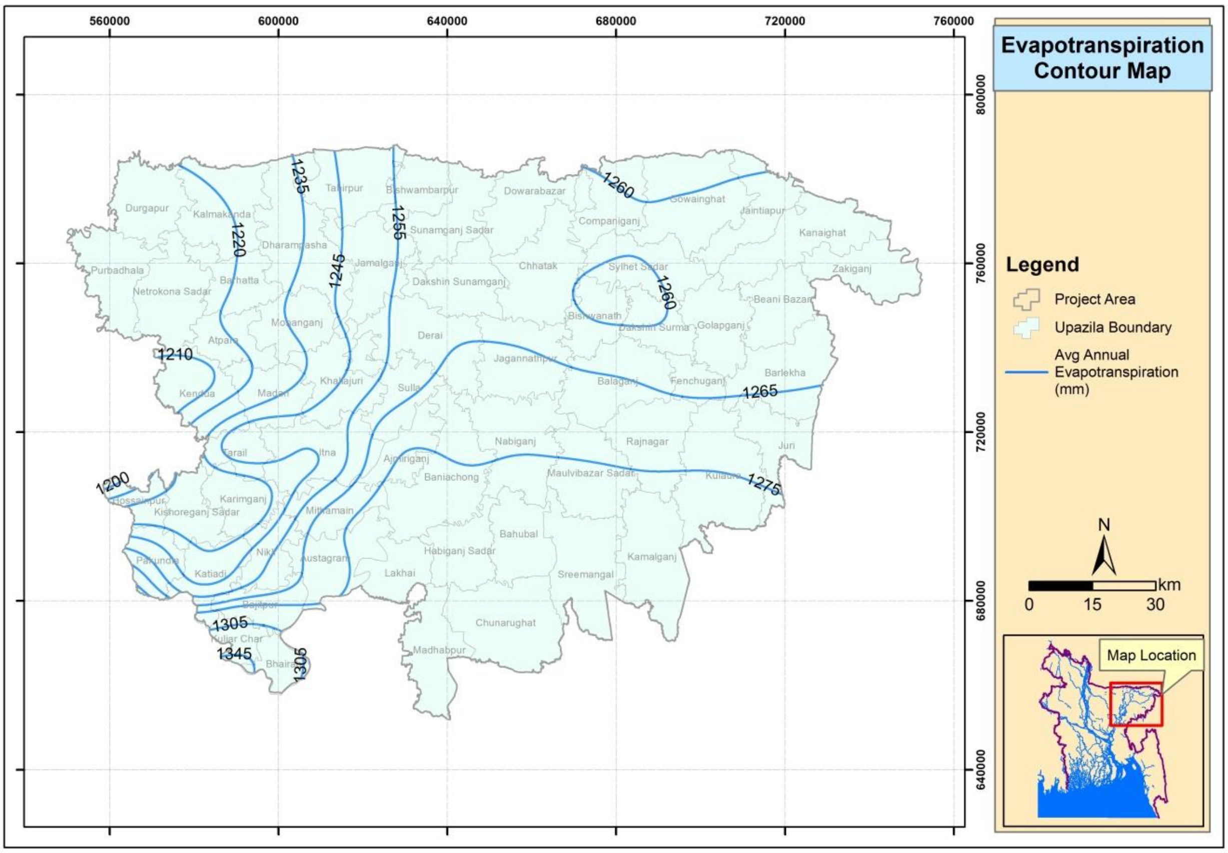


Figure 3-4: Spatial Distribution of the Evapotranspiration in the Study Area

3.4 River System

Three major river systems govern in the haor area inside Bangladesh: the Surma-Baulai, the Kalni- Kushiyara and the Kangsa-Dhanu as shown in Figure 3-5. The Barak River (Indian River) feeds the Surma and the Kushiyara. Consequently, it plays an important role in the two major systems, the Surma-Baulai and the Kalni-Kushiyara. The rivers contributing in these systems are described below:

Surma-Baulai System: This system carries the flow of the Surma and a large number of transboundary rivers flowing from the north to south. The Surma is the main river of this system which fed by Barak River. The Baulai is another important river of this system which flows entirely within Bangladesh. The Surma River conveys a part of the Barak river discharge and the discharges of its rught bank tributaries. At the bifurcation near Amalshid, the channel bed of the Surma is higher than that of the Kushiyra; as a result, the inflow from the Barak River into the Surma is less. Major tributaries of this river system are Sarigowain, Piyan, Dhalagang, Chela, Jalukhali, Jadukata and Someswari rivres. This river system meets the Kalni-Kushiyara system at Bajitpur upazila of Kishoreganj district.

Kalni-Kushiyara System: The Barak River is bifurcated forming two wings namely Surma and Kushiyara near Amalshid in Bangladesh just after the Indian border. The Barak River drains about 25260 sq km of land in the state of Assam, Manipur and Mizorum and crosses Bangladesh border near Amalshid.

The main left tributaries of Kushiyara are Sonai-Bardal river, Juri river and Manu river flowing in between Amalshid and Sherpur. Downstream of Sherpur, Kushiyara River flows in a westerly direction through the Suriya channel until reaching Markuli. Before 1978, the upper Kalni river would collect runoff from Surma-Kushiyara inter basin and drained southwards into Kalni river at Markuli. In 1978, a closure was constructed across the Kalni River at Markuli and the flow from the inter basin were diverted into Darain River system.

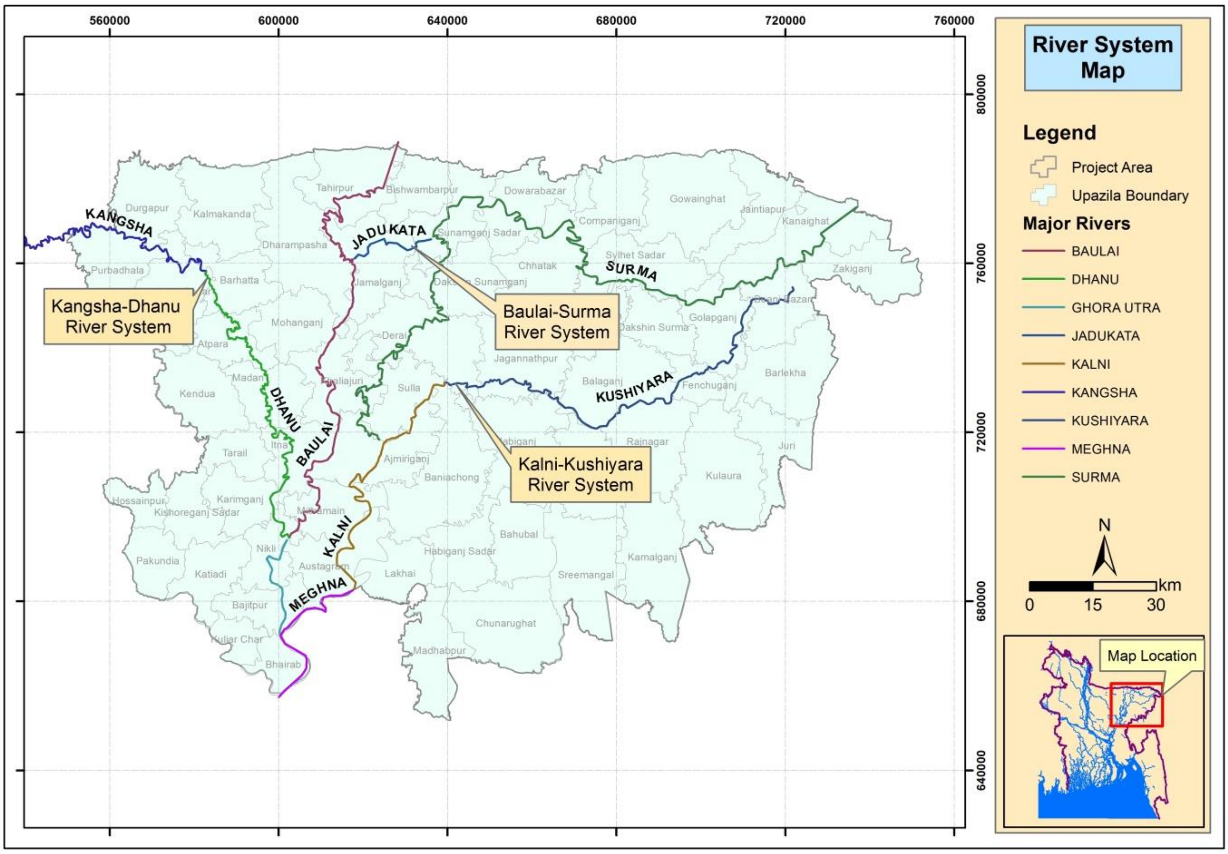


Figure 3-5: Major River System in the Study Area

The Kalni River flows to downstream of Markuli through the low-lying areas of Sylhet Basin. It is controlled by backwater flow of the Meghna River during monsoon season. Spills occur at several locations along the river in monsoon. These spills divert water from the Kalni River into the north and south floodplain. The Kalni River splits near Issapur, with the western branch (the Baida River) flowing through the Meghna Estuarine floodplain and the eastern branch takes the name as the Dhaleswari River. The Ratnasatai and Khowai River falls into Dhaleswari River near Madna. This river has an irregular, split channel pattern with abandoned channels and ox-bows adjacent to the main channel. The river is tidal at low flows, and water levels are controlled by backwater from the Meghna River.

Kangsa-Dhanu System: The Kangsha River originates from the confluence of the Bhugai and Malijhee, just upstream of Sarchapur, from where it follows as easterly course until it joins the Baulia just south of Sukdevpur. The Kangsha River receives cross-boundary inflows coming from the north via the Malijhee, Chillakhali, Bhugai, Nitai, Shibganjdhala and other hilly streams. The river also receives rainfall-runoff from the local area within Bangladesh, which is mostly located to the north of the Kangsha. The Dhanu River originates from the Bhogai River and Kangsa River at the border of Mohanganj and Jamalganj upazilas. The combined flow of the Dhanu River and Baulai River forms the Ghora-Utra River.

The combined flow of these three systems ultimately drains through Bhairab Bazaar to the Meghna River.

3.5 Geological Setting of the Study Area

The project area includes Habiganj, Maulavibazar, Sylhet, Sunamganj, Netrokona and Kishoreganj Districts are under the physiographic units of Jamuna (Young Brahmaputra) Floodplain, Haor Basin, Surma-Kushiyara Floodplain, Old Meghna Estuarine Floodplain and Low Hill Ranges. Hydrogeological parameters of these areas are governed by the lithostratigraphic and prevailing tectonic activities, which is part of regional hydrogeological setting and tectonic features. A Physiographic map of study area is shown in Figure 3-6.

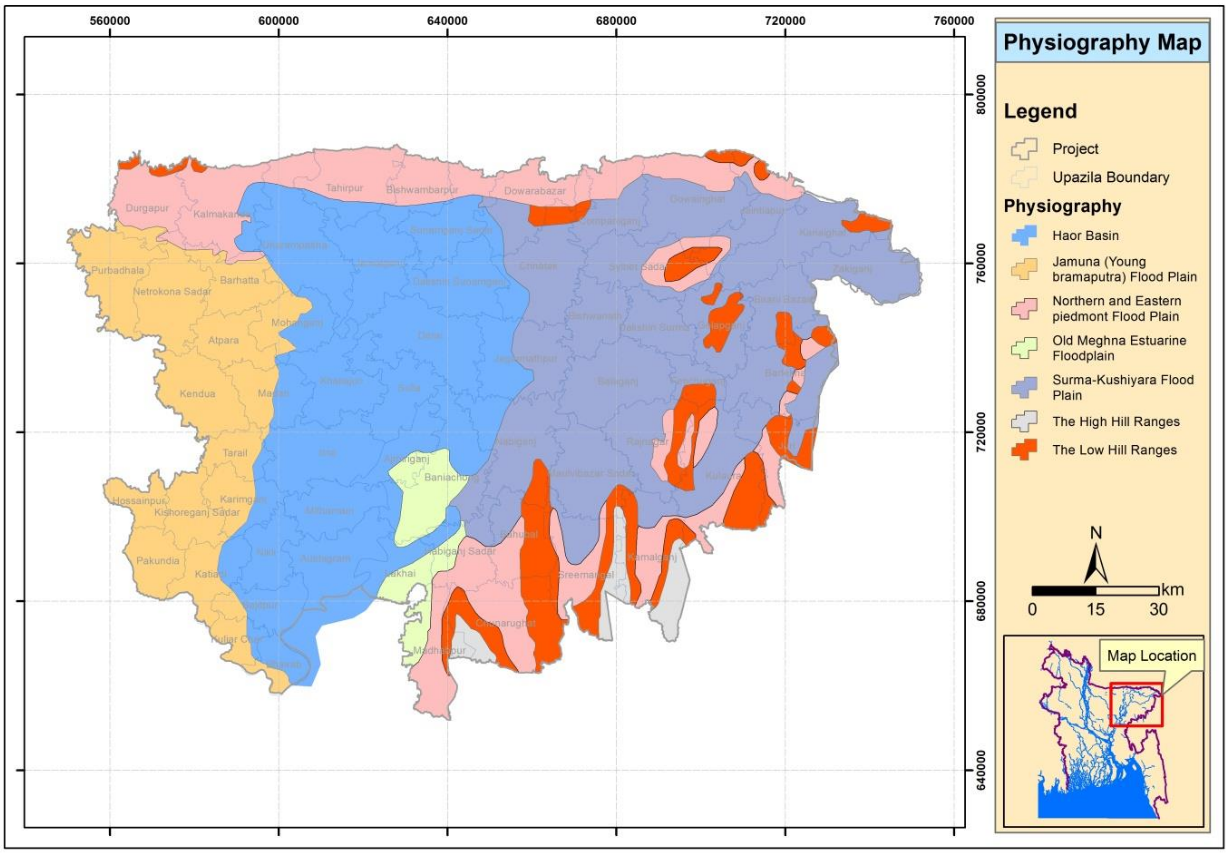


Figure 3-6: Physiographic Map of the Study Area (SRDI, 1997; Rashid, 1991; Reimann, 1993)

The detail description of each physiographic unit is described as below:

Haor Basin: A large, gentle depressional feature is bounded by the Old Brahmaputra floodplain in the west, the Meghalaya Plateau's foothills in the north, Sylhet High Plain in the east and Old Meghna Estuarine floodplain on the south. Its greatest length, both E-W and N-S, is just over 113 km. Numerous lakes (beels), large swamps and haors cover this saucer-shaped area of about 7,250 sq km. The sinking of this large area into its present saucer-shape seems to be intimately connected with the uplift of Madhupur Tract. Local tradition has it that the land sank 9 to 12m in the last 200 years. This area is still undergoing persistent subsidence. In addition to the hills located along the southern spur of the Shillong Massif, a number of hillocks, locally known as Tila, form minor but morphologically distinct, ranges around Sylhet in northeastern Bangladesh. These elevations, as for instance Kailas Tila, Dupi Tila and the tilas at Beanibazar, east of Sylhet, are generally built up of Plio-Pleistocene clastic sediments and reach maximum elevations of about 60m above MSL. It is regularly flooded during the monsoon.

Jamuna (Young Brahmaputra) Floodplain: A dual name is used for the mighty Brahmaputra, because the Jamuna channel is comparatively new and this course must be clearly distinguished from that of the older Brahmaputra. Before 1787, the Brahmaputra's course swung east to follow the course of the present Old Brahmaputra. In that year, apparently, a severe flood had the effect of turning the course southwards along the Jenai and Konai rivers to form the broad, braided Jamuna channel. The change in course seems to have been completed by 1830. Due to the uplift of the two large Pleistocene blocks of Barind and Madhupur, the zone of subsidence between those turned to a rift valley and became the new course of the Brahmaputra and came to be known as the great Jamuna. Both the left and right banks of the river are included in this sub-region. The Brahmaputra-Jamuna floodplain can again be subdivided into the Bangali-Karatoya floodplain, Jamuna-Dhaleshwari floodplain, and diyaras and chars.

The right-bank of the Jamuna - once a part of the Tista floodplain is part of the bigger floodplain. Several distributaries of the Jamuna flow through the left-bank floodplain, of which the Dhaleshwari is by far the largest and sub-classed, namely, the Jamuna-Dhaleshwari floodplain. The southern part of this sub-region was once a part of the Ganges floodplain. Along the Brahmaputra-Jamuna, as along the Ganges, there are many diyaras and chars. In fact, there are more of them along this channel than in any other river in Bangladesh. There is a continuous line of chars from where this river enters Bangladesh to the off-take point of Dhaleshwari River. Both banks are punctuated by a profusion of diyaras. The soil and topography of chars and diyaras vary considerably. Some of the largest ones have point bars and swales. The elevation between the lowest and highest points of these accretions may be as much as 5m. The difference between them and the higher levees on either bank can be up to 6m. Some of the ridges are shallowly flooded but most of the ridges and all the basins of this floodplain region are flooded more than 0.91m deep for about four months (mid-June to mid-October) during the monsoon.

Northern and Eastern Piedmont Plains: The unit is generally sloping piedmont plains border the northern and eastern hills; (similar piedmont plains adjoining the hills in Chittagong region have been included in the Chittagong coastal plain). These plains, which comprise coalesced alluvial fans, mainly have silty or sandy deposits near to the hills, grading into clays in the basin adjoining the neighbouring floodplains. The whole area is subject to flash floods during the rainy season. On the higher parts, flooding is mainly intermittent and shallow; but it is moderately deep or deep in the basin. The sub-region covers most or parts of the upazilas of Nalitabari (Sherpur), Tahirpur, Bishwamvarpur, Dowarabazar, Companiganj (Sylhet), Gowainghat, Madhabpur, Habiganj Sadar, Chunarughat, Sreemangal, Kamalganj and Kulaura.

Old Meghna Estuarine Floodplain: The landscape in this extensive unit is quite different from that on river and tidal floodplains. The relief is almost level, with little difference in elevation between ridges and basins. Natural rivers and streams are far apart in the southern part and drainage is provided by a network of man-made canals (khal). The sediments are predominantly deep and silty, but a shallow clay layer in some basin centres overlies them. Seasonal flooding is mainly deep, but it is shallow in the southeast. Some basin centres stay wet throughout the dry season. Virtually everywhere, this flooding is by rainwater ponded on the land when external rivers flow at high levels; the exceptions are the narrow floodplains alongside small rivers (such as the Gumti) which cross the unit from adjoining hill and piedmont areas.

Surma-Kushiyara Floodplain: This unit comprises the floodplain of rivers draining from the eastern border towards the Sylhet Basin (Haor Basin). Some small hill and piedmont areas near Sylhet are included within the boundaries. Elsewhere, the relief generally is smooth, comprising broad ridges and basins, but it is locally irregular alongside river channels. The soils are mainly heavy silts on the ridges and clays in the basins. This area is subject to flash floods in the pre-monsoon, monsoon and post-monsoon seasons, so the extent and depth of flooding can vary greatly within a few days. Normal flooding is mainly shallow on the ridges and deep in the basins.

Low Hill Ranges: The unit comparatively low hill ranges occur between and outside the high hill ranges. They are mainly formed over unconsolidated sandstone and shale. Their summits generally are <300m above MSL. Most areas are strongly dissected, with short steep slopes, but there are some areas with rolling to early-level relief (e.g. in the best tea-growing areas of Sylhet region). In the Sylhet region, there are four main hillocks in the northern zone and six hill ranges project into the south of Sylhet district from the Indian state of Tripura. These six ranges, which project into the plains from the south, are, from east to west, Patharia, Harargaj, Rajkandi-Ita, Bhanugach, Tarap and Raghunandan.

3.6 Hydro-geology of the Study Area

Hydrogeological parameters of the study area are governed by the litho-stratigraphic and prevailing tectonic activities, which is part of regional hydrogeological setting and tectonic features.

The haor areas are underlain by a thick sequence of Quaternary deposits (Mebius 2003). These Quaternary deposits and the Dupi Tila formation below constitute the potential aquifers. The areas have an aquifer system of semi-confined to confined types. Most of the areas are covered by alluvial clay and silt deposits of the Meghna River and its tributaries (Mebius 2003). The sediments are not as well sorted and uniform as the deposits of the Brahmaputra River to the west. The top silty clay layer of the system is relatively thick and the main aquifer is located at relatively greater depth below the land surface (MPO 1987). Generally, the alluvial deposits in the haor areas show rapid lithological changes, both vertically and laterally. Probably all Quaternary aquifers in the haor areas are of a local character (Mebius 2003). In Sunamganj district, a shallow alluvial aquifer is also available which is used for domestic water supplies with HTWs screened at 10-60 m below the land surface (Joarder et al. 2008). Irrigation wells typically tap deeper aquifers in the region at 70-100 m depth. The main aquifer of the haor areas has low transmissivity. The specific yield is also low in the central part of the haor basin. Irrigation development in the haor areas has been moderate, except for Sylhet where such development has been very low (Mondal 2015). A major part of this irrigation development has also been by using surface water based low lift pumps. Thus, groundwater use in the haor areas has been in general very low. However, in Baniachong and Ajmiriganj areas, a good number of DTWs are used to irrigate rabi crops. The groundwater recharge in the haor areas is high due to high rainfall, and extensive, deep and extended period of flooding. Even with a low level of groundwater development, there is some scattered evidence of groundwater mining in the haor areas. However, the evidence is not as strong as it is in the barind areas and could be due to the localized character of the aquifer. The presence of iron in groundwater is an acute problem for the haor areas. Except the Dharmapasha upazila, all other upazilas in the haor region have iron problem. All upazilas except Jagannathpur of Sunamganj district also have arsenic in groundwater exceeding the Bangladesh standard. Even the deeper aquifer in Chhatak and Sadar upazilas, where data was available from DTWs, have arsenic problem. The worst-affected upazilas are Derai, Dharmapasha and Jamalganj, where more than 50% hand/shallow tube wells contain arsenic exceeding the Bangladesh standard. All the upazilas of the haor region have a manganese problem in groundwater. The badly affected upazilas are Nabiganj, Baniachong, Bishwambarpur, Jagannathpur, Derai, Jamalganj and Companiganj. In addition to the above chemical quality concerns, there is also a major microbiological quality concern with the source water in the haor region as about 62% households of the Sylhet division fetch drinking water from sources containing E. coli bacteria over 1 cfu/100 mL (BBS 2015).

Limited information is available on the aquifer system in the hilly areas. The main aquifer in the north-eastern hilly region is of semi-confined to confined types and that in the south-eastern hilly region is of confined type. The hills in the north-east are overlain by Plio-Pleistocene and Holocene deposits (Mebius 2003). A prospective aquifer in the north-eastern hills is the highly weathered alluvial sands of the Dupi Tila formation (Hoque et al. 2003; Khan 2000; Mebius 2003). These sands are fine to medium grained and crop out in small hillocks in Sylhet and Maulavibazar districts and in some parts of Habiganj district. However, the permeability of these sands is lower than that of the alluvial deposits. The young gravelly sands also form a potential aquifer, although they are poorly sorted and contain large amounts of gravel and pebbles, making it difficult to use low-cost drilling techniques.

According to Rahman M. S. 2002, in the greater Sylhet area, aquifers are thinner and deeper, individual aquifer layers are less well sorted and often contain a higher proportion of fine sand. Existing stones, rocks and gas pockets make the aquifer conditions poorer. The whole of the upper aquifer sequence behaves as a single multiple aquifer system in which all the units are hydraulically connected. The thickness and extent of the aquifer layers are highly variable and unpredictable in the area. The overall lithology of the greater Sylhet is highly discontinuous in nature having less extensive to relatively extensive layers with poor to moderate yielding capacity aquifers.

According BWDB, 1986 the groundwater flow of the study area is mainly centralized in haor areas and the hydraulic gradient varies from 0.27 meter to 0.29 meter per kilometer. The maximum depth to groundwater table of the study area varies from 0.77 meter to 9 meter from land surface. Groundwater fluctuation of the area varies from 0.19 meter to 6 meter.

Analysis of present groundwater table data reveals that groundwater table varies from 0.23m to 15.03m in Sylhet, 0.52m to 8.70m in Habiganj, 0.61m to 7.10m in Sunamganj, 0.30m to 8.50m in Maulavibazar, 0.41m to 10.54m in Kishoreganj and 0.31m to 10.60m in Netrokona. It is observed that maximum groundwater table occurs during the month of March and April. Depth to groundwater table has been increased in the present condition with comparison to study conducted by BWDB, 1986. Countrywide historical groundwater table data was analyzed under CSIRO, 2014 study, they also founded the steady decline evident in the groundwater level in Sunamganj, Sylhet and Maulavibazar (CSIRO 2014).

Regional groundwater elevation contour map as shown in Figure 3-7 for dry season of 2015 has been prepared with for better understanding of regional flow direction. Water level data has been taken from Bangladesh Water Board (BWDB). In the mapped area groundwater is flowing mainly towards the central part (haor area) of the study area from neighboring area.

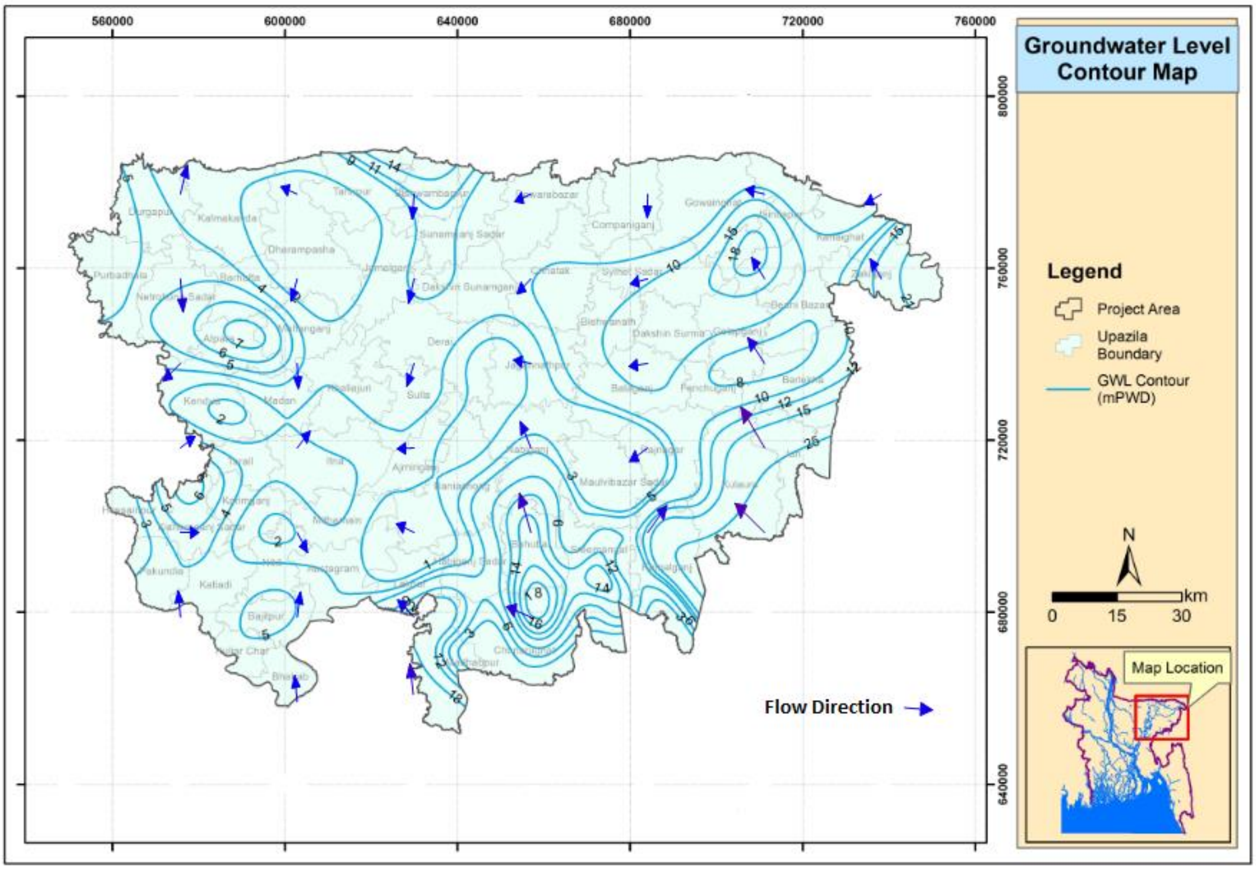


Figure 3-7: Groundwater Elevation Contour and Flow Direction Map of the Study Area (Dry Season, 2015)

3.7 Landuse Pattern

Since the depth of flooding is one of the major determining factors of the crop production practices, the cultivated area under different flood depth classifications regions the monsoon season of the study area is crucial. Rainfall runoff from the hills within and outside Bangladesh, rushes overland as well as through the rivers to the Haors. This results in flash floods characterized by rapid increase in flood levels during the pre-monsoon season and deep flooding in the monsoon season. The farmers have adjusted their crop production practices according to the mentioned hydrologic regime. The Soil Resources Development Institute (SRDI) prepared landuse maps of the country including the study area which shown in Figure 3-8. From Figure 3-8 it is shown that Boro and T. Aman are the major crops in the study area. Sylhet is famous for tea-producing area in the world. Out of 152 tea estates in the country, 130 are in Sylhet. These estates account for 93% of the total area and contribute 96% of the total tea production in Bangladesh (IWM 2009).

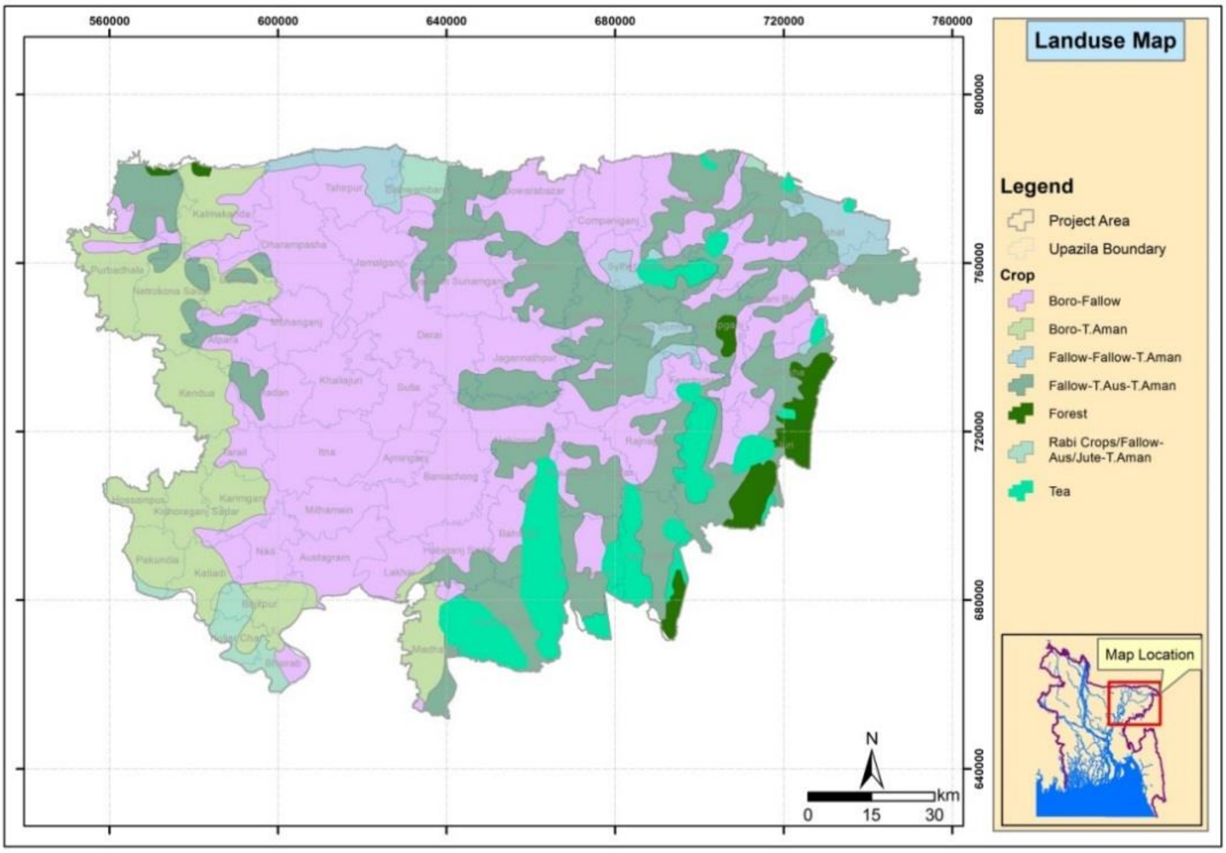


Figure 3-8: Landuse Pattern of the Study Area (SRDI 2005)

3.8 Soil Condition

The Soil Resources Development Institute (SRDI) prepared soil association maps of the country including the study area as shown in Figure 3-9. A general soil type of the project area may broadly be classified into four groups: flood plain soils, brown hilly soil, peat and terrace soils. Flood plain soil mainly consists of Silty Clay, Clay and Loamy soil texture.

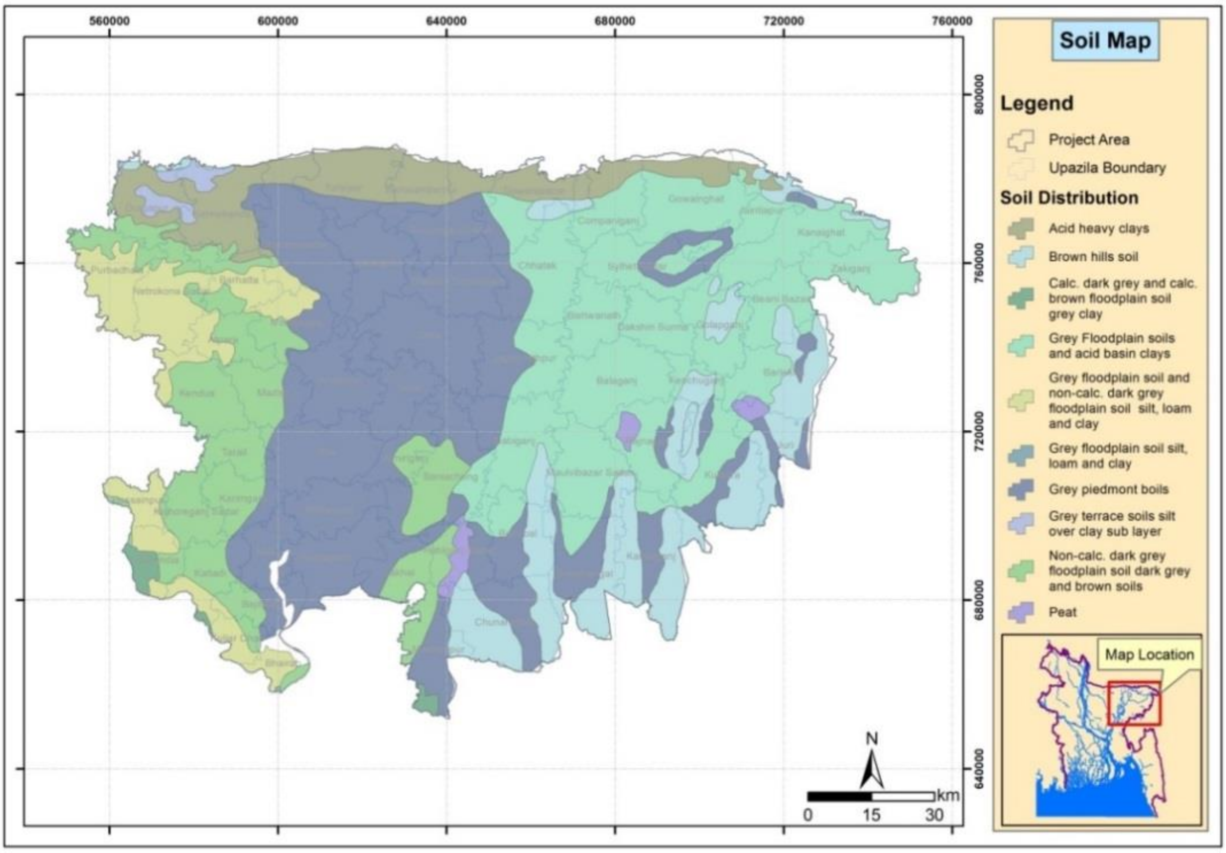


Figure 3-9: Soil Map of the Study Area (SRDI 1997)

3.9 Irrigation Practice

In the study area, surface water is being used mostly to expand irrigated area by LLPs for agricultural development since 1962. During the recent past years, groundwater use for irrigation has significantly been increased due to decrease of availability of surface water in the rivers flowing through the area during dry months. Groundwater is being extracted for irrigation mainly by Deep Tube Wells (DTW) and Shallow Tube Wells (STW). Flooding irrigation is practiced for both groundwater and surface water irrigation.

4 DATA COLLECTION AND PROCESSING

4.1 General

It is understood from review of the ToR, available reports, field visits and discussion with project officials that the aim of the proposed study is to explore the availability of both the surface water as well as groundwater to develop future irrigation expansion plan for proper management of water resources in an integrated manner. An integrated approach has been taken incorporating the land and water ecosystem, interaction between the surface and groundwater of the area to assess the availability of water resources. Prior to application of models for simulation, different data collected both from primary and secondary sources have been analyzed. Data collection and processing is required to understand and comprehend the following issues:

- Physical characteristics: topographical, hydrological, meteorological and hydrogeological variables.
- Performance of existing physical settings: irrigation canals, DTW and STW, various infrastructures etc.
- Inputs for the model: cross-section, rainfall, evaporation, water use, land use, surface water levels, river flows, groundwater levels, water use and demand, aquifer characteristics etc.
- Stakeholders' responses on development scenarios.
- Existing and future project operations.

Different type of data that has been collected under the proposed study have broadly classified into following groups:

- Hydro-meteorological
- Hydrogeological
- Agriculture and Soils
- Water Abstraction
- Seepage and Percolation
- Water Quality

Different organizations such as DBHWD, BMD, BWDB, BADC, DAE, SRDI and LGED are the secondary sources for these data and information. It has been observed that, some of the data are not sufficient while some are not available from secondary sources. To fulfill the study requirements, IWM has undertaken a field data collection programme. All secondary and primary data has been checked for quality and consistency using standard procedure. The following sections discusses the primary and secondary data collection and processing.

4.2 Secondary Data

Hydro-meteorological data that has been collected for the study includes rainfall, evaporation, temperature, relative humidity, sunshine hours. BWDB and BMD have very good data collection network in the area as shown in Figure 4-1. Existing historical data has been collected from BWDB, BMD and other relevant agencies. The central database of IWM also contains historical time-series data for all monitoring stations in Bangladesh maintained by BWDB.

Rainfall

The list of BWDB rainfall stations along with the data availability are given in Table 4-1. The available rainfall data have been collected from BWDB. In general, most of the stations contain long time series data. However, there are certain gaps in the data record, which has been duly filled in after carrying out necessary quality checking following the standard procedures of IWM Data Processing Manual (IWM Handbook). Quality checking of rainfall includes visual observation of plots of rainfall, preparation of double mass curves, estimation of yearly mean values, and comparison of monthly values. Double mass analysis reveals that rainfall data for most of the stations are consistent. After necessary consistency and quality checking, rainfall data has been used for the model development.

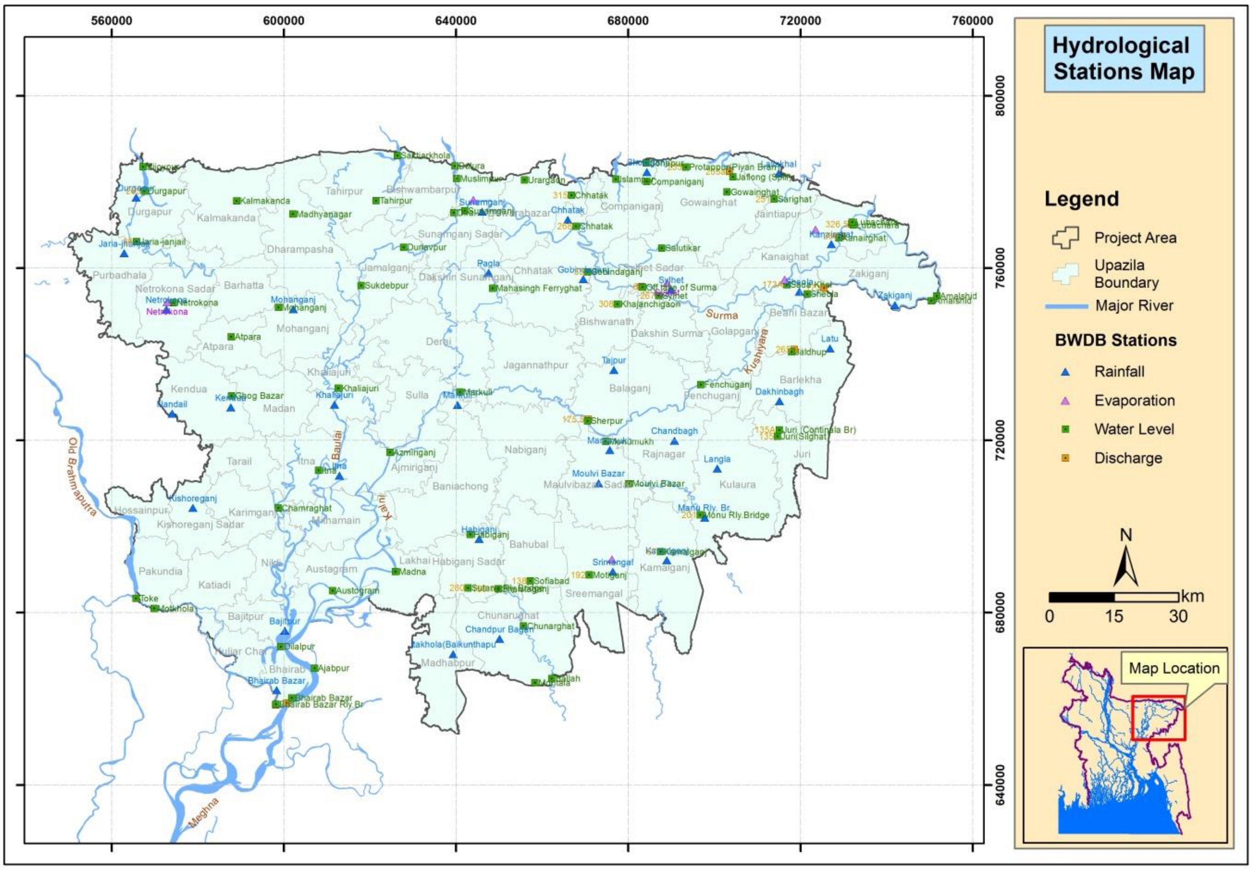


Figure 4-1: Hydrometeorological and Hydrological Stations in the Study Area

Table 4-1: List of Rainfall Stations of BWDB for the Study Area

SL No.	Station ID	Station Name	Data available	
			From	To
1	CL105	Chandpur Bagan	Apr-61	Dec-18
2	CL110	Habiganj	Apr-61	Dec-18
3	CL111	Itakhola (Baikunthapur)	Apr-61	Dec-18
4	CL120	Markuli	Apr-62	Dec-18
5	CL101	Bhairab Bazar	Apr-62	Dec-18
6	CL112	Itna	Apr-62	Dec-18
7	CL61	Bajitpur	Apr-62	Dec-18
8	CL71	Kishoreganj	Apr-61	Dec-18
9	CL104	Chandbagh	Apr-61	Dec-18
10	CL108	Dakhinbagh	May-61	Dec-18
11	CL114	Kamalganj	Apr-61	Dec-18
12	CL117	Langla	Apr-61	Dec-18
13	CL118	Latu	Apr-66	Dec-18
14	CL122	Moulvi Bazar	Apr-61	Dec-18
15	CL126	Srimangal	Apr-61	Dec-18
16	CL229	Manu Rly. Br.	Apr-85	Dec-18
17	CL113	Khaliajuri	Apr-62	Dec-18
18	CL115	Kendua	Jun-62	Dec-18
19	CL121	Mohanganj	Apr-62	Dec-18
20	CL123	Netrokona	Apr-61	Dec-18
21	CL63	Durgapur	Apr-61	Dec-18
22	CL68	Jaria-jhanjail	Apr-62	Dec-18
23	CL107	Chhatak	Apr-67	Dec-18
24	CL109	Gobindaganj	Apr-62	Dec-18
25	CL124	Pagla	Apr-62	Dec-18
26	CL127	Sunamganj	Apr-61	Dec-18
27	CL102	Bholaganj	Apr-62	Dec-18
28	CL116	Lallakhal	Apr-61	Dec-18
29	CL119	Manumukh	Apr-61	Dec-18
30	CL125	Sheola	Oct-62	Dec-18
31	CL130	Zakiganj	Apr-62	Dec-18
32	CL228	Kanairghat	Apr-84	Dec-18
33	CL64	Gafargaon	Apr-62	Dec-18
34	CL65	Goaripur	May-62	Dec-18
35	CL73	Mymensing	Apr-61	Dec-18
36	CL75	Nandail	Jun-62	Dec-18
37	CL77	Phulpur	Jun-62	Dec-18
38	CL103	Brahmanbaria	Apr-61	Dec-18
39	CL128	Sylhet	Apr-57	Dec-18
40	CL129	Tajpur	Apr-62	Dec-18
41	CL131	Sarail	Apr-64	Dec-18
42	CL132	Nasirnagar	Nov-61	Dec-18

Evaporation

Evaporation pans are subject to errors arising from intervention by cattle, birds and children, and the data must always be treated with due caution. BWDB maintains 6 evaporation stations in the vicinity of the project area. Information of this station is given in Table 4-2.

Table 4-2: List of Evaporation Stations for the Study Area

SL No.	Station ID	Station Name	Data available	
			From	To
1	E16	Jamalpur	Jan-1964	Dec-2018
2	E38	Sylhet	Jan-1964	Dec-2018
3	E37	Sunamganj	Jan-1964	Dec-2018
4	E26	Netrokona	Jan-1964	Dec-2018
5	E24	Mymensingh	Jan-1964	Dec-2018
6	E46	Shimrail	Jan-1975	Dec-2018

Groundwater Level

There are 152 nos. of BWDB groundwater monitoring wells located in the study area which have been monitored by BWDB for a long period of time. To fill up the data gap and comparison with the existing data available from secondary sources, 40 nos. of groundwater monitoring wells have been installed under this project. The list of all groundwater monitoring wells available from BWDB is given in Table 4-3.

After necessary quality checking these data has been used in groundwater model and various analyses have been carried out for evaluating seasonal variation, regional fluctuation and flow dynamics of groundwater in the study area.

Table 4-3: List of Groundwater Level Monitoring Stations for the Study Area

Sl. No.	Station ID	Source	Data Available	
			From	To
1	GT5814001	BWDB	Jan-79	Dec-18
2	GT5814002	BWDB	Jan-79	Dec-18
3	GT5814003	BWDB	Jan-79	Dec-18
4	GT5856004	BWDB	Jan-79	Dec-18
5	GT5856005	BWDB	Jan-79	Dec-18
6	GT5856006	BWDB	Jan-79	Dec-18
7	GT5856007	BWDB	Jan-79	Dec-18
8	GT5856008	BWDB	Jan-79	Dec-18
9	GT5856009	BWDB	Jan-79	Dec-18
10	GT5856010	BWDB	Jan-79	Dec-18
11	GT5865011	BWDB	Jan-79	Dec-18
12	GT5865012	BWDB	Jan-79	Dec-18
13	GT5865013	BWDB	Jan-79	Dec-18

Sl. No.	Station ID	Source	Data Available	
			From	To
14	GT5865014	BWDB	Jan-79	Dec-18
15	GT5865015	BWDB	Jan-79	Dec-18
16	GT5865016	BWDB	Jan-79	Dec-18
17	GT5865017	BWDB	Jan-95	Dec-18
18	GT5865018	BWDB	Jan-95	Dec-18
19	GT5865019	BWDB	Jan-79	Dec-18
20	GT5865020	BWDB	Jan-79	Dec-18
21	GT5865021	BWDB	Jan-80	Dec-18
22	GT5865022	BWDB	Jan-79	Dec-18
23	GT5874023	BWDB	Jan-87	Dec-18
24	GT5874024	BWDB	Jan-79	Dec-18
25	GT5874025	BWDB	Jan-79	Dec-18
26	GT5874026	BWDB	Feb-81	Dec-18
27	GT5880028	BWDB	Jan-79	Dec-18
28	GT5883030	BWDB	Jan-79	Dec-18
29	GT5883031	BWDB	Jan-79	Dec-18
30	GT5883032	BWDB	Jan-79	Dec-18
31	GT5883033	BWDB	Jan-79	Dec-18
32	GT5883034	BWDB	Jan-79	Dec-18
33	GT5883035	BWDB	Jan-79	Dec-18
34	GT5883036	BWDB	Jan-79	Dec-18
35	GT5883037	BWDB	Jan-79	Dec-18
36	GT5883038	BWDB	Jan-79	Dec-18
37	GT5883039	BWDB	Jan-79	Dec-18
38	GT5883040	BWDB	Jan-79	Dec-18
39	GT3602001	BWDB	Jan-76	Dec-18
40	GT3605002	BWDB	Jan-70	Dec-18
41	GT3605003	BWDB	Mar-77	Dec-18
42	GT3611004	BWDB	Oct-75	Dec-18
43	GT3611005	BWDB	Oct-75	Dec-18
44	GT3611006	BWDB	Jan-78	Dec-18
45	GT3626007	BWDB	Jan-70	Dec-18
46	GT3626008	BWDB	Jan-70	Dec-18
47	GT3626009	BWDB	Jan-70	Dec-18
48	GT3626010	BWDB	Jan-70	Dec-18
49	GT3626011	BWDB	Jan-70	Dec-18
50	GT3626012	BWDB	Jan-70	Dec-18
51	GT3644013	BWDB	Feb-94	Dec-18
52	GT3668014	BWDB	Jan-94	Dec-18
53	GT3671015	BWDB	Jan-94	Dec-18
54	GT3671016	BWDB	Jan-94	Dec-18
55	GT3671017	BWDB	Jan-94	Dec-18
56	GT3671018	BWDB	Jan-94	Dec-18
57	GT3671019	BWDB	Jan-94	Dec-18

Sl. No.	Station ID	Source	Data Available	
			From	To
58	GT3671020	BWDB	Jan-94	Dec-18
59	GT3671021	BWDB	Jan-94	Dec-18
60	GT3677022	BWDB	Jan-94	Dec-18
61	GT4802001	BWDB	Jan-71	Dec-18
62	GT4802002	BWDB	May-77	Dec-18
63	GT4805003	BWDB	Jan-70	Dec-18
64	GT4805004	BWDB	Apr-76	Dec-18
65	GT4805005	BWDB	Jul-76	Dec-18
66	GT4811006	BWDB	May-76	Dec-18
67	GT4811007	BWDB	Apr-76	Dec-18
68	GT4827008	BWDB	Jan-70	Dec-18
69	GT4827009	BWDB	Sep-75	Dec-18
70	GT4833010	BWDB	Jan-71	Dec-18
71	GT4833011	BWDB	Apr-76	Dec-18
72	GT4842012	BWDB	Jan-70	Dec-18
73	GT4842013	BWDB	May-76	Dec-18
74	GT4845014	BWDB	Jan-70	Dec-18
75	GT4845015	BWDB	Jan-70	Dec-18
76	GT4849016	BWDB	Jan-70	Dec-18
77	GT4849017	BWDB	May-76	Dec-18
78	GT4849018	BWDB	Jun-76	Dec-18
79	GT4849019	BWDB	Jan-70	Dec-18
80	GT4854020	BWDB	May-76	Dec-18
81	GT4854021	BWDB	Jan-70	Dec-18
82	GT4876022	BWDB	Apr-74	Dec-18
83	GT4876023	BWDB	May-76	Dec-18
84	GT4876024	BWDB	Jul-76	Dec-18
85	GT4876025	BWDB	Jan-70	Dec-18
86	GT4879026	BWDB	Mar-76	Dec-18
87	GT4879027	BWDB	Apr-76	Dec-18
88	GT4879028	BWDB	Jan-71	Dec-18
89	GT4892029	BWDB	Jan-71	Dec-18
90	GT7204001	BWDB	Jan-70	Dec-18
91	GT7209002	BWDB	Jan-70	Dec-18
92	GT7218003	BWDB	Sep-75	Dec-18
93	GT7218004	BWDB	Jul-74	Dec-18
94	GT7238010	BWDB	Apr-76	Dec-18
95	GT7238011	BWDB	Jan-71	Dec-18
96	GT7240005	BWDB	Jan-75	Dec-18
97	GT7240006	BWDB	Oct-75	Dec-18
98	GT7240007	BWDB	Oct-75	Dec-18
99	GT7247008	BWDB	Feb-74	Dec-18
100	GT7247009	BWDB	Dec-74	Dec-18
101	GT7256012	BWDB	Sep-75	Dec-18

Sl. No.	Station ID	Source	Data Available	
			From	To
102	GT7256013	BWDB	Oct-75	Dec-18
103	GT7263014	BWDB	Feb-74	Dec-18
104	GT7263015	BWDB	Oct-75	Dec-18
105	GT7263016	BWDB	Jul-77	Dec-18
106	GT7263017	BWDB	Jan-70	Dec-18
107	GT7274018	BWDB	Feb-74	Dec-18
108	GT7274019	BWDB	Feb-75	Dec-18
109	GT7274020	BWDB	Jan-80	Dec-18
110	GT7274021	BWDB	Jan-70	Dec-18
111	GT7283022	BWDB	Jan-70	Dec-18
112	GT7283023	BWDB	Jan-75	Dec-18
113	GT9023001	BWDB	Jan-75	Dec-18
114	GT9023002	BWDB	Oct-75	Dec-18
115	GT9023003	BWDB	Jun-76	Dec-18
116	GT9029004	BWDB	Jan-76	Dec-18
117	GT9047005	BWDB	Sep-76	Dec-18
118	GT9047006	BWDB	Jun-76	Dec-18
119	GT9047007	BWDB	Jan-81	Dec-18
120	GT9050008	BWDB	Jan-76	Dec-18
121	GT9050009	BWDB	Apr-77	Dec-18
122	GT9050010	BWDB	Feb-79	Dec-18
123	GT9089011	BWDB	Jun-75	Dec-18
124	GT9089012	BWDB	Jun-76	Dec-18
125	GT9092013	BWDB	Jan-78	Dec-18
126	GT9108001	BWDB	Jun-75	Dec-18
127	GT9108002	BWDB	May-76	Dec-18
128	GT9108003	BWDB	May-76	Dec-18
129	GT9117004	BWDB	Jan-70	Dec-18
130	GT9117005	BWDB	Jan-75	Dec-18
131	GT9120006	BWDB	May-76	Dec-18
132	GT9127007	BWDB	Apr-77	Dec-18
133	GT9135008	BWDB	Jan-70	Dec-18
134	GT9138009	BWDB	Jan-70	Dec-18
135	GT9138010	BWDB	Sep-76	Dec-18
136	GT9141011	BWDB	Jan-70	Dec-18
137	GT9141012	BWDB	Sep-79	Dec-18
138	GT9141013	BWDB	Sep-79	Dec-18
139	GT9141014	BWDB	Jan-75	Dec-18
140	GT9141015	BWDB	Jan-78	Dec-18
141	GT9153016	BWDB	Jan-75	Dec-18
142	GT9153017	BWDB	Jan-75	Dec-18
143	GT9159018	BWDB	May-76	Dec-18
144	GT9159019	BWDB	Apr-77	Dec-18
145	GT9162020	BWDB	Jan-70	Dec-18

Sl. No.	Station ID	Source	Data Available	
			From	To
146	GT9162021	BWDB	Jan-70	Dec-18
147	GT9162022	BWDB	Jan-70	Dec-18
148	GT9162023	BWDB	Jan-70	Dec-18
149	GT9162024	BWDB	Jan-75	Dec-18
150	GT9162025	BWDB	May-76	Dec-18
151	GT9162026	BWDB	Jan-81	Dec-18
152	GT9194027	BWDB	Jan-75	Dec-18

Data have been checked for consistency following the standard procedures of IWM Handbook. A sample plot of groundwater level and along with daily rainfall data is shown in Figure 4-2.

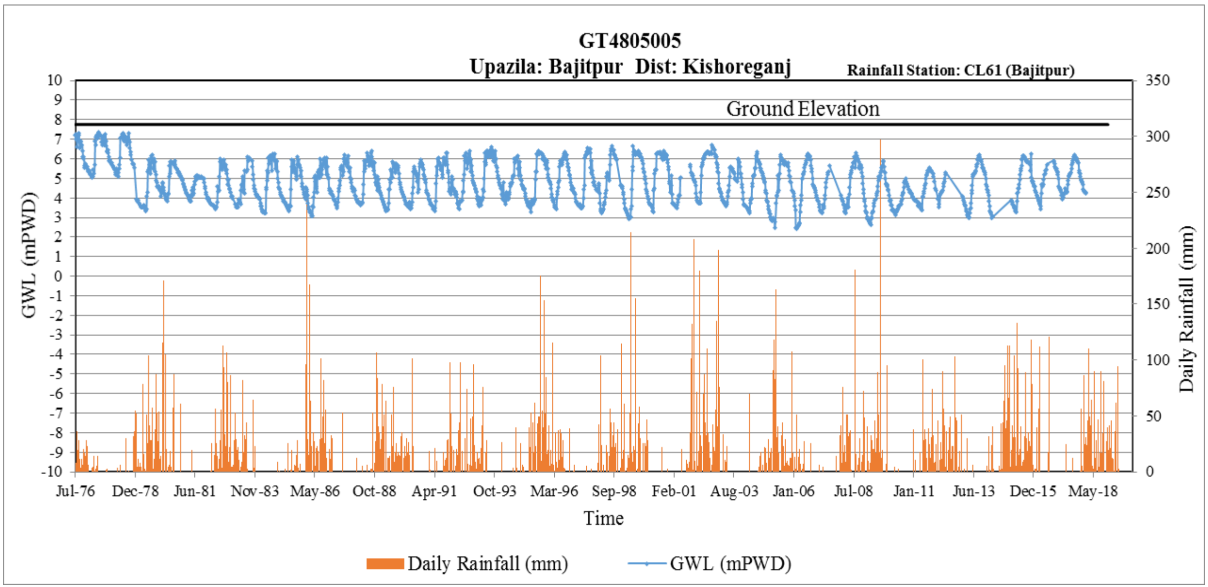


Figure 4-2: A Sample Plot of Groundwater Level Data at Bajitpur for GT 4805005

Surface Water Level

There are 57 nos. of BWDB surface water monitoring stations available in the study area as shown in Table 4-4. After necessary quality checking, these data have been used in surface water model setup and various analyses have been carried out for evaluating seasonal variation and trend analysis.

Table 4-4: List of Surface Water Level Stations for the Study Area

Sl. No.	Station ID	Station Name	River Name	Data Available	
				From	To
1	SW138	Sofiabad	Korangi	Apr-97	Dec-18
2	SW157	Ballah	Khowai	Jan-99	Dec-18
3	SW158	Chunarghat	Khowai	Jan-96	Dec-18
4	SW158.1	Shaistaganj	Khowai	Jan-97	Dec-18
5	SW159	Habiganj	Khowai	Jan-96	Dec-18

Sl. No.	Station ID	Station Name	River Name	Data Available	
				From	To
6	SW264A	Montala	Sonai	Jan-99	Dec-18
7	SW272	Madna	Lower Meghna	Jan-95	Dec-18
8	SW280	Sutang Rly.Bridge	Sutang	Jan-97	Dec-18
9	SW230.1	Bhairab Bazar Rly Bridge	Old Brahmaputra	Jan-96	Dec-18
10	SW271	Azmiriganj	Upper Meghna	Apr-95	Dec-18
11	SW272.1	Austagram	Upper Meghna	Jan-95	Dec-18
12	SW273	Bhairb Bazar	Upper Meghna	Jan-95	Dec-18
13	SW311.4	Chamraghat	Meghna	Jul-96	Dec-18
14	SW73	Itna	Dhanu-Boulai Ghorutrautra	Jan-96	Dec-18
15	SW74	Dilalpur	Dhanu-Boulai Ghorutrautra	Jan-96	Dec-18
16	SW135	Juri Branch (Silghat)	Juri	Jan-04	Dec-18
17	SW135A	Juri (Continala Bridge)	Juri	Jan-93	Dec-18
18	SW192	Motiganj	Lungla	Apr-96	Dec-18
19	SW201	Monu Rly.Bridge	Monu	Apr-96	Dec-18
20	SW202	Moulvi Bazar	Monu	Apr-96	Dec-18
21	SW67	Kamalganj	Dhalai	Apr-96	Dec-18
22	SW262	Bijoypur	Someswari	Apr-96	Dec-18
23	SW263	Durgapur	Someswari	Apr-96	Dec-18
24	SW263.1	Kalmakanda	Someswari	Apr-96	Dec-18
25	SW310	Netrokona	Mogra	Apr-96	Dec-18
26	SW311	Atpara	Mogra	Apr-96	Dec-18
27	SW344	Ghog Bazar	Baruni	Jul-96	Dec-18
28	SW36	Jaria-janjail	Bhogai-Kangsa	Apr-96	Dec-18
29	SW36.1	Mohanganj	Bhogai-Kangsa	Apr-96	Dec-18
30	SW72	Khaliajuri	Dhanu-Boulai Ghorutrautra	Jan-95	Dec-18
31	SW131.5	Laurergarh Saktiarkhola	Jadukata	Apr-96	Dec-18
32	SW268	Chhatak	Surma-Meghna	Apr-96	Dec-18
33	SW269	Sunamganj	Surma-Meghna	Apr-96	Dec-18
34	SW269.5	Dirai	Jhalu Khali	Apr-96	Dec-18
35	SW270	Markuli	Lower Meghna	Jan-95	Dec-18
36	SW33	Gobindaganj	Bhattakhal	Apr-97	Dec-18
37	SW333	Muslimpur	Julakhali	Apr-96	Dec-18
38	SW333A	Dulura	Jhalu Khali	Jul-97	Dec-18
39	SW337	Urargaon	Noyagang	Apr-96	Dec-18
40	SW345	Durlavpur	Dhanu	Jul-97	Dec-18
41	SW72B	Sukdebpur	Dhanu-Boulai	Apr-96	Dec-18
42	SW172.5	Amalshid	Kushiyara	Apr-96	Dec-18
43	SW173	Sheola	Kushiyara	Apr-96	Dec-18

Sl. No.	Station ID	Station Name	River Name	Data Available	
				From	To
44	SW174	Fenchuganj	Kushiyara	Apr-96	Dec-18
45	SW175.5	Sherpur	Kushiyara	Apr-96	Dec-18
46	SW233	Protappur (Piyan Bran)	Piyan	Apr-96	Dec-18
47	SW233A	Jaflong (Spill)	Piyan (Dauki)	Apr-96	Dec-18
48	SW234	Companiganj	Piyan	May-96	Dec-18
49	SW251	Sarighat	Sari-Gowain	Apr-96	Dec-18
50	SW252	Gowainghat	Sari-Gowain	Apr-96	Dec-18
51	SW252.1	Salutikar	Sari-Gowain	Apr-96	Dec-18
52	SW265	Jaldhup	Sonai-Bardal	Apr-96	Dec-18
53	SW266	Kanairghat	Surma-Meghna	Apr-96	Dec-18
54	SW267	Sylhet	Surma-Meghna	Apr-96	Dec-18
55	SW326	Lubachara	Lubachara	Jul-92	Dec-18
56	SW332	Islampur	Dhala	Apr-96	Dec-18
57	SW341	Sonapur	Omayan Chella	Apr-96	Dec-18

Discharge Data

Discharge data have been collected for 33 locations to define the boundary conditions of the surface water model as well as to calibrate the hydrodynamic model. Details of the availability of data are shown in the Table 4-5.

Table 4-5: List of Discharge Measurement Stations for the Study Area

Sl. No.	Station ID	Station Name	River Name	Data Available	
				From	To
1	SW138	Sofiabad	Korangi	Apr-64	Dec-18
2	SW158.1	Shaistaganj	Khowai	Jun-64	Dec-18
3	SW264A	Montala	Sonai	Jun-88	Dec-18
4	SW280	Sutang Rly.Bridge	Sutang	Apr-64	Dec-18
5	SW230.1	Bhairab Bazar Rly Bridge	Old Brahmaputra	Jun-79	Dec-18
6	SW273	Bhairb Bazar	Upper Meghna	Jun-64	Dec-18
7	SW262	Bijoypur	Someswari	Jan-97	Dec-18
8	SW263	Durgapur	Someswari	Jul-65	Dec-18
9	SW36	Jaria-janjail	Bhogai-Kangsa	Apr-64	Dec-18
10	SW131	Saktiarkhola	Jadukata	Apr-88	Dec-18
11	SW131.5	Laurergarh Saktiarkhola	Jadukata	Apr-93	Dec-18
12	SW269	Sunamganj	Surma-Meghna	Jan-01	Dec-18
13	SW33	Gobindaganj	Bhattakhal	Apr-64	Dec-18
14	SW333	Muslimpur	Julakhali	Apr-88	Dec-18
15	SW333A	Dulura	Jhalu Khali	Nov-06	Dec-18
16	SW337	Urargaon	Noyagang	May-92	Dec-18

Sl. No.	Station ID	Station Name	River Name	Data Available	
				From	To
17	SW135	Juri Branch (Silghat)	Juri	Jan-12	Dec-18
18	SW135A	Juri (Continala Bridge)	Juri	Apr-64	Dec-18
19	SW192	Motiganj	Lungla	Apr-64	Dec-18
20	SW201	Monu Rly.Bridge	Monu	Apr-64	Dec-18
21	SW67	Kamalganj	Dhalai	Apr-64	Dec-18
22	SW173	Sheola	Kushiyara	Apr-64	Dec-18
23	SW175.5	Sherpur	Kushiyara	Apr-82	Dec-18
24	SW233	Protappur (Piyan Bran)	Piyan	Apr-88	Dec-18
25	SW233A	Jaflong (Spill)	Piyan (Dauki)	Apr-96	Dec-18
26	SW251	Sarighat	Sari-Gowain	Apr-65	Dec-18
27	SW265	Jaldhup	Sonai-Bardal	Apr-64	Dec-18
28	SW266	Kanairghat	Surma-Meghna	Apr-69	Dec-18
29	SW267	Sylhet	Surma-Meghna	Apr-64	Dec-18
30	SW326	Lubachara	Lubachara	Aug-01	Dec-18
31	SW332	Islampur	Dhala	Apr-88	Dec-18
32	SW341	Sonapur	Omayan Chella	Apr-92	Dec-18
33	SW6	Off take of Surma	Bahia	Apr-64	Dec-18

Bore Log Data

The occurrence and storage of groundwater are generally governed by sedimentary structure, lithology, thickness and depth of different aquifers. Subsurface lithological characterization of the model area and configuration of the hydro stratigraphic units for groundwater flow model has been prepared by analyzing these parameters. For assessing the aquifer geometry of different aquifer systems exist in and around the study area, 556 nos. of litholog data have been collected from BADC, BWDB and DPHE to define the regional geology of the model area as shown in Table 4-6. The depth of collected data varies from the depth of 26m to 300m and most of the data are with 100m to 200m as shown in Figure 4-3.

Table 4-6: Sources of Borehole Data

Sl. No.	District	Well Number	BADC	BWDB	DPHE
1	Habiganj	89	30	30	29
2	Maulavibazar	52	13	12	27
3	Sylhet	102	31	25	46
4	Sunamganj	37	0	3	34
5	Kishoreganj	181	13	85	83
6	Netrokona	95	16	72	7
Total		**556**	**103**	**227**	**226**

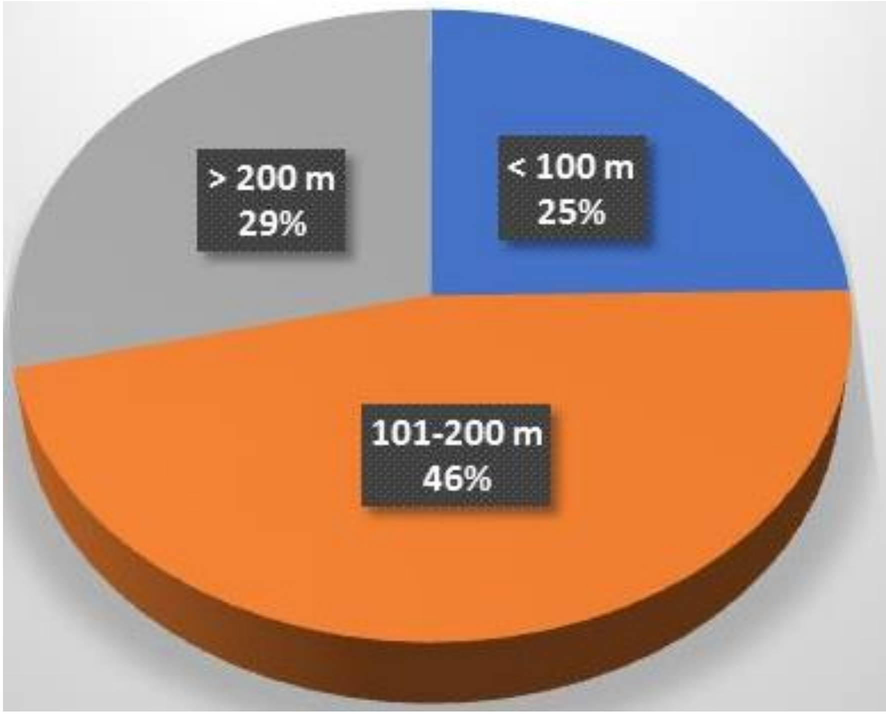


Figure 4-3: Depth Variation of Collected Bore Log Data

Landuse Pattern

Since the depth of flooding is one of the major determining factors of the crop production practices, the cultivated area under different flood depth classifications regions the monsoon season of the study area is crucial. Rainfall runoff from the hills within and outside Bangladesh, rushes overland as well as through the rivers to the Haors. This results in flash floods characterized by rapid increase in flood levels during the pre-monsoon season and deep flooding in the monsoon season. The farmers have adjusted their crop production practices according to the mentioned hydrologic regime. The Soil Resources Development Institute (SRDI) prepared landuse maps of the country including the study area which shown in Figure 4-4. From Figure 4-4 it is shown that Boro and T. Aman are the major crops in the study area. Sylhet is famous for tea-producing area in the world. Out of 152 tea estates in the country, 130 are in Sylhet. These estates account for 93% of the total area and contribute 96% of the total tea production in Bangladesh (IWM 2009).

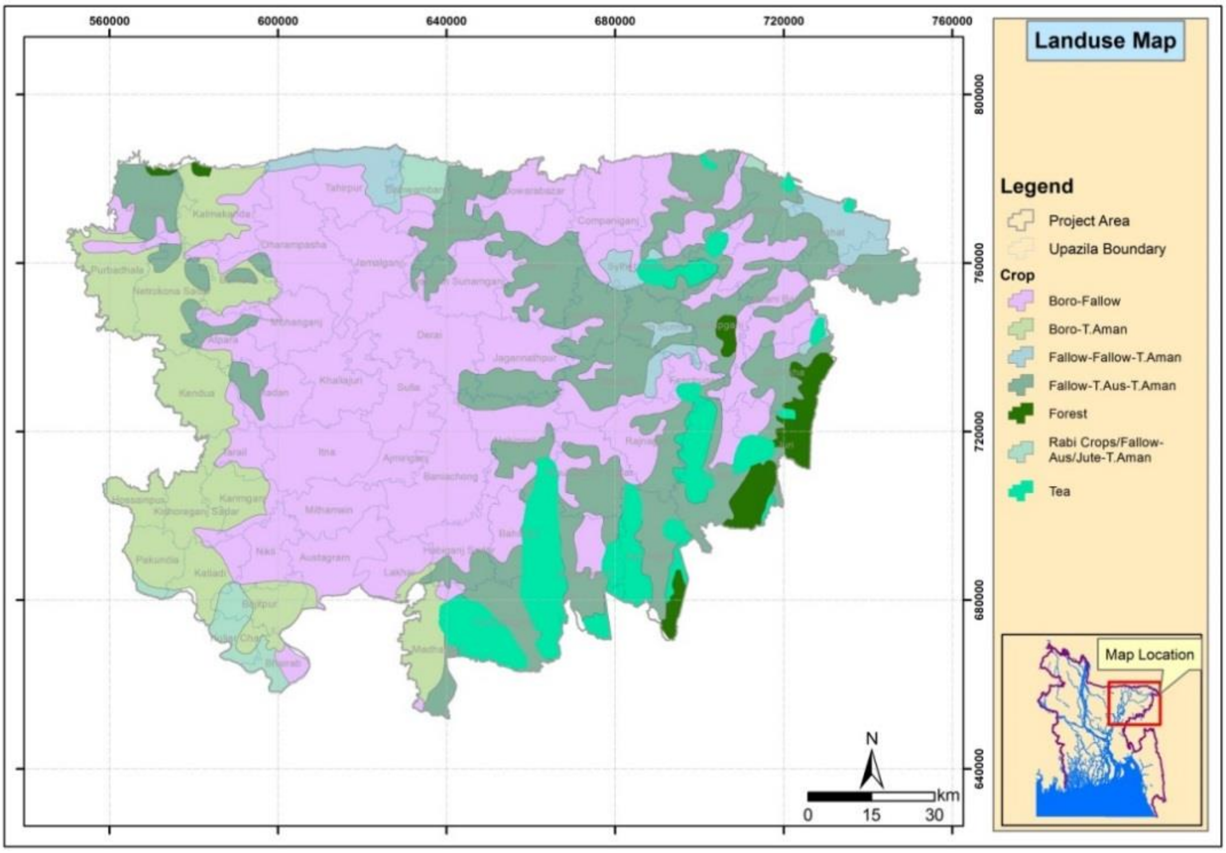


Figure 4-4: Landuse Pattern of the Study Area (SRDI 2005)

Soil Condition

The Soil Resources Development Institute (SRDI) prepared soil association maps of the country including the study area as shown in Figure 4-5. In general soil type of the study area may broadly be classified into four groups: flood plain soils, brown hilly soil, peat and terrace soils. Flood plain soil mainly consists of Silty Clay, Clay and Loamy soil texture.

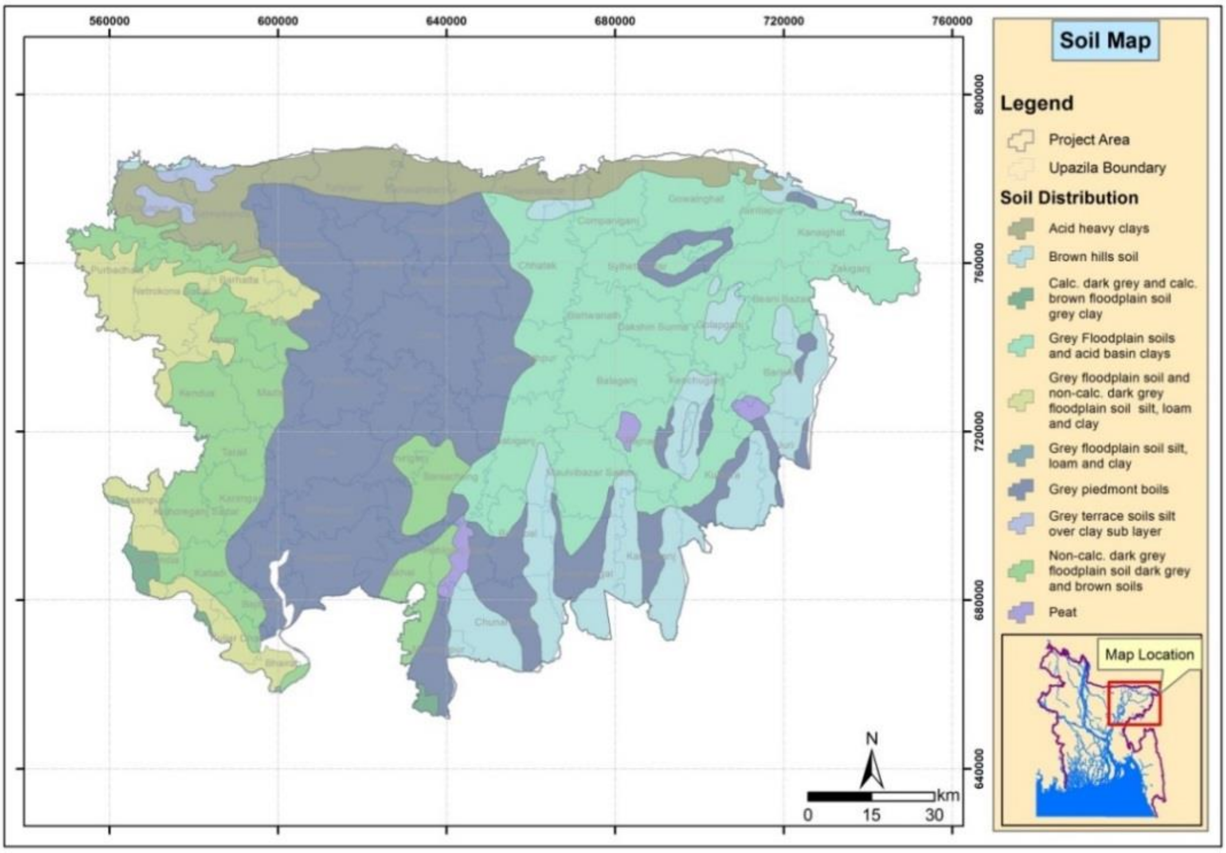


Figure 4-5: Soil Map of the Study Area (SRDI 1997)

Preparation of Digital Elevation Model (DEM)

A total of 139 nos. of digital sheets of topographical and basic map have been collected from Survey of Bangladesh (SoB) for the study area. All these sheets are produced in 1:25000 and thirteen numbers of feature layers in digital form. The Contour and Spot point layers are utilized for preparing the DEM which is shown in Figure 4-6.

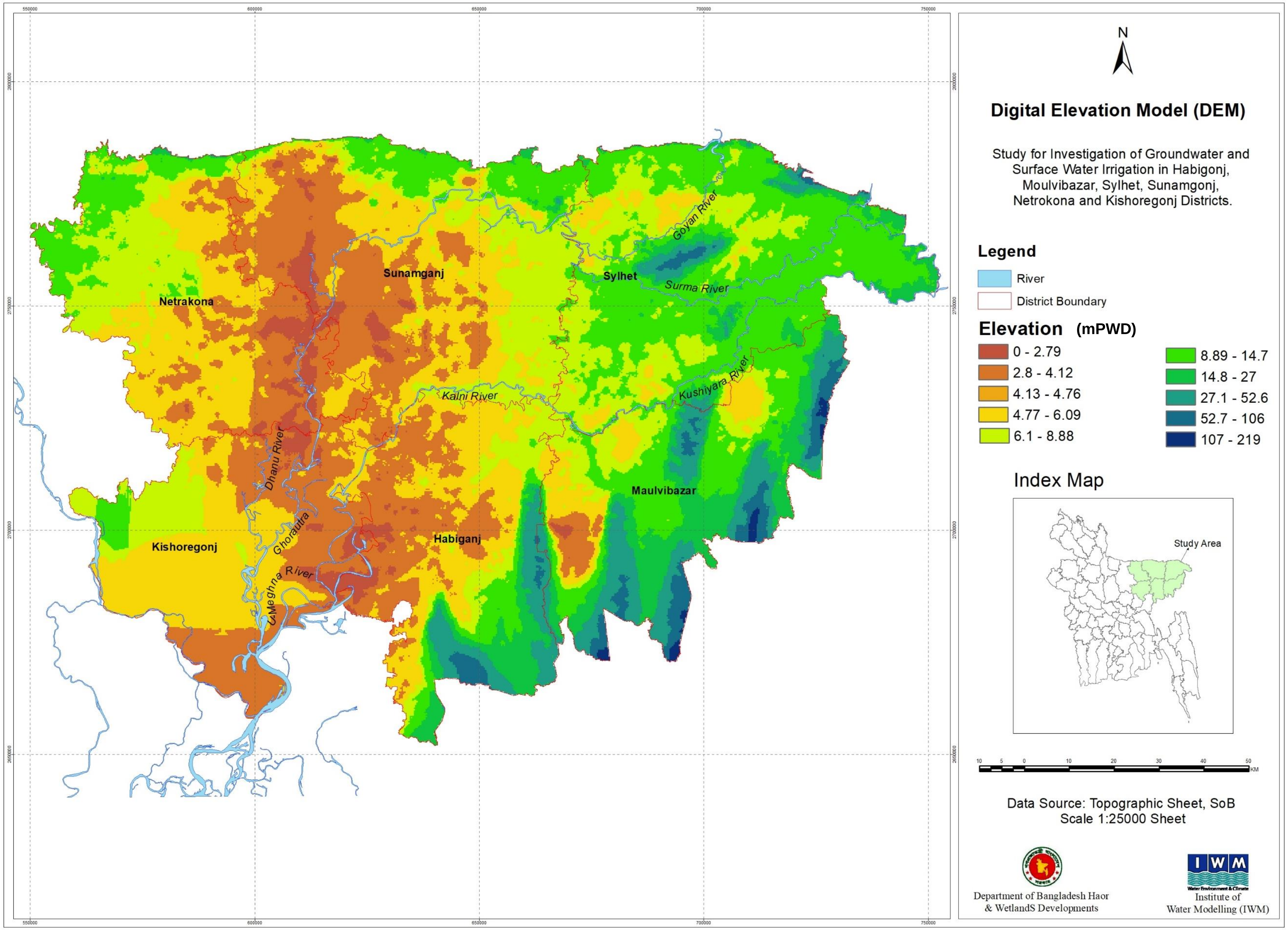


Figure 4-6: Digital Elevation Model (DEM) of the Project Area

4.3 Primary Data

Existing hydro-geological data that includes groundwater level, lithologs and aquifer properties has been collected from available secondary sources. In addition, to fulfill the data gap, IWM has initiated a comprehensive hydrogeological investigation program that includes (i) Exploratory drilling (ii) Installation of groundwater monitoring wells (iii) Monitoring of groundwater level (iv) Construction of production well (v) Aquifer test (vi) Seepage and Percolation measurement (vii) Geophysical survey and (viii) Water quality sampling and analysis.

4.3.1 Exploratory Drilling and Installation of Monitoring Well

Exploratory drilling and installation of monitoring well have been started in January 2017 and completed the works accordingly. Forty nos. of exploratory drilling and monitoring wells installation have been conducted in the study area. The list of exploratory drilling and monitoring well locations are given in the Table 4-7 and in the Figure 4-7. The target drilling depth was about 200m, which may vary based on probable depth of the aquifer. During exploratory drilling washed sediment samples have been collected at 3m interval and preserved as shown in Figure 4-8. A sample plot of monitoring well design with lithology has been shown in Figure 4-9 and other analysis have been given in Volume-II, Appendix A. The water jetting or direct circulation method has been used for exploratory drilling considering the work volume, time and sedimentary nature of the subsurface formation of the study area.

Table 4-7: List of Exploratory Drilling and Monitoring Well

Sl No	District	Upazila	Union	Village	Well ID	Latitude	Longitude
1	Habiganj	Lakhai	Karab	Karab	HGLH1	24.32628	91.33452
2	Habiganj	Madhabpur	Adair	Baksayed	HGMP2	24.1219	91.32177
3	Habiganj	Chunarughat	Deorgach	Deorgach	HGCG3	24.17532	91.50758
4	Habiganj	Habiganj	Nizampur	Dhuliakhal	HGHG4	24.32432	91.43673
5	Habiganj	Bahubal	Satkapan	Cholitala Bari	HGBB5	24.35667	91.54271
6	Habiganj	Nabiganj	Kurshi	Kurshi	HGNG6	24.58925	91.58428
7	Habiganj	Baniachong	Baniachong	Tatarpara	HGBC7	24.50088	91.37142
8	Maulavibazar	Sreemangal	Ashidron	Tikria Bichot	MBSM1	24.27957	91.72337
9	Maulavibazar	Moulvibazar	Kanakpur	Damia	MBMB2	24.4984	91.71597
10	Moulvibazar	Kulaura	Joychandi	Pushainagar	MBKU3	24.53927	92.05106
11	Moulvibazar	Kamalganj	Rahimpur	Lakshmipur	MBKG4	24.43866	91.83637
12	Moulvibazar	Rajnagar	Rajnagar	Bhabanipur	MBRN5	24.54475	91.87595
13	Sunamganj	Dowarabazar	Mannargaon	Jalalpur	SGDB1	25.06158	91.51382
14	Sunamganj	Sunamganj	Lakshmansree	Jogirgaon	SGSG2	25.01199	91.37943
15	Sunamganj	Chhatak	Uttar Khurma	Tokirai	SGCT3	24.93898	91.655
16	Sunamganj	Bishwambarpur	Palash	Palashgaon	SGBP4	25.11931	91.33597
17	Sunamganj	Jagannathpur	Jagannathpur	Habibnagar	SGJP5	24.76198	91.55111
18	Sunamganj	Derai	Karimpur	Notun	SGDR6	24.82883	91.36012
19	Sunamganj	Jamalganj	Bhimkhali	Noagaon	SGJG7	24.97603	91.29085

Sl No	District	Upazila	Union	Village	Well ID	Latitude	Longitude
20	Sunamganj	Dharmapasha	Paikurati		SGDP8	24.97294	90.97958
21	Sylhet	Beani Bazar	Bara Mollahpur		SYBB1	24.8033	92.16131
22	Sylhet	Balaganj	Goula Bazar	Brahmangram	SYBG2	24.69414	91.72644
23	Sylhet	Sylhet	Daudpur	Noikhai	SYSY3	24.81058	91.91082
24	Sylhet	Golabganj	Golabganj	Rankali	SYGG4	24.85619	92.02802
25	Sylhet	Jaintiapur	Darbasta	Mahalikhala	SYJP5	25.0609	92.13695
26	Sylhet	Kanaighat	Kanaighat	Dharmapur	SYKG6	25.0027	92.24182
27	Kishoreganj	Karimganj	Niamatpur	Duliakanda	KGKM1	24.48859	90.95266
28	Kishoreganj	Katiadi	Shahasram Dhuldia	Gachihata	KGKT2	24.34072	90.82986
29	Kishoreganj	Kuliar Char	Kuliar Char	Singla	KGKC3	24.14935	90.90418
30	Kishoreganj	Tarail	Tarail Sachail	Sachail	KGTR4	24.54369	90.88998
31	Kishoreganj	Hossainpur	Hossainpur	Purba Depashar	KGHP5	24.41414	90.65659
32	Kishoreganj	Pakundia	Pakundia	Pakundia Modhapara	KGPD6	24.33611	90.68646
33	Kishoreganj	Bajitpur	Bajitpur	Pollanpur	KGBJ7	24.21596	90.94367
34	Netrokona	Durgapur	Birisiri	Telunjia	NTDP1	25.10097	90.67022
35	Netrokona	Purbadhala	Gohalakanda	Kismat Barenga	NTPD2	24.85294	90.6149
36	Netrokona	Netrokona	Thakurakona	Barni	NTNT3	24.9246	90.7858
37	Netrokona	Barhatta	Sahata	Swalpa Dashal	NTBH4	24.90423	90.86642
38	Netrokona	Madan	Jahangirpur	Chandgaon	NTMD5	24.70863	90.94189
39	Netrokona	Atpara	Sarmaisa	Ubhiapacha	NTAP6	24.79638	90.80876
40	Netrokona	Kendua	Kandiura	Kamolpur	NTKN7	24.65853	90.83562

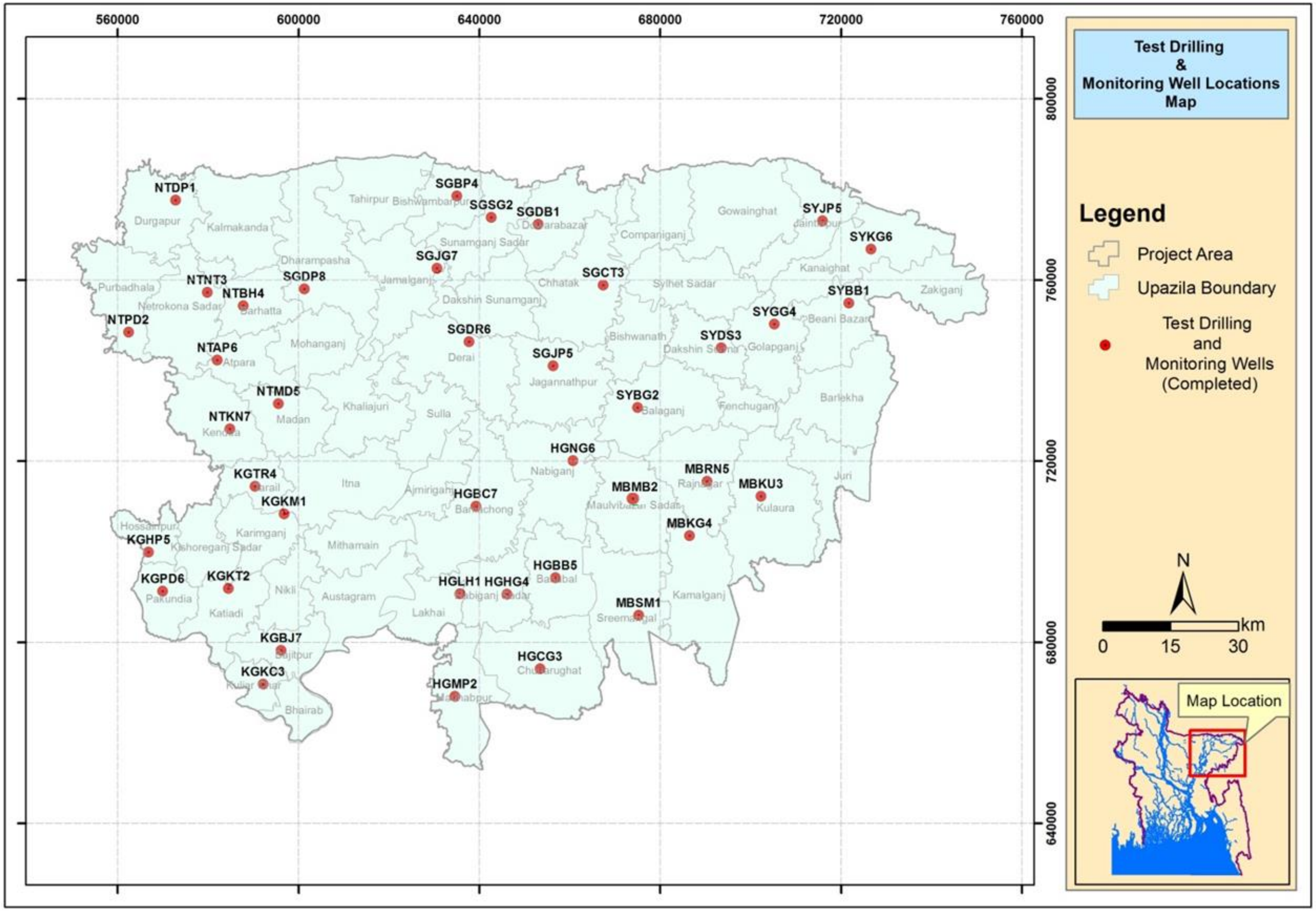


Figure 4-7: Location of Exploratory Drilling

Figure 4-8: Sediment Sample Collection during Exploratory Drilling

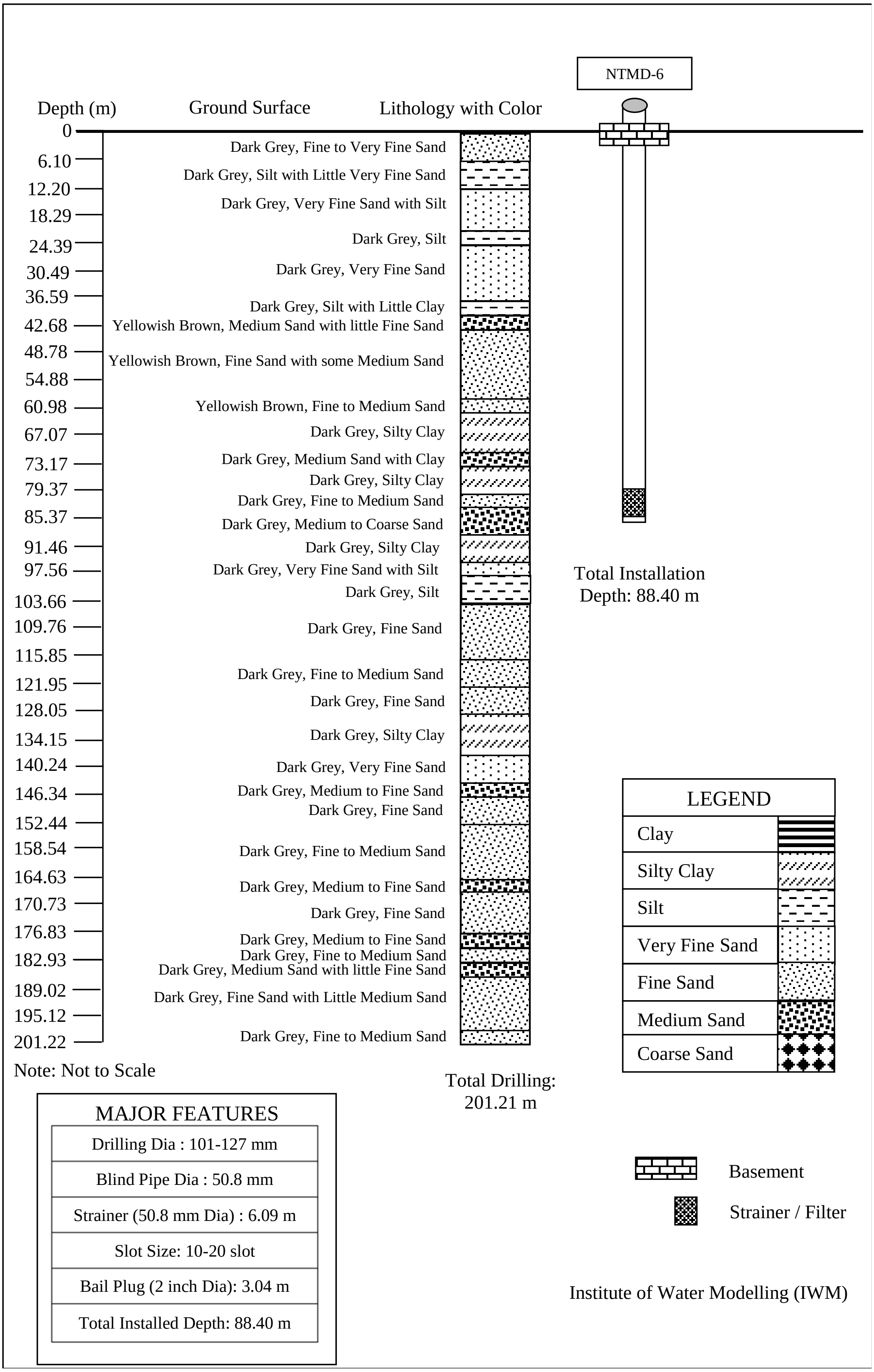


Figure 4-9: Monitoring Well Design with Lithology at Madan, Netrokona

4.3.2 Measurement of Groundwater Level

A total of 40 monitoring wells have been installed in the project area. Daily groundwater depth have been measured for the duration of two years to visualize the fuluction of groundwater level. Bench Mark connection have been established for each monitoring well. The plots of groundwater depth are presented in Volume-II, Appendix B.

4.3.3 Construction of Production Tubewell

A total of 12 nos. production well have been constructed under the present study at different locations. The location have been shown in Figure 4-10. These production wells have been used for aquifer test to determine the hydraulic properties of the aquifer. A sample of production well design is given in Figure 4-11 whereas the details of the production wells have been given in Volume-II, Appendix C.

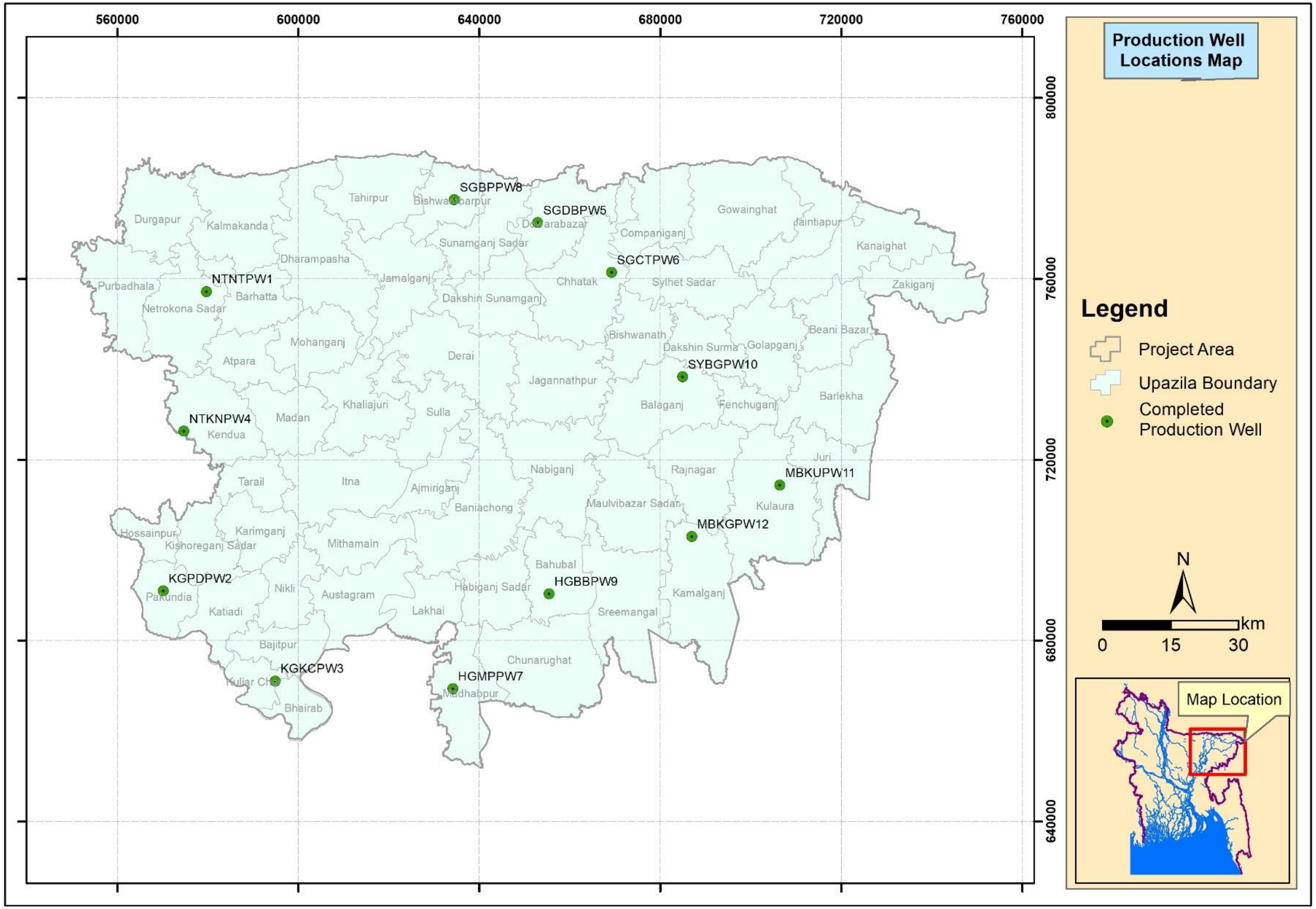


Figure 4-10: Location of Production Well

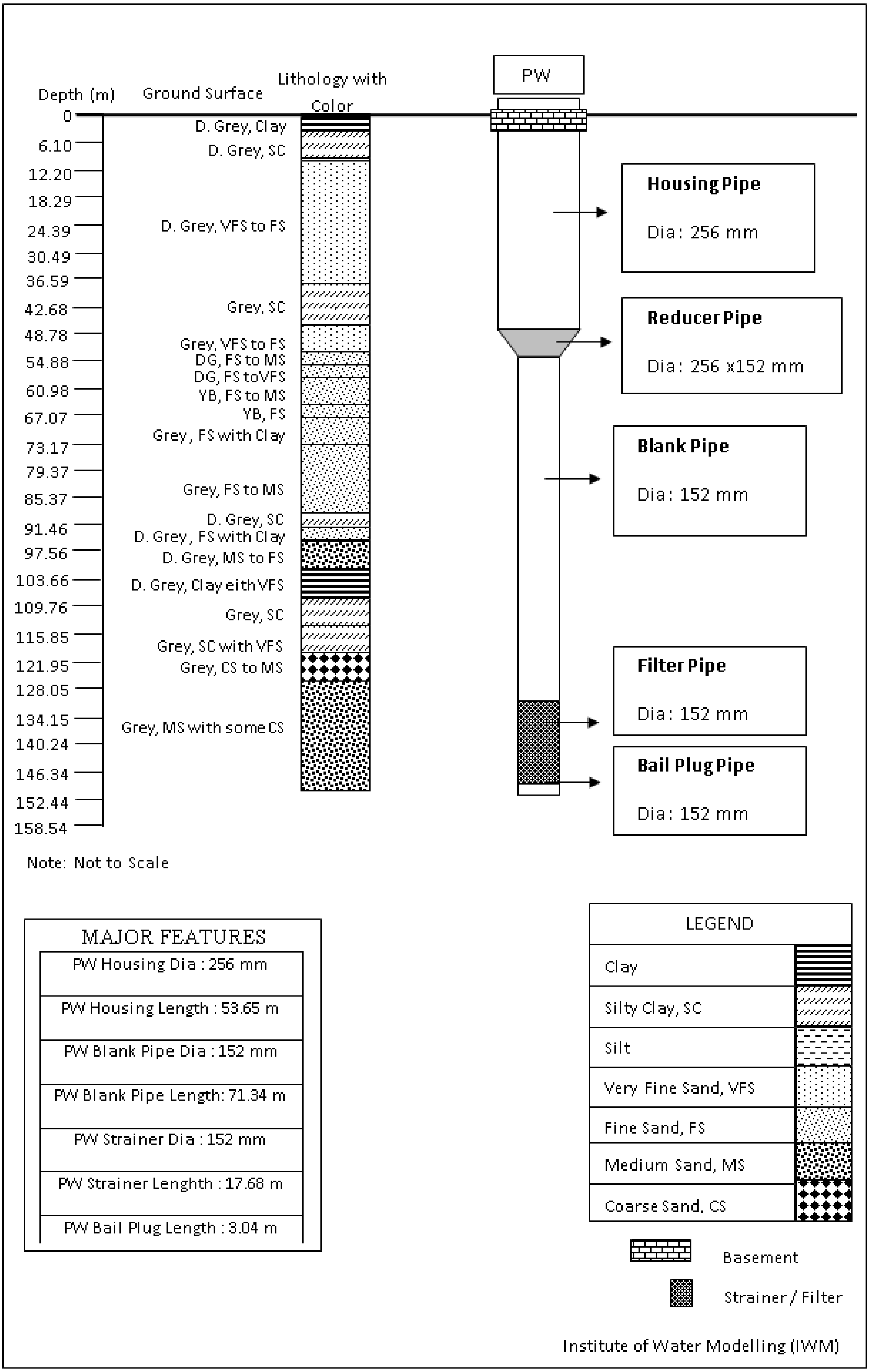


Figure 4-11: Detail Design of Production Well at Netrokona Sadar

4.3.4 Aquifer Test

To cover the entire study area and to get an updated understanding of aquifer properties, total of 25 aquifer tests have been carried out, of which, 12 were in installed production well and remaining 13 were in existing wells. Aquifer test was performed in continuous pumping method with constant discharge rate. Pumping was continued until static water level is achieved. Observation wells were installed at different distances to monitor the groundwater level and drawdown. Judging from the boundary conditions of aquifers and the nature of the aquifer tests conducted in the study area, different equations have been applied for analyzing the field data to calculate aquifer properties. The details of the analysis has been presented in Section 6.1

4.3.5 Seepage and Percolation in the Paddy Field

For assessment of S&P rate of the soil of the study area, necessary data collection arrangement from the field has been made in 50 locations as shown in Figure 4-12. The list of the S&P measurement locations has been presented in Table 4-8. Data collection commenced in January 2018 and continued upto April, 2018. Data on depth of water above the ground surface in the irrigated field has been collected. A sample plot of the daily field water status is shown in Figure 4-13 where as the rest is given in Volume-II, Appendix D.

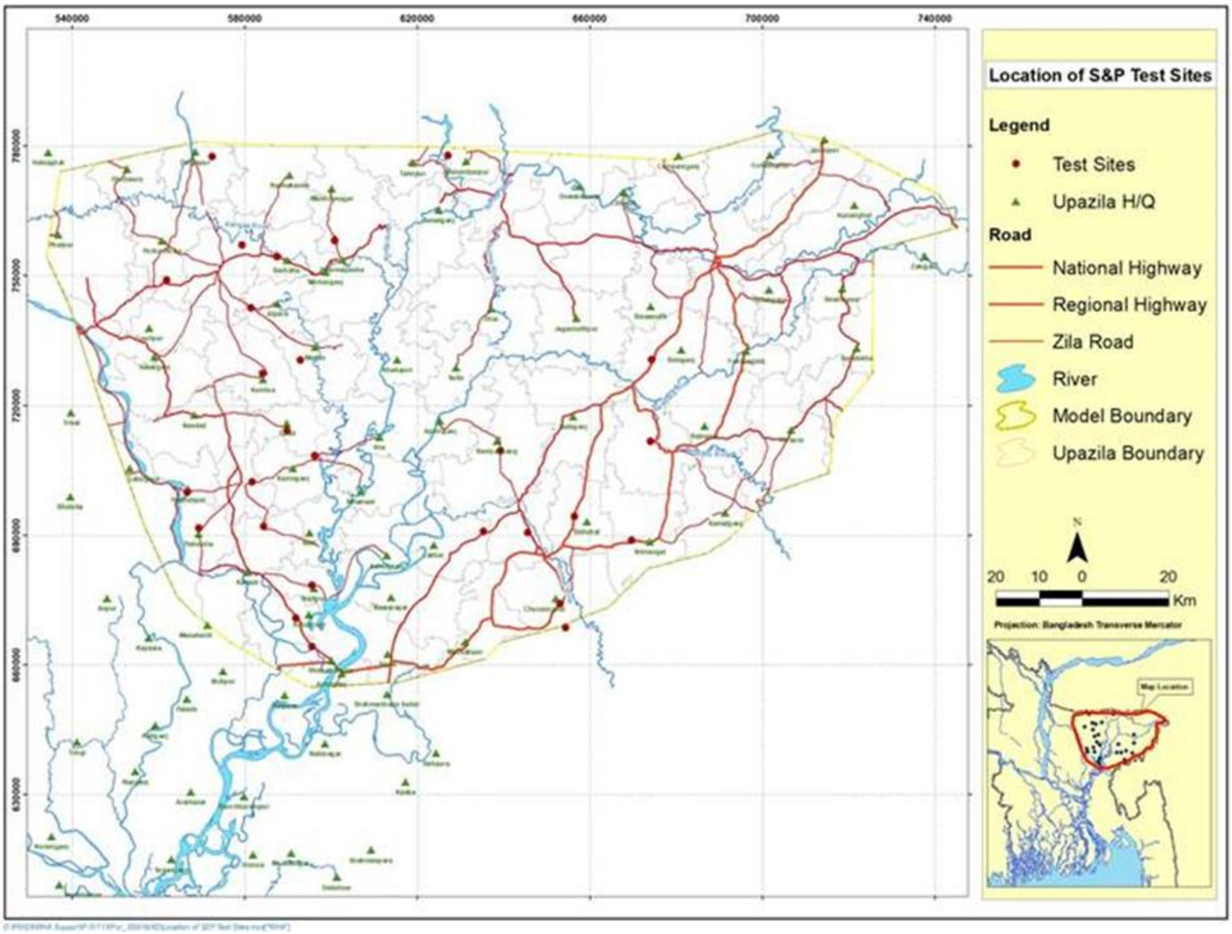


Figure 4-12: Map Showing the Location of Seepage and Percolation Measurement

Table 4-8: List of S&P Measurement Locations

SL No	Observer Name	District Name	Upazilla	Lat	Long
1	Smad Islam Chayon	Sunamganj	Dhormopasha	24.94	91.00
2	Md. Abul Mashuk	Sunamganj	Tahirpur	25.11	91.26
3	Md. Azad	Sunamganj	Chatok	24.94	91.66
4	Md. Nayem Islam	Sunamganj	Chatok	24.94	91.66
5	Amir Ali	Sunamganj	Shantiganj	24.92	91.46
6	Md. Johur Mia	Sunamganj	Sunamganj Sadar	25.00	91.38
7	Mokhlesur Rahman	Sunamganj	Sunamganj Sadar	24.97	91.34
8	Md. Amir Hossain	Sunamganj	Dowara Bazar	25.06	91.51
9	Mehedi Hasan Joy	Sunamganj	Jamalganj	24.98	91.29
10	Sujon Khan	Sylhet	Osmaninogor	24.68	91.72
11	Akther Ali	Sylhet	Dakkhin Surma	24.81	91.95
12	Rejan Ali	Sylhet	Dakkhin Surma	24.81	91.91
13	Ambia	Sylhet	Joyentapur	25.08	92.12
14	Abul Kalam	Sylhet	Sylhet Sadar	24.91	91.78
15	Ibrahim	Sylhet	Golapganj	24.83	92.00
16	Akmol Hossen	Sylhet	Biyanibazar	24.83	92.00
17	Khadiza Begum	Sylhet	Biyanibazar	24.90	92.19
18	Fazlur Rahman	Sylhet	Kanaighat		
19	Abiron Chondro	Maulvibazar	Maulvibazar	24.51	91.72
20	Md. Millat Mia	Moulvibazar	Sreemongol	24.31	91.67
21	Islam Uddin	Moulvibazar	Borolekha	24.72	92.18
22	Seba Akhter	Moulvibazar	Kulaura	24.51	91.99
23	Touhidul Islam	Moulvibazar	Rajnagar	24.54	91.88
24	Anzoli Rani Mollick	Moulvibazar	Moulvibazar Sadar	24.51	91.72
25	Md. Harun	Moulvibazar	Komolganj	24.38	91.85
26	Abdul Hannan	Habiganj	Habiganj	24.32	91.44
27	Humayan Kabir Bappi	Habiganj	Lakhai	24.33	91.33
28	Lutfa Aktar	Habiganj	Baniachong	24.50	91.38
29	Ahad Miah	Habiganj	Chunarughat	24.18	91.51
30	Sompa Rani Das	Habiganj	Madhabpur	24.12	91.52
31	Salman Ahmed	Habiganj	Bahubal	24.36	91.54
32	Md. Ikbal	Netrokona	Purbadhala	24.86	90.61
33	Md. Mamun Mia	Netrokona	Atpara	24.80	90.81
34	Md. Sha-alom	Netrokona	Madan	24.69	90.92
35	Sariful Islam	Netrokona	Kendua	24.66	90.83
36	Abul Kashem	Netrokona	Barhatta		
37	Md. Abdul Matleb	Netrokona	Durgapur	25.12	90.22
38	Md. Siddikur Rahman	Netrokona	Netrokona	24.93	90.79
39	MD. Omor Faruk	Netrokona	Netrokona		
40	Jamal Khan	Kishoreganj	Kuliar Char	24.15	90.90
41	Ziaur Rahman	Kishoreganj	Katiadi	24.34	90.83
42	Md. Alamgir	Kishoreganj	Pakundia	24.34	90.68
43	Md. Rasel	Kishoreganj	Hossainpur	24.41	90.66
44	Md. Sajib Mahbub	Kishoreganj	Bajitpur	24.22	90.94

SL No	Observer Name	District Name	Upazilla	Lat	Long
45	Mehedi Hasan Roky	Kishoreganj	Bajitpur	24.22	90.94
46	Humayan	Kishoregonj	Kishoregonj Sadar	24.43	90.81
47	Mokaddes	Kishoregonj	Karimgonj	24.49	90.95
48	Babul Mia	Kishoregonj	Tarail	24.54	90.89
49	Md. Raihan Uddin	Kishorgonj	Voirav	24.09	90.94
50	Fazle Rabbi	Sunamganj	Tahirpur	25.11	91.26

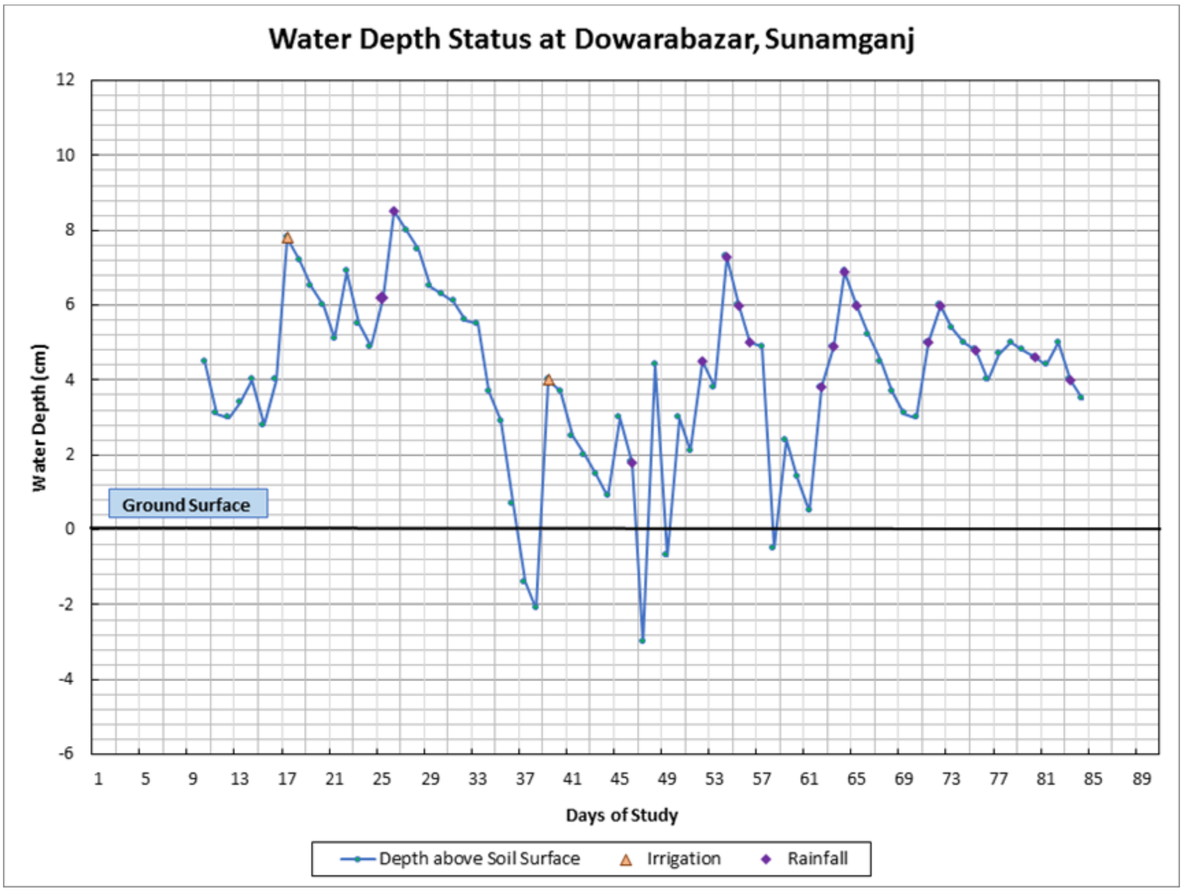


Figure 4-13: A Sample Plot of Daily Field Water Status

As mentioned earlier, necessary field data as well as other climatic data required for assessment of S&P rate of the study area have been collected and analyzed for the assessment of the S&P rate at the test locations. The computed S&P rate of the test sites are presented in Table 4-9.

Table 4-9: Calculated S&P Rate at the Test Locations

Sl. No	Location (Union, Upazila, District)	S&P Rate (mm/day)
1	Uttar Khurma, Chatok, Sunamganj	8.6
2	Shantiganj, Shantiganj, Sunamganj	14.6
3	Kathoir, Sunamganj Sadar, Sunamganj	11.6
4	Shosharkandi, Osmaninogor, Sylhet	10.6
5	Dorboz, Joyentapur, Sylhet	8.69
6	Sylhet, Sylhet Sadar, Sylhet	10.3

Sl. No	Location (Union, Upazila, District)	S&P Rate (mm/day)
7	Biyanibazar, Sylhet	7.7
8	Shula, Biyanibazar, Sylhet	7.1
9	Kanakpur, Moulovibazar, Moulovibazar	6.25
10	Gazitaka, Borolekha, Moulovibazar	7.8
11	Kadipur, Kulaura, Moulovibazar	8.2
12	Kanakpur, Moulovibazar Sadar, Moulovibazar	7.2
13	Karab, Lakhai, Hobiganj	7.7
14	Deogach, Chunarughat, Hobiganj	6.5
15	Adair, Modhabpur, Hobiganj	10
16	Satkapan, Bahubal, Hobiganj	6.75
17	Kandiura, Kendua, Netrokona	6
18	Sahata, Barhatta, Netrokona	10.7
19	Kuliar Char, Kuliar Char, Kishoreganj	9.3
20	Shahasram Dhuldia, Katiadi, Kishoreganj	5.5
21	Pakundia, Pakundia, Kishoreganj	5.1
22	Bajitpur, Bajitpur, Kishoreganj	11.3
23	DakkhinSurma, Sylhet	8.3
24	Bonubi 2no, Sreemongol, Moulovibazar	5.3
25	Komolgani, Moulovibazar	10.9
26	Nizampur, Habiganj, Habiganj	5.1
27	3no union, Banaichong, Habiganj	12
28	Sarmaisa, Atpara, Netrokona	11
29	Nayebpur, Madan, Netrokona	9.7
30	Chandigor, Durgapur, Netrokona	7.5
31	Thakurakokna, Netrokona, Netrokona	3
32	Netrokona pouroshova, Netrokona, Netrokona	10.3
33	Hossainpur, Hossainpur, Kishoreganj	8.8
34	Bajitpur, Bajitpur, Kishoreganj	9.4
35	Niamotpur, Karimgonj, Kishoreganj	6.2
36	TarailSachail, Tarail, Kishoreganj	3.6
37	Kalikaproshad, Voirav, Kishoreganj	13
38	Dhaka Dakkhin, Golapganj, Sylhet	11.4

4.3.6 Geophysical Survey

Geophysical Resistivity Survey at 60 locations have been conducted in the study area. Vertical Electrical Sounding (VES) with 600 m spread were carried out at the selected 60 different points in the study area as shown in Figure 4-14. The survey has been done by the Department of Geology, University of Dhaka. IWM professionals were supervised the GPRS works as given in Figure 4-15. The details analysis and outputs are illustrated in the Section 5.2.

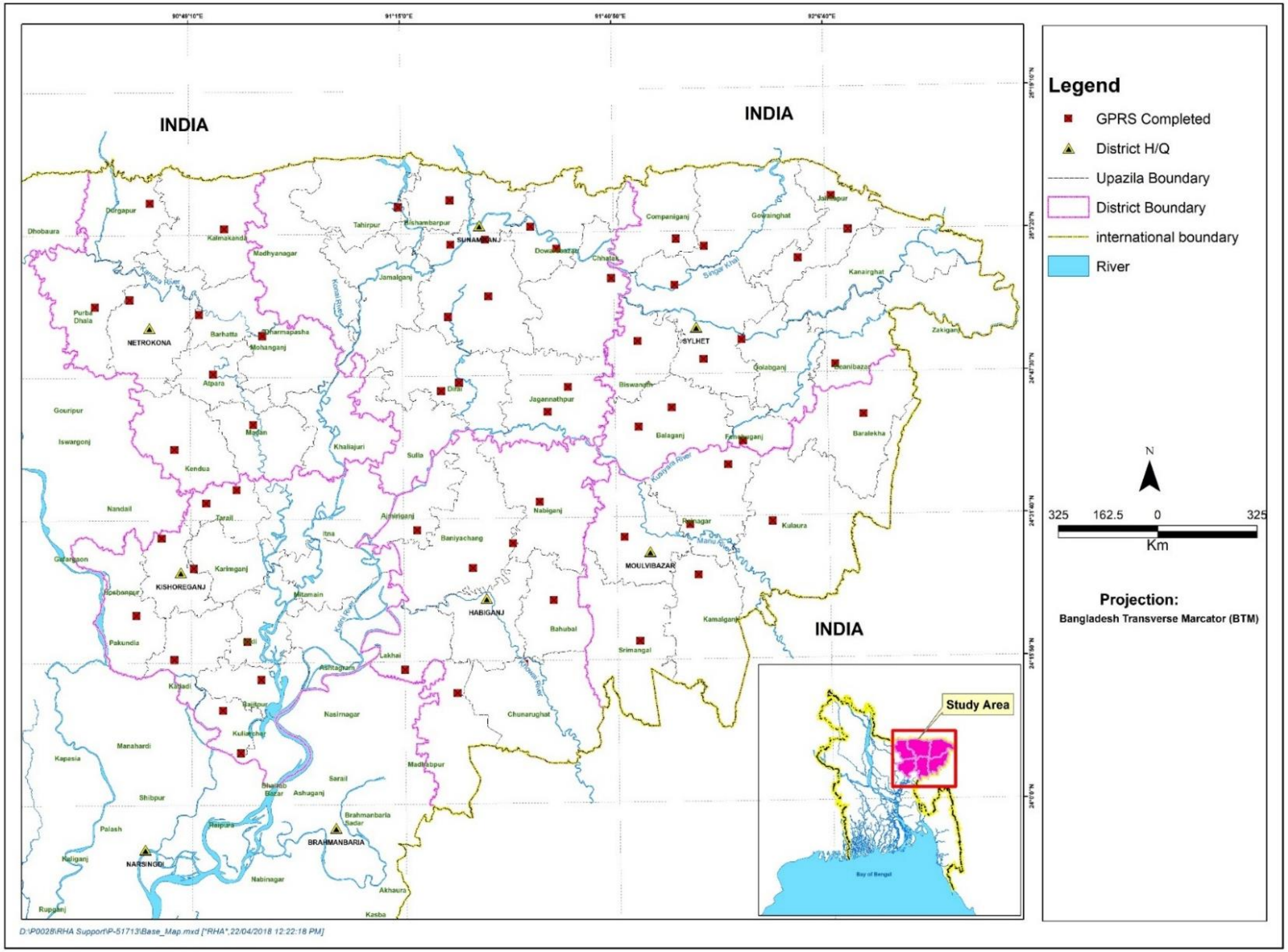


Figure 4-14: Geophysical Resistivity Survey Location Map

Figure 4-15: VES Data Collection in the Field

4.3.7 Water Quality

In order to assess the suitability of water for different uses, hydro-geochemical investigation has been carried out. The quality of water used or drinking and agriculture purposes depend on major, minor and trace elements present in water. Forty groundwater sample have been collected from installed monitoring wells. Information for field parameters such as: pH, EC, TDS (measured) and temperature of water are also important, because these parameters control the chemical environment of water.

The present hydro-geochemical investigation of the study area is mainly to assess the baseline water quality conditions for drinking and agriculture purposes for 19 parameters at 40 locations as shown in Figure 4-16. The details of the locations along with the depth of the well is furnished in Table 4-10. IWM officials have been collected the water quality samples as shown in Figure 4-17 and the Geology Department of Dhaka University has been assigned to do the laboratory analysis.

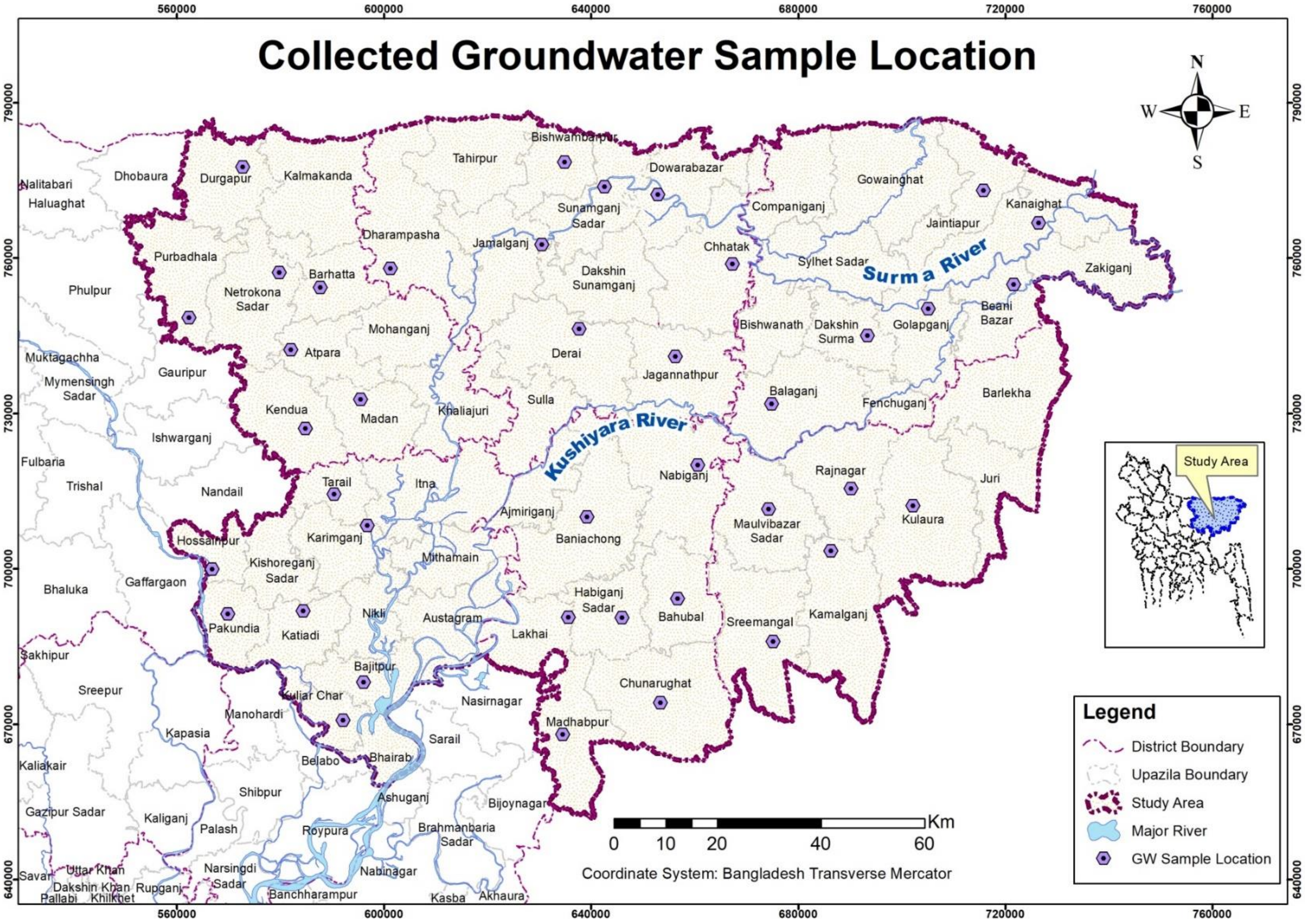


Figure 4-16: Groundwater Sampling Location

Table 4-10: Details of Groundwater Sampling Locations

Sl. No	Well ID	District	Upazila	Union	Easting (m)	Northing (m)	Depth (m)
1	HGLH_1	Habiganj	Lakhai	Karab	635681.71	690705.07	85
2	HGMP_2		Madhabpur	Adair	634602.23	668060.50	117
3	HGCG_3		Chunarughat	Deorgach	653423.34	674166.87	70
4	HGHG_4		Habiganj	Nizampur	646055.40	690591.36	43
5	HGBB_5		Bahubal	Satkapan	656770.12	694289.15	50
6	HGNG_6		Nabiganj	Kurshi	660692.41	720094.37	79
7	HGBC_7		Baniachong	Baniachong	639234.68	710076.72	88
8	MBSM_1	Moulvibazar	Sreemangal	Ashidron	675204.85	685965.75	64
9	MBMB_2		Moulvibazar	Kanakpur	674336.40	711587.20	73
10	MBKU_3		Kulaura	Kadipur	702224.90	712246.30	116
11	MBKG_4		Kamalganj	Rahimpur	686414.30	703517.20	82
12	MBRN_5		Rajnagar	Rajnagar	690297.60	715536.78	95
13	SGDB_1	Sunamganj	Dowarabazar	Mannargaon	652976.79	772324.77	70
14	SGSG_2		Sunamganj	Sunamganj	642629.60	773826.30	113
15	SGCT_3		Chhatak	Uttar Khurma	667385.33	758912.77	72
16	SGBP_4		Bishwambarpur	Palash	634972.28	778529.25	64
17	SGJP_5		Jagannathpur	Jagannathpur	656308.50	741021.00	76
18	SGDR_6		Derai	Karimpur	637729.79	746383.63	84
19	SGJG_7		Jamalganj	Bhimkhali	630574.28	762617.20	79
20	SGDP_8		Dharamapasha	Salboros	601292.00	758008.80	67
21	SYBB_1	Sylhet	Beanibazar	Shula	721661.70	754906.70	43
22	SYBG_2		Balaganj	Goula Bazar	674942.91	731884.63	117
23	SYDS_3		Dakhin Surma	Daudpur	693420.30	745029.50	125
24	SYGG_4		Golabganj	Golabganj	705194.32	750252.72	128
25	SYJP_5		Jaintiapur	Darbasta	715846.77	773098.16	21
26	SYKG_6		Kanaighat	Kanaighat	726535.65	766821.95	113
27	KGKM_1	Kishoreganj	Karimganj	Niamatpur	596812.50	708358.90	79
28	KGKT_2		Katiadi	Shahasram Dhuldia	584467.13	691905.51	46
29	KGKC_3		Kuliar Char	Kuliar Char	592144.10	670762.94	90
30	KGTR_4		Tarail	Tarail Sachail	590421.70	714417.80	82
31	KGHP_5		Hossainpur	Hossainpur	566851.07	699940.83	101
32	KGPD_6		Pakundia	Pakundia	569922.21	691315.73	128
33	KGBJ_7		Bajitpur	Bajitpur	596106.57	678164.85	105
34	NTDP_1	Netrokona	Durgapur	Chandigor	572794.80	777594.00	110
35	NTPD_2		Purbadhala	Gohalakanda	562406.93	748508.22	79
36	NTNT_3		Netrokona	Thakurkona	579798.60	757249.70	204
37	NTBH_4		Barhatta	Sahata	587782.93	754325.84	98
38	NTMD_5		Madan	Jahangirpur	595554.43	732716.81	52
39	NTAP_6		Atpara	Sarmaisa	582030.46	742347.48	61
40	NTKN_7		Kendua	Kandiura	584838.63	727099.50	63

Figure 4-17: Water Sample Collection and Testing

The field parameter such as Temperature, pH, Electrical Conductivity (EC), Total Dissolved Solid (TDS) and Salinity have been measured at 40 locations in the study area. The measured field parameters have been presented in Table 4-11. pH values range from 5.68 to 6.96, indicating neutral to slightly acidic groundwater conditions; Ec values range from 110µs/cm to 1537µs/cm, TDS values range from 55mg/l to 578mg/l and salinity value varies from 0.0 ppt to 0.7 ppt and temperature of groundwater samples are more or less uniform, ranges from 23.5^0C to 29^0C. But in Dowarabazar upazila of Sunamganj district, the groundwater posses slightly higher temperature and found 34.2^0C.

Table 4-11: Groundwater-related Field Parameters

Sl. No.	Well ID	Temp (^{0}C)	pH	EC (µs/cm)	TDS (mg/l)	Salinity (ppt)
1	HGLH_1	28.6	6.13	223	112	0
2	HGMP_2	25.6	6.37	151	76	0
3	HGCG_3	26.8	6.86	123	62	0
4	HGHG_4	25.7	6.04	211	105	0
5	HGBB_5	26.3	6.11	157	78	0
6	HGNG_6	29.2	6.49	319	160	0.1
7	HGBC_7	27.2	6.87	297	148	0.1
8	MBSM_1	26.4	5.69	111	55	0
9	MBMB_2	25.7	6.08	388	194	0.1
10	MBKU_3	25.7	6.39	359	180	0.1
11	MBKG_4	26.4	6.51	164	82	0
12	MBRN_5	26.6	6	109	54	0
13	SGDB_1	34.2	6.96	524	262	0.2
14	SGSG_2	25.5	6.58	352	176	0.1
15	SGCT_3	24.6	5.89	714	357	0.3
16	SGBP_4	25.2	6.19	529	265	0.2
17	SGJP_5	24.7	6.38	203	101	0

Sl. No.	Well ID	Temp (^{0}C)	pH	EC (µs/cm)	TDS (mg/l)	Salinity (ppt)
18	SGDR_6	26.4	6.13	521	260	0.2
19	SGJG_7	27.6	6.6	402	201	0.1
20	SGDP_8	26.5	6.22	583	292	0.2
21	SYBB_1	25.8	6.34	172	86	0
22	SYBG_2	27.0	6.44	447	221	0.2
23	SYDS_3	25.8	6.93	194	97	0
24	SYGG_4	26.3	6.9	447	223	0.2
25	SYJP_5	26.3	6.27	231	116	0
26	SYKG_6	23.5	5.68	393	196	0.1
27	KGKM_1	27.7	6.39	747	374	0.3
28	KGKT_2	27.1	6.52	577	288	0.2
29	KGKC_3	27.8	6.2	307	153	0.1
30	KGTR_4	28.7	6.19	557	368	0.5
31	KGHP_5	26.7	6.29	418	209	0.2
32	KGPD_6	27.2	6.38	331	165	0.1
33	KGBJ_7	28.8	6.63	338	169	0.1
34	NTDP_1	28.0	6.73	***1537***	***769***	0.7
35	NTPD_2	25.7	5.71	319	159	0.1
36	NTNT_3	26.7	6.32	353	176	0.1
37	NTBH_4	27.3	6.47	412	206	0.1
38	NTMD_5	29.2	6.44	***1155***	***578***	0.5
39	NTAP_6	27.7	6.53	686	336	0.3
40	NTKN_7	27.8	6.55	245	123	0
Maximum		**34.2**	**6.96**	**1537**	**769**	**0.7**
Minimum		**23.5**	**5.68**	**109**	**54**	**0**
Average		**27**	**6**	**408**	**206**	**0**
Standard Deviation		**1.73**	**0.32**	**278**	**141**	**0.16**

The quality of water used or drinking and agriculture purposes depend on major, minor and trace elements present in water. To assess groundwater quality for drinking and Agriculture purposes major (Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, HCO_3^-, NO_3^- and SO_4^{2-}), minor (Fe, B, PO_4^{3-} and F) and trace (As and Mn) constituents have been selected to analyze. A detailed analysis was carried out after data collection. Chemistry of all cations and anions of major, minor and trace constituents are presented in Table 4-12, these are expressed in mg/l.

Table 4-12: Results of Chemical Analysis of all Major, Minor and Trace Constituents

Sample ID	Upazila	Depth (m)	Major Constituents (mg/l)								Minor Constituents (mg/l)				Trace Constituents	
			Cations				Anions								Mn	As
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	PO_4^{3-}	F^-	Fe	B	(mg/l)	µg/l
HGLH_1	Lakhai	85	8.12	4.30	43.67	1.24	152.50	3.06	0.12	0.61	bdl	0.34	2.16	0.05	0.12	3.73
HGMP_2	Madhabpur	117	12.36	5.46	12.14	0.99	91.50	0.73	1.89	0.11	bdl	0.10	4.06	0.09	0.21	4.40
HGCG_3	Chunarughat	70	9.16	4.02	7.02	1.25	68.63	1.67	0.40	1.25	bdl	0.09	7.99	0.60	0.27	2.72
HGHG_4	Habiganj	43	12.50	5.36	26.48	0.71	129.63	2.27	0.09	0.15	0.35	0.36	2.49	0.06	0.44	8.57
HGBB_5	Bahubal	50	7.78	4.22	17.84	0.65	91.50	0.87	0.10	0.10	bdl	0.11	9.43	0.12	0.12	3.36
HGNG_6	Nabiganj	79	31.38	7.94	39.00	1.24	221.13	3.28	0.10	0.06	bdl	0.05	0.93	0.05	0.16	2.11
HGBC_7	Baniachong	88	15.96	7.28	43.87	1.27	205.88	2.04	0.11	0.51	0.34	0.07	4.37	0.06	0.12	2.23
MBSM_1	Sreemangal	64	6.22	3.38	5.75	2.43	61.00	2.05	0.14	0.10	0	0.15	8.91	0.08	0.37	3.22
MBMB_2	Moulvibazar	73	10.64	9.38	69.73	1.44	205.88	26.87	0.05	1.56	2.09	0.66	2.36	0.08	0.10	14.09
MBKU_3	Kulaura	116	7.12	3.90	83.79	0.80	244.00	3.30	0.08	0.82	4.72	1.86	1.20	0.04	0.05	1.92
MBKG_4	Kamalganj	82	8.14	4.72	19.04	1.71	83.88	6.78	0.20	0.01	0.12	0.36	0.09	0.11	0.32	4.08
MBRN_5	Rajnagar	95	6.98	4.00	8.36	1.58	68.63	1.65	0.11	1.44	bdl	0.16	5.18	0.11	0.34	3.06
SGDB_1	Dowarabazar	70	3.16	1.52	134.33	1.28	381.25	2.76	0.34	0.37	bdl	0.22	0.15	0.06	0.01	2.55
SGSG_2	Sunamganj	113	22.30	11.06	36.85	1.09	198.25	1.41	0.06	0.39	2.11	0.17	2.94	0.03	0.14	15.84
SGCT_3	Chhatak	72	38.02	19.64	78.00	3.65	320.25	45.11	0.17	0.42	0.15	0.07	6.81	0.13	0.15	21.23
SGBP_4	Bishwambarpur	64	41.58	21.64	33.17	2.89	312.63	7.40	0.05	0.10	bdl	0.45	3.58	0.22	0.24	6.40
SGJP_5	Jagannathpur	76	31.72	4.02	4.11	0.39	114.38	2.01	1.33	0.77	bdl	0.12	2.24	0.05	0.17	7.23
SGDR_6	Derai	84	22.70	12.66	76.56	2.25	274.50	19.53	0.09	0.06	0.87	0.58	7.96	0.14	0.45	26.19
SGJG_7	Jamalganj	79	29.80	12.20	46.68	0.93	236.38	26.74	0.31	0.04	0.18	0.45	0.47	bdl	0.70	6.43
SGDP_8	Dharamapasha	67	13.66	6.94	105.98	1.94	205.88	97.24	0.05	0.05	1.57	1.09	1.69	0.06	0.08	21.92
SYBB_1	Beanibazar	43	2.88	4.22	23.07	2.28	91.50	1.08	0.91	3.45	bdl	0.18	4.04	0.02	0.89	3.02
SYBG_2	Balaganj	117	8.72	8.42	89.73	1.09	274.50	1.03	0.10	0.59	8.33	0.40	1.83	0.12	0.04	10.33
SYDS_3	Dakhin Surma	125	6.80	3.56	27.36	1.00	106.75	1.23	0.10	0.64	bdl	0.05	11.39	0.17	0.29	2.89
SYGG_4	Golabganj	128	5.48	3.20	114.33	0.75	312.63	1.11	0.12	0.60	12.67	0.25	0.51	0.13	0.04	3.05
SYJP_5	Jaintiapur	21	10.82	9.48	18.84	0.56	122.00	2.49	0.11	0.84	bdl	0.13	11.28	0.06	0.79	2.55

Sample ID	Upazila	Depth (m)	Major Constituents (mg/l)								Minor Constituents (mg/l)				Trace Constituents	
			Cations				Anions								Mn	As
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	PO_4^{3-}	F^-	Fe	B	(mg/l)	μg/l
SYKG_6	Kanaighat	113	17.36	8.30	32.34	3.62	178.25	2.45	0.10	0.01	0.27	0.07	30.05	0.13	0.84	5.93
KGKM_1	Karimganj	79	12.38	5.24	164.98	1.86	411.75	46.84	0.09	0.26	1.94	0.31	2.18	0.30	0.10	8.41
KGKT_2	Katiadi	46	20.50	9.56	101.47	1.39	305.00	41.92	0.06	0.32	bdl	0.27	5.18	0.05	1.12	3.79
KGKC_3	Kuliar Char	90	20.30	9.98	33.57	1.42	178.75	2.68	0.12	0.35	bdl	0.18	1.80	0.05	0.34	1.89
KGTR_4	Tarail	82	31.42	8.08	176.24	1.30	474.13	126.23	0.19	0.05	1.47	0.05	2.14	bdl	2.09	19.27
KGHP_5	Hossainpur	101	31.60	17.68	39.15	1.35	265.00	4.50	0.28	0.09	bdl	0.23	0.39	0.04	0.32	1.73
KGPD_6	Pakundia	128	26.70	11.20	33.18	1.53	205.88	10.36	0.53	0.08	bdl	0.12	1.78	0.04	0.42	1.98
KGBJ_7	Bajitpur	105	37.20	5.64	28.60	0.97	255.25	1.81	0.02	0.16	0.07	0.07	0.44	0.06	0.07	2.35
NTDP_1	Durgapur	110	11.06	6.28	36.69	0.93	152.50	2.65	0.05	0.76	bdl	0.53	4.11	0.05	0.23	6.23
NTPD_2	Purbadhala	79	20.24	9.76	34.29	2.02	221.13	2.61	0.08	0.10	bdl	0.19	4.69	0.04	0.32	1.43
NTNT_3	Netrokona	204	20.50	7.12	46.86	0.65	183.00	37.44	0.11	0.02	bdl	0.42	2.81	0.04	0.19	6.04
NTBH_4	Barhatta	98	30.84	10.32	49.79	0.73	251.63	23.76	0.13	0.02	bdl	0.31	1.22	0.03	0.74	4.27
NTMD_5	Madan	52	61.40	41.40	159.22	2.14	327.88	199.60	0.31	0.19	bdl	0.40	3.83	0.20	2.06	7.93
NTAP_6	Atpara	61	38.70	13.58	74.54	1.28	175.38	156.14	0.05	0.38	bdl	0.32	4.74	0.07	0.62	6.49
NTKN_7	Kendua	63	156.80	29.80	184.22	1.26	388.25	394.60	0.15	0.01	bdl	0.17	2.07	0.32	2.65	1.92

As per the cliental requirements and descision of the PIC committee meeting held on dated 8th March 2017, the surface water quality has been tested. For detail characterization of river water samples, a water sampling program has been chalked out, which involves collection of water samples from selected locations of different River during dry season as shown in Figure 4-18. Surface water sample has been collected from 10 locations as shown in Figure 4-19. The detailed information of the sampling locations has been shown in Table 4-13. The collected samples have been preserved by the regulations and standard set by ICDDRB and BUET to keep the properties of water unchanged and transported carefully to Dhaka for laboratory analysis.

Figure 4-18: Surface Water Sample Collection by IWM Professionals

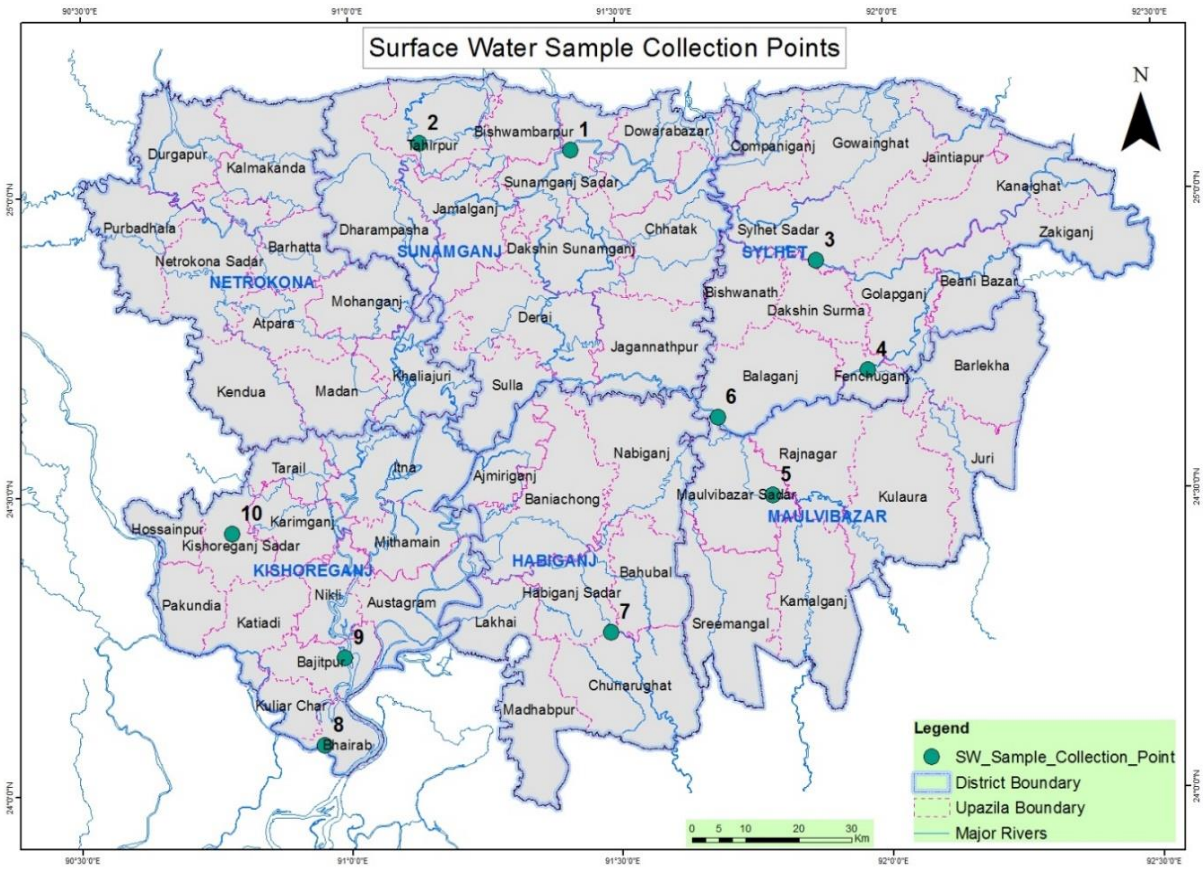


Figure 4-19: Surface Water Sampling Locations

Table 4-13: Details of Surface Water Sampling Locations

Sample No	Sampling Date	River Name	District	Upazilla	Lattitude	Longitude
1	07/01/2019	Surma	Sunamganj	Sunamgonj Sadar	25.07722	91.411641
2	07/01/2019	Baulai	Sunamganj	Tahirpur	25.09057	91.130283
3	07/01/2019	Surma	Sylhet	Sylhet Sadar	24.88784	91.868073
4	08/01/2019	Sunai	Sylhet	Fenchuganj (Hakaluki)	24.704	91.961026
5	08/01/2019	Manu	Maulovibazar	Maulovibazar Sadar	24.49672	91.781235
6	08/01/2019	Kusiyara	Sylhet	Balaganj	24.62788	91.681053
7	08/01/2019	Kowai	Habiganj	Sayestaganj	24.27062	91.47926
8	09/01/2019	Meghna	Kishoreganj	Bhairab	24.08555	90.946652
9	09/01/2019	Gorautra	Kishoreganj	Bajitpur	24.23136	90.984621
10	09/01/2019	Norosundha	Kishoreganj	Kishoreganj Sadar	24.43978	90.776229

The water quality parameters for the test conducted by ICDDRB are: Total coliforms, Faecal coliforms, Thermotolerent Escherichia coli, pH, Total Dissolved Solids (TDS), Dissolved Oxygen, Chloride, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), and Total Suspended Solids. Whereas, six water quality parameters have been conducted by BUET are: Ammonia- Nitrogen (NH_3-N), Nitrate – Nitrogen (NO_3-N), Mercury (Hg), Calcium (Ca), and Lead (Pb). The results of laboratory analysis (at BUET and ICDDRB) of water samples collected from the different River during dry season have been presented in Table 4-14**.** Details of the analysis of water quality data is given in Volume-II, Appendix E.

Table 4-14: Characteristics of Raw Water Collected from Different River

SL No	Water Quality Parameters	Unit	Bangladesh Standard for Waste Water (ECR'97)	Surma, Sylhet Sadar, Sylhet (3)	Surma, Sunamganj Sadar, Sunamganj (1)	S-4-Sunai River, Fenchuganj, Sylhet (Hakaluki Haor) (4)	Baulai, Thairpur, Sunamgonj (Tanguar Haor) (2)	Norosundha River, Kishoreganj Sadar, Kishoreganj ((10)	Meghna River, Bhairab, Kishoreganj (8)	S-6-Kusiyara River, Balaganj, Sylhet (6)	S-5-Manu River, Maulovibazar Sadar, Moulavibazar (5)	7-kowai River, Sayestaganj, Hobiganj (7)	Gorautra River, Bajitpur, Kishoreganj (9)
1	Total coliforms	CFU/ 100mL	-	**10000**	**1400**	**800**	**1100**	**7200**	**1800**	**680**	**19000**	**500**	**91000**
2	Faecal coliforms	CFU/ 100mL	-	**5000**	**520**	**500**	**380**	**2000**	**400**	**400**	**900**	**400**	**1200**
3	Thermotole-rent (Escherichia coli)	CFU/ 100mL	-	**4000**	14	**125**	17	**800**	**300**	88	**300**	**120**	**800**
4	pH	-	6-9	6.62	6.85	7.64	6.87	7	6.63	7.55	7.69	7.54	7.49
5	Total dissolved solids (TDS)	mg/L	2100	103.7	86.3	63.1	79.3	482	268	75.5	109.7	116.8	65.6
6	Dissolved Oxygen (DO)	mg/L	4.5-8	6.21	6.75	7.25	7.22	2.58	6	7.48	7.66	**8.22**	6.67
7	Chloride	mg/L	-	3.33	2.84	3.83	4.52	43.82	23.86	2.76	2.95	3.5	3.22
8	Chemical Oxygen Demand (COD)	mg/L	200	70	24	7	<3.0	25	24	52	4	<3.0	16
9	Biochemical Oxygen Demand (BOD5;20°C)	mg/L	50	15.5	12.8	4.2	<2.0	11	9.1	15	<2.0	<2.0	8

SL No	Water Quality Parameters	Unit	Bangladesh Standard for Waste Water (ECR'97)	Surma, Sylhet Sadar, Syhlet (3)	Surma, Sunamganj Sadar, Sunamganj (1)	S-4-Sunai River, Fenchuganj, Sylhet (Hakaluki Haor) (4)	Baulai, Thairpur, Sunamgonj (Tanguar Haor) (2)	Norosundha River, Kishoreganj Sadar, Kishoreganj ((10)	Meghna River, Bhairab, Kishoreganj (8)	S-6-Kusiyara River, Balaganj, Sylhet (6)	S-5-Manu River, Maulovibazar Sadar, Moulavibazar (5)	7-kowai River, Sayestaganj, Hobiganj (7)	Gorautra River, Bajitpur, Kishoreganj (9)
10	Total Suspended Solids (TSS)	mg/L	150	12	18	54	72	16	<10.0	90	<10.0	14	18
11	Ammonia-Nitrogen (NH_3-N)	mg/L	0.5	0.05	0.1	0.28	0.16	**20.75**	0.06	0.1	0.09	0.13	0.15
12	Nitrate-Nitrogen (NO_3-N)	mg/L	10	1.3	0.2	0.7	0.8	0.2	0.3	0.2	0.5	0.2	0.4
13	Mercury (Hg)	mg/L	0.001	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
14	Calcium (Ca)	mg/L	75	18.81	16.88	3.58	5.21	35.94	74.99	5.58	16.31	13.65	11.7
15	Cadmium (Cd)	mg/L	0.005	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
16	Lead (Pb)	mg/L	0.05	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL

4.4 Quality Control of Data

Data quality checking is an essential part of the study. Quality control of all survey and data has been maintained in the field as well as in the office through standard procedures as stipulated in the Data Processing Manual developed by IWM. Following steps has been adopted to check the quality control of various types of data required under the present study.

Hydro-meteorological Data

Quality control of hydro-meteorological data has been carried out according to the standard procedures described in IWM Data Processing Manual (IWM Handbook). Quality control of rainfall included visual observation of plots of rainfall, estimation of yearly mean values, preparation of double mass curves and comparison of monthly values. Quality control of water levels has been checked through on-screen plotting to detect inconsistencies by comparing upstream and downstream water level variations and differences with the adjacent stations. Two separate rating curves (dry season and monsoon) have been established for each discharge stations. Daily discharge data has been generated from the established rating curves.

Hydrogeological Data

Quality control of lithological and aquifer test data has been carried at field level during the data collection. Quality control of lithological data includes ensuring completeness of information such as colour, texture, formation depth and thickness. Any missing information will make the data doubtful. To ensure the quality of aquifer test data, the time series discharge data of the testing wells and consistency of pumping levels have been checked. The layout plan of the test site have been checked for correctness of observation well design. Consistency of groundwater level has been checked through on-screen plotting to detect inconsistencies and also by comparing with the data from neighboring stations and regional rainfall pattern.

5 AQUIFER SYSTEM IN THE PROJECT AREA

5.1 Hydrogeological Setting

Available aquifer information gives an idea about the depth and variable thickness of the aquifer in the study area. Hydrogeological parameters of this area are governed by the litho-stratigraphic characteristic and prevailing tectonic features, which is a part of regional hydrogeological setting.

Tectonically Bangladesh occupies the major part of Bengal Basin and forms the largest delta complex in the world. It is bounded in the east by the Indo-Burma ranges, in the west by the Indian shield, in the north by the Shillong massif and the Himalayan thrust fault and in the south it is open towards Bay of Bengal for a considerable distance (Alam et al., 1990). The delta development activities are still going on in the south by deposition of the major river system. Quaternary sediments deposited mainly by the river Ganges, Brahmaputra and Meghna.

The geology of the study area can be attributed to Quaternary alluvial sequence, which is a part of the Ganges flood plain. The quaternary climatic fluctuations were the controlling factors in the deposition of recent sediments and the late Quaternary sedimentary sequences. In the late Holocene, Low land areas became marshy and poorly drained as the rate of transgression slowed down and silt and clays were deposited. Thus the sedimentary environment changed from braided streams and meandering rivers to flood plains with the deposition of first sand and later finer silty sediment.

The Quaternary sequence provides good aquifers, which have been extensively exploited in Bangladesh. The aquifers are generally thick multilayered with high transmissivity and storage coefficient. Aquifer systems can broadly be distinguished in the study area as recent sands forming both semi-confine and confined aquifer.

Generalized aquifer system i.e. stratigraphy of the study area is presented in section 5.2 based on geoelectric and lithologic information while upazila wise detailed description of aquifer units, based on, borehole lithologic logs, is presented in section 5.3.

5.2 Geophysical Survey

The main objective of the geophysical investigation is to delineate aquifer system of the study area. The specific objectives of the investigation are to identify the different geological layers along with its vertical and horizontal extent minimum up to the depth of 200 meters within the study area and to identify the potential aquifers minimum up to the depth of 200 meters along with their depth, extent and thickness. Resistivity soundings were carried to establish the characteristics of the aquifer in the study area the north eastern part of Bangladesh. Results of resistivity soundings revealed that the subsurface formations are made up of clay, silty clay, clayey sand, fine sand, medium sand and coarse grained sand. After analyzing the collecting data three aquifer units have been identified in the study area. These aquifers are separated by aquitard which is made up of clay or silty clay.

Surface aquitard is underlain by Aquifer-1 (shallow aquifer) which shows resistivity range of 25 Ωm to 164 Ωm. Thickness of this unit varies from 4 m to 104 m. Maximum thickness of Aquifer-1 is about 104m at Atpara, Kishoreganj and minimum thickness is about 4m at Madan, Netrokona. Aquifer-2 also shows the same resistivity range. Thickness of this unit varies from 3 m to 135 m. Maximum thickness of Aquifer-2 is about 135m at Madhabpur, Habiganj and minimum thickness is about 3m at Bajitpur, Kishoreganj. The deep aquifer, Aquifer-3, the base of which couldn’t not be identified. Maximum depth of the lower boundary of this unit is about 171 m at Madhabpur, Habiganj and minimum depth is about 100m at Mohanganj, Netrokona. At Madan, Netrokona low resistivity value of about 7 Ωm below 107 m depth is found.

To know the aquifer system of an area, bore log data contributes the most important information. Though boreholes are not distributed all around the area, it can provide an average information of the study area. Moreover, to support this data Vertical Electrical Sounding (VES) are conducted in this area. So, based on these data geologic cross-sections have been made to delineate the aquifer system for perception about hydrogeological condition of the area.

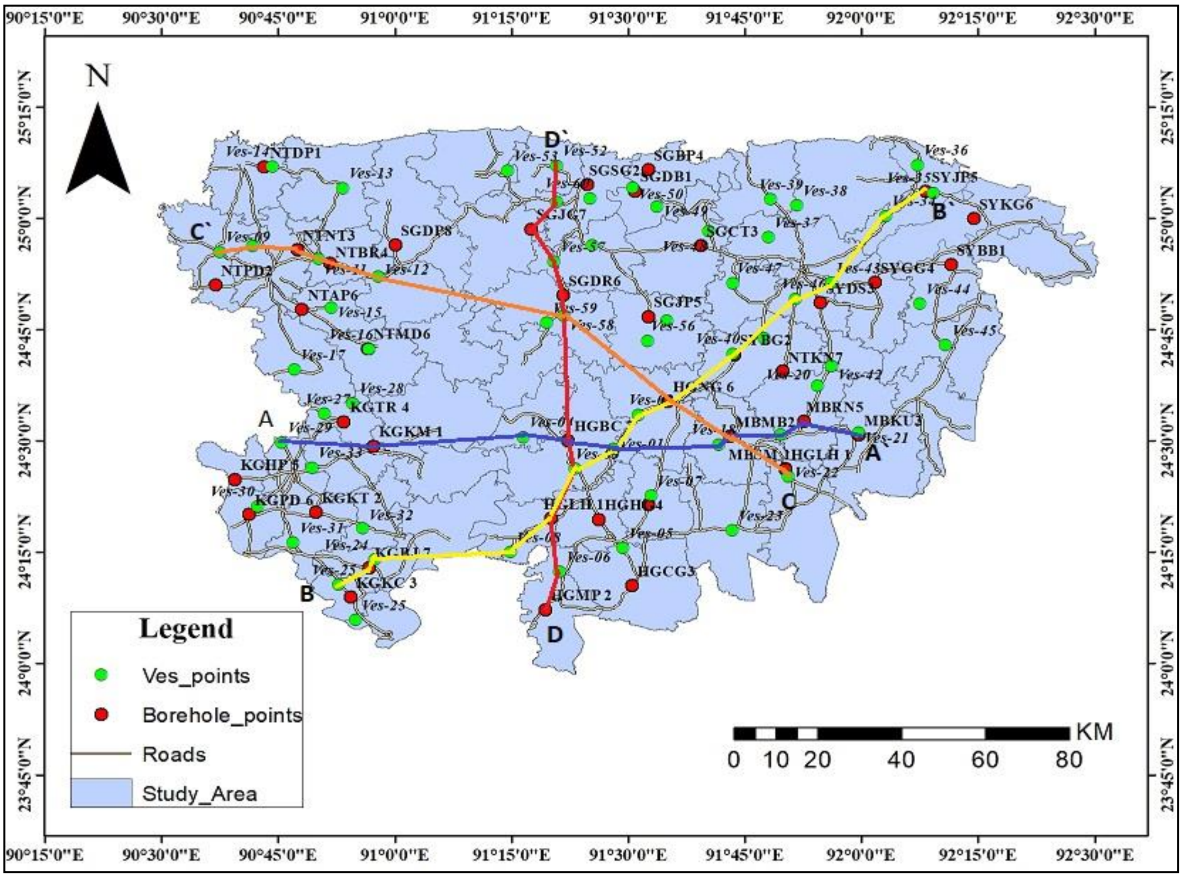


Figure 5-1: Map Showing the Lines of Cross Sections in the Study Area

5.2.1 Interpretation of Geoelectric Cross Section along A-A`

Geolelectric and lithological cross sections along A-A` as shown in Figure 5-2 and Figure 5-3 has been executed from west to east towards the southern part of the study area covering parts of Kishoreganj, Habiganj and Maulavibazar districts. Three aquifer units have been encountered till the investigated depth of about 200m below ground surface. Surface layer is composed of silty clayey soil and the following layer is Aquitard-1. This Aquitard-1 is relatively thin in the western part and slightly thick in the middle part of the cross section. The following layer is Aquifer-1 which is thick in the western part and thinner in the middle and in the eastern part. Aquifer-1 is underlain by a thin Aquitard-2 which is continuous throughout the cross section. The following layer Aquifer-2 is thick in the middle part of the section. Aquifer-2 is underlain by Aquitard-3 which is slightly thick in the western and eastern parts, but in the middle part Aquitard-3 is very thin and hard to show in the cross section. The deepest identified layer is Aquifar-3 thickness of which couldn't be identified within the investigated depth.

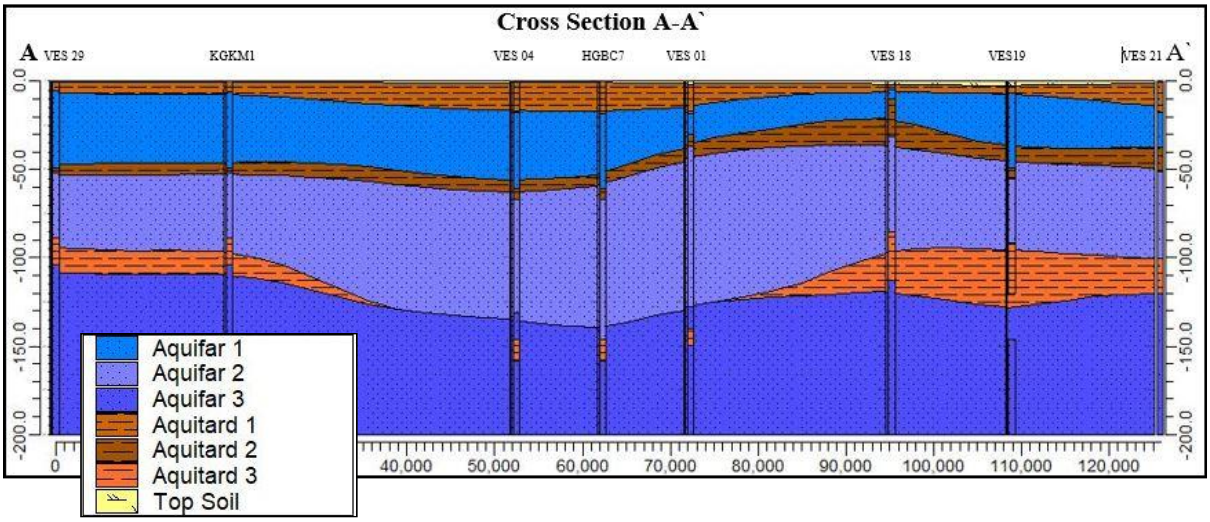


Figure 5-2: Geo-electric Cross Section along Line A-A`

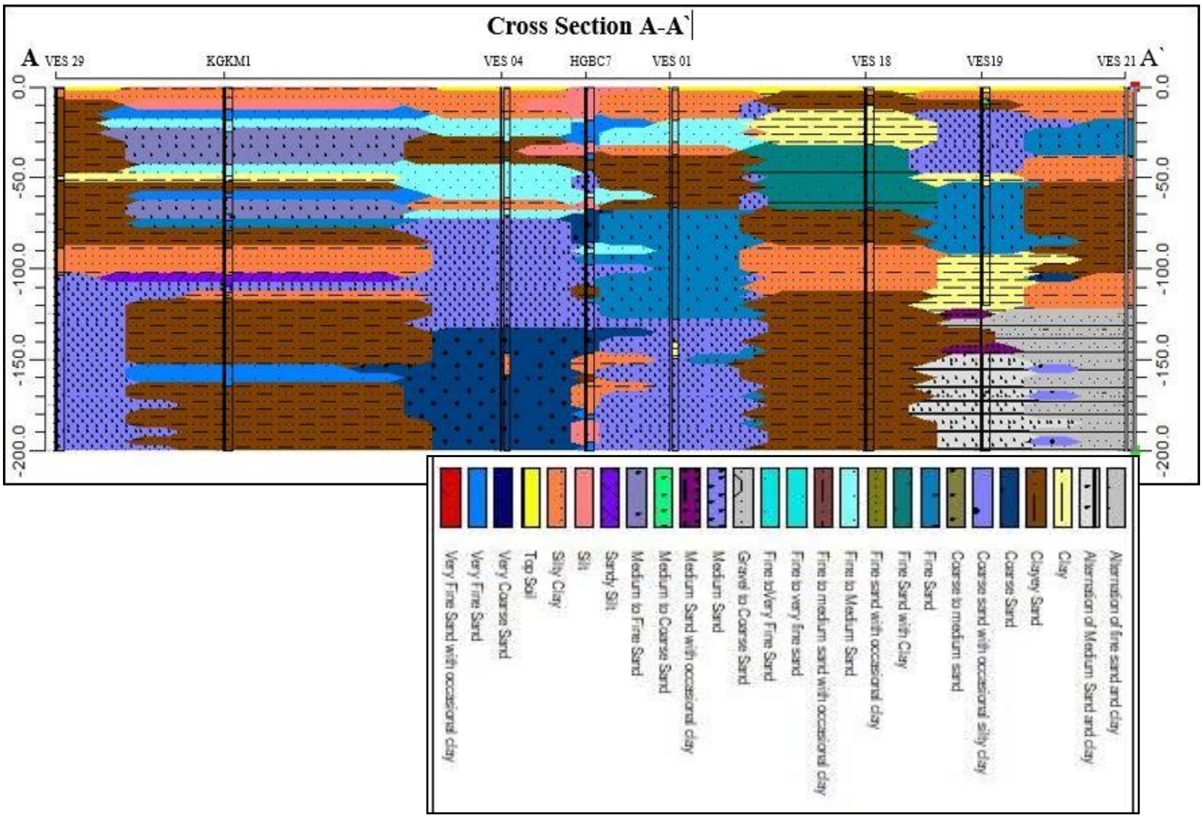


Figure 5-3: Lithological Cross Section along Line A-A`

5.2.2 Interpretation of Geoelectric Cross Section along B-B`

Geoelectric and lithological cross sections along B-B` as shown in Figure 5-4 and Figure 5-5 has been executed from SW to NE of the study area covering SE of Kishoreganj, NW of Habiganj and Sylhet districts. The top layer is composed of silty clayey soil and is underlain by Aquitard-1. Aquitard-1 is thin in the middle part of the cross section. Aquitard-1 is underlain by Aquifer-1 which is thick in the middle part of the section. The following hydrostratigraphic unit is Aquitard-2 which is relatively thin in the middle part. Aquifer-2 with a more or less uniform thickness is overlain by Aquitard-2. Aquifer-2 is underlain by Aquitard-3 which is thinner than the Aquitard-2 and in the middle part it is very thin and hard to show in the cross section. The deepest identified layer is Aquifar-3 thickness of which couldn’t be identified but may continue below the investigated depth of about 200m.

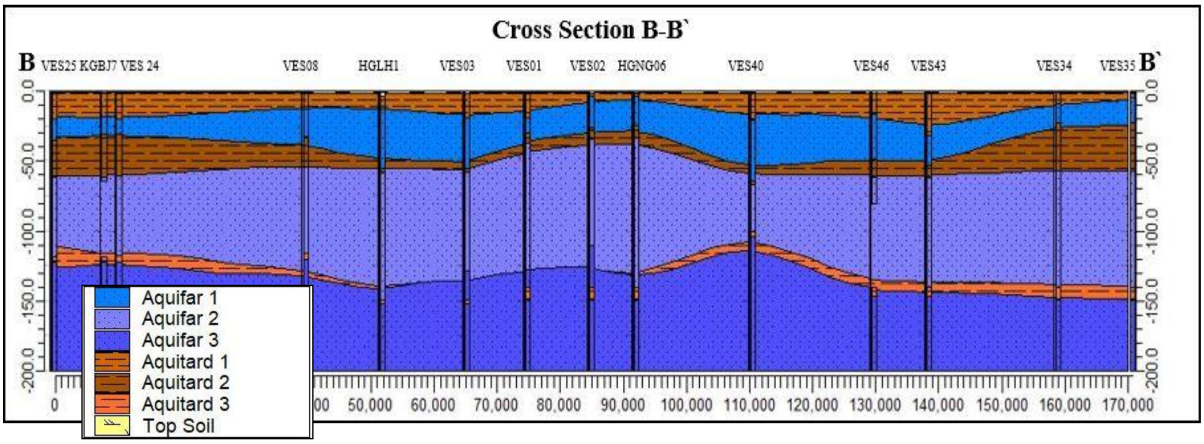


Figure 5-4: Geo-electric Cross Section along Line B-B`

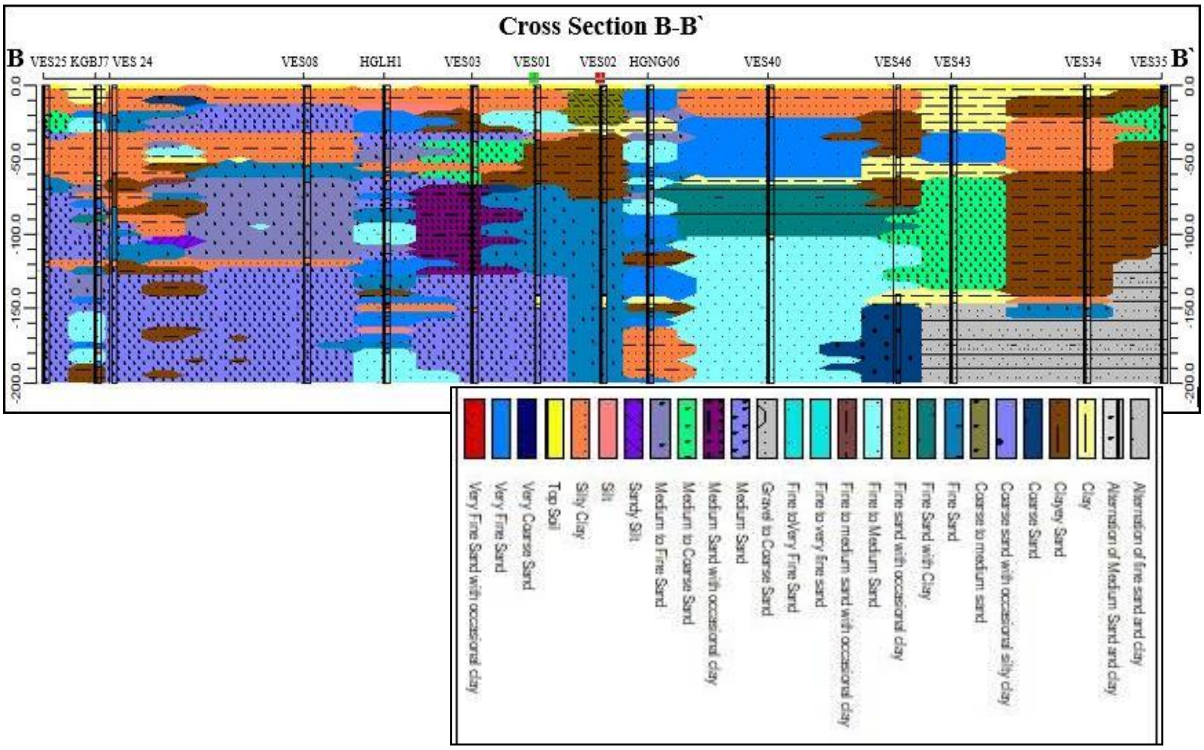


Figure 5-5: Lithological Cross Section along Line B-B`

5.2.3 Interpretation of Geoelectric Cross Section along C-C`

Geoelectric and lithologic cross sections along line C-C ` as shown in Figure 5-6 and Figure 5-7 is started from SE and ended to NW corner of the study area covering Netrokona, SW of Sunamganj, NE of Habiganj and Maulavibazar districts. The top layer is composed of silty clayey soil and is followed by Aquitard-1. Aquitard-1 is thin and extended throughout the section. Aquitard-1 is underlain by Aquifer-1 which is thick in the middle part of the section. The following hydrostratigraphic unit is Aquitard-2 of uniform thickness. Aquifer-2 with a more or less uniform thickness of more than 50m, overlain by Aquitard-2. Aquifer-2 is underlain by Aquitard-3 which is thinner than the Aquitard-2 and in the middle, it is very thin and hard to show in the cross section. The deepest identified layer is Aquifar-3 and encountered till the investigated depth of about 200m.

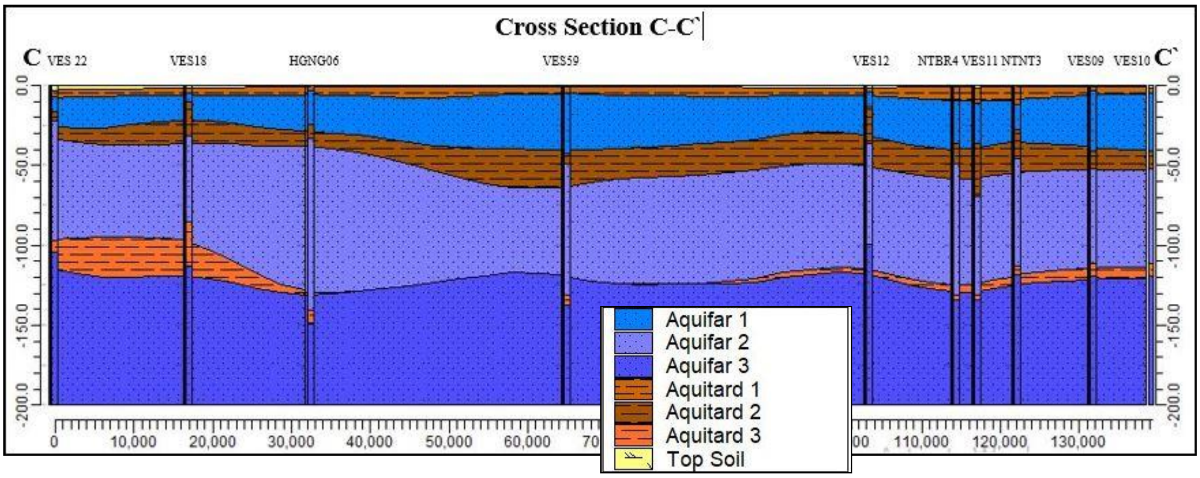


Figure 5-6: Geoelectric Cross Section along Line C-C`

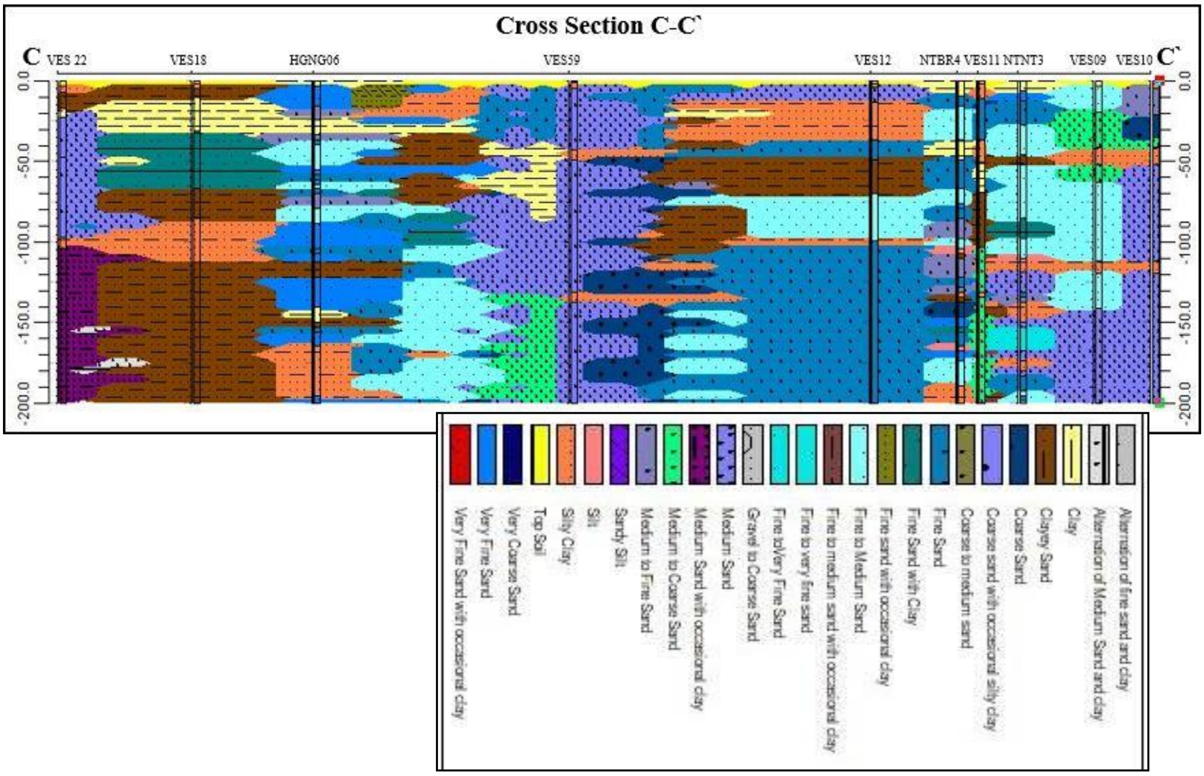


Figure 5-7: Lithologic Cross Section along Line C-C`

5.2.4 Interpretation of Geoelectric Cross Section along D-D`

Geoelectric and lithologic cross sections along line D-D` from south to north of the study area, covering Sunamganj and western margin of Habiganj districts in Figure 5-8 and Figure 5-9 show the top most layer is composed of silty clayey soil. The top soil is underlain by Aquitard-1. Aquitard-1 is slightly thick in the middle part of the cross section. Aquitard-1 is underlain by Aquifer-1 which is relatively thick (~25m) and uniform along the section.

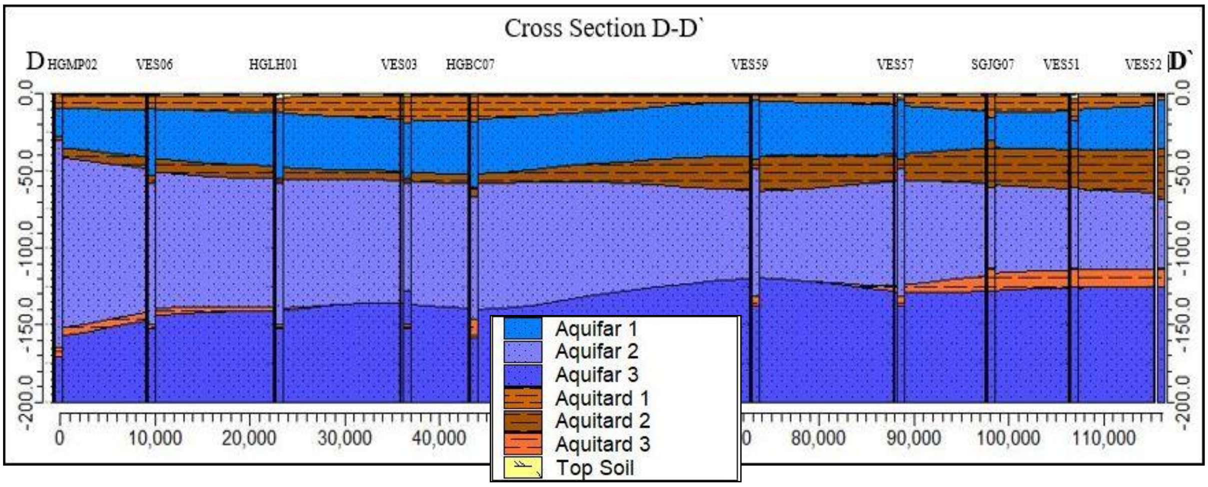


Figure 5-8: Geoelectric Cross Section along Line D-D`

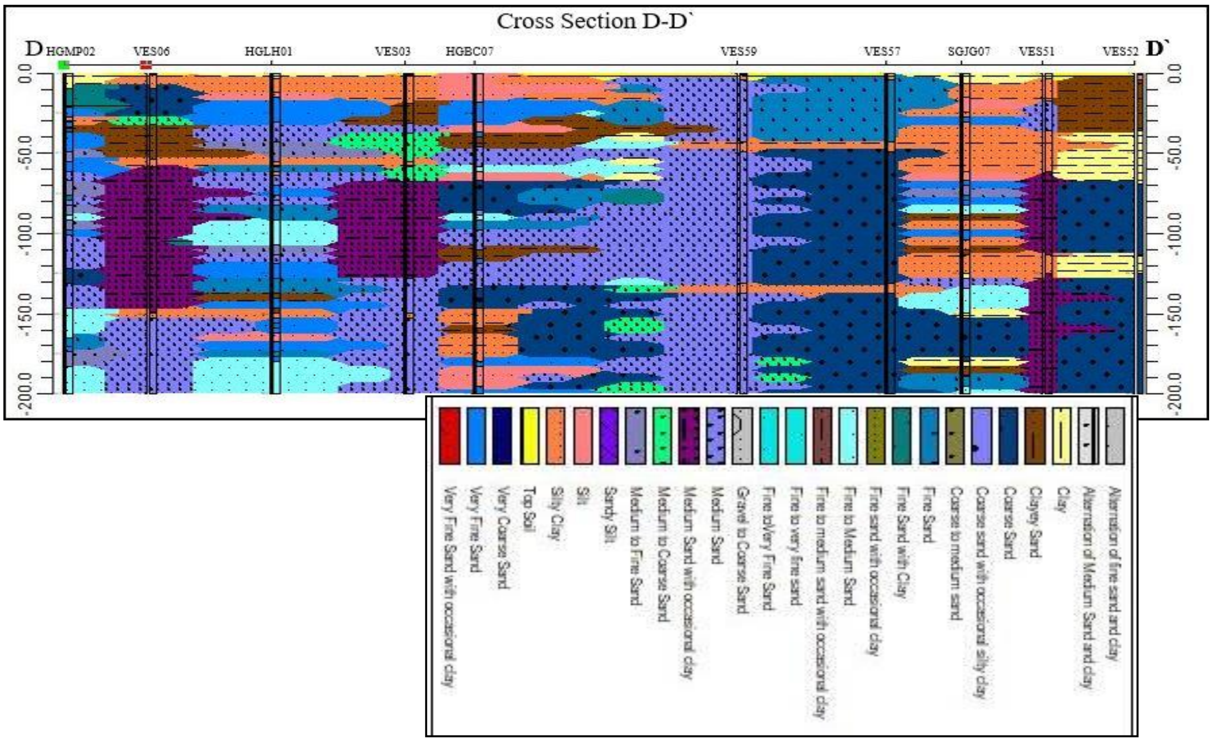


Figure 5-9: Lithologic Cross Section along Line D-D`

The following unit is Aquitard-2 which is relatively thin in the soutern part of the cross section. Aquifer-2 is thick and is about 110m thick in the soutern part and diminishes to about 65m in torthern part. Aquifer-2 is underlain by Aquitard-3 which is thin and around 10 to 15m in the southern and northern parts and in the middle it is very thin and hard to show in the cross section. The deepest identified layer is Aquifar-3 thickness of which couldn't be identified. Depth to the 3rd Aquifer reduces from south (~155m) to north (~125m) direction till the investigated depth of about 200m.

5.2.5 Contour Maps of the Depths to Aquifer Units

The Upper and the Lower Boundary of Aquifer-1

The depth contour map along the upper boundary of Aquifer-1 in Figure 5-10 shows maximum depth of this unit in the north eastern part of the survey area. Maximum depth to the upper boundary of this unit is about 31m at Golapganj, Sylhet and minimum depth is about 3m at Madan, Netrokona. 3D view clearly indicates the rapid increase and decrease of the aquifer boundary. Rapid increase in the depth of upper boundary of aquifer in 3D view is seen in the north eastern part of the study area which is shown in Figure 5-10.

The depth contour map along the lower boundary of Aquifer-1 in Figure 5-11 shows maximum depth of this unit in the western part of the area and decrease in depth in the northern and southern part. Maximum depth of the lower boundary of this unit is about 116m at Atpara, Kishoreganj and minimum depth is about 7m at Madan, Netrokona. 3D view clearly indicates the rapid fluctuations in the depth of upper and lower boundaries of the aquifer which are shown in Figure 5-10 and Figure 5-11 respectively.

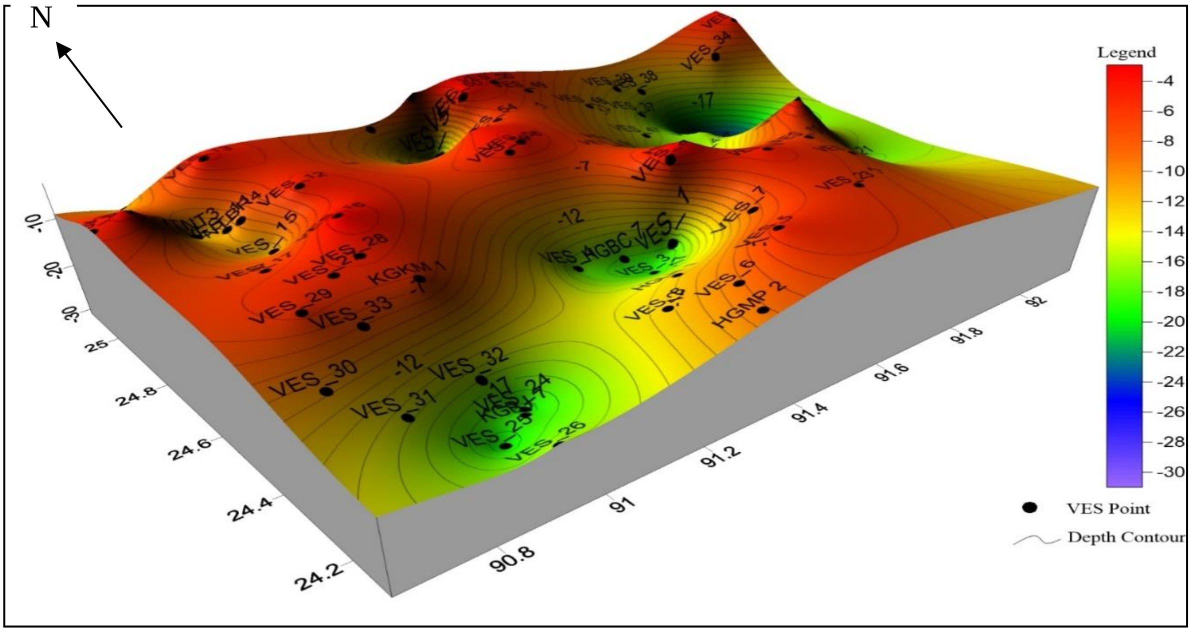


Figure 5-10: Depth Contour Map Along Upper Boundary of Aquifer-1 (3D view)

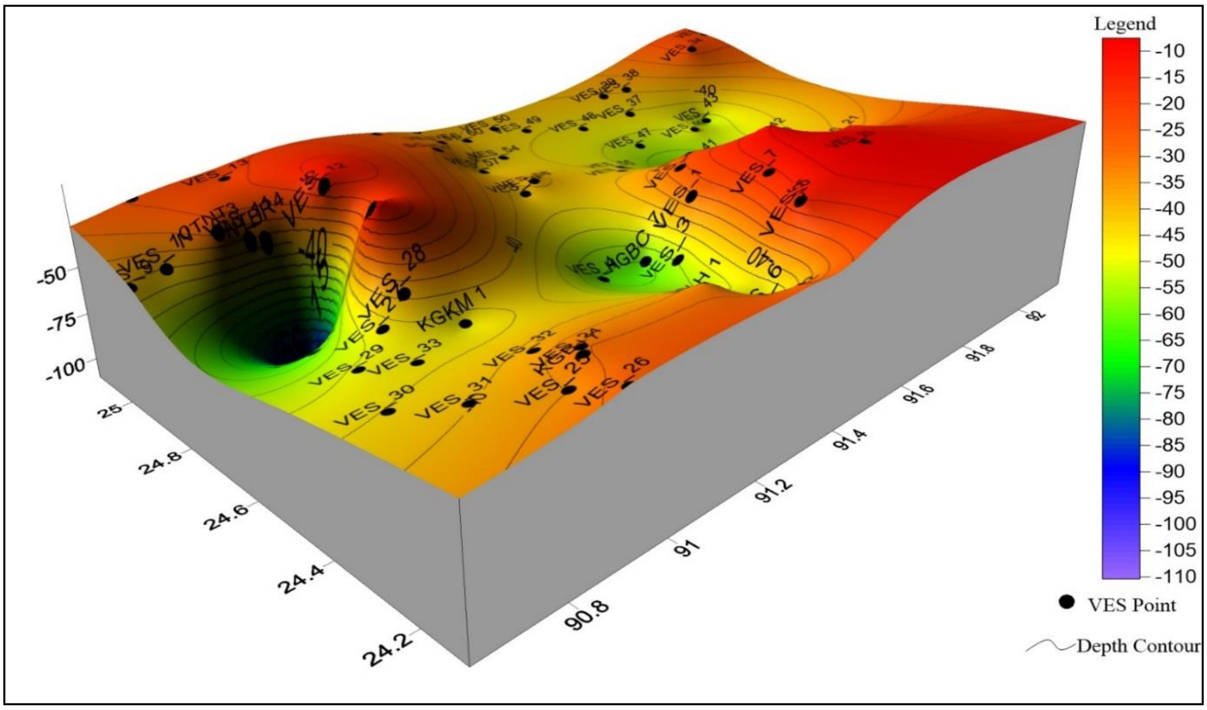


Figure 5-11: Depth Contour Map Along Lower Boundary of Aquifer-1 (3D View)

The Upper and the Lower Boundary of Aquifer-2

The depth contour map along the upper boundary of Aquifer-2 in Figure 5-12 shows maximum depth of this unit in the southern part of the survey area. Maximum depth to the upper boundary of this unit is about 165m at Madhabpur, Habiganj and minimum depth is about 64m at Bajitpur, Kishoreganj. 3D view clearly indicates the rapid rise of the aquifer boundary in the southern part of the study area as shown in Figure 5-13.

The Upper Boundary of Aquifer-3

The depth contour map along the upper boundary of Aquifer-3 in Figure 5-14 shows maximum depth of this unit in the southern part of the survey area. Maximum depth to the upper boundary of this unit is about 171m at Madhabpur, Habiganj and minimum depth is about 100m at Mohanganj, Netrokona. 3D view clearly indicates the rapid rise of the aquifer boundary in the southern part of the study area as shown in Figure 5-14. The lower boundary of Aquifer-3 is not encountered till the investigated depth of 200m.

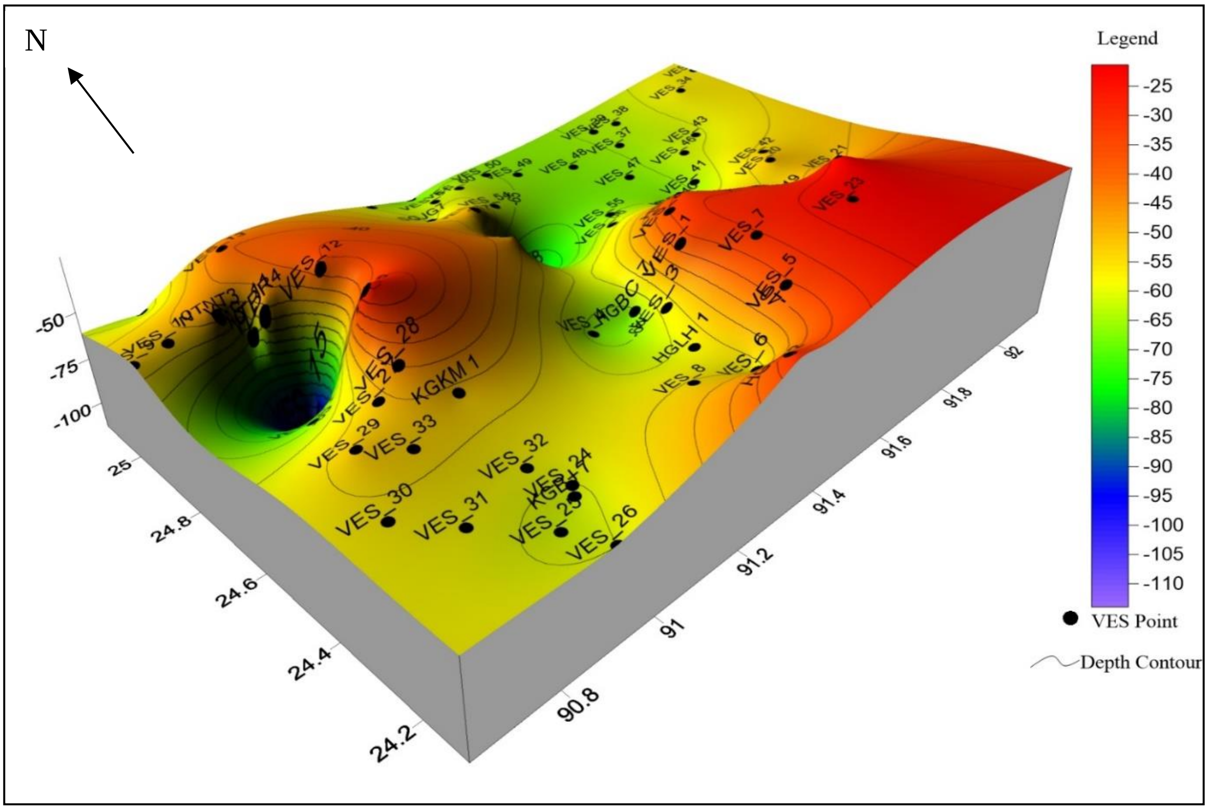


Figure 5-12: Depth Contour Map Along Upper Boundary of Aquifer-2 (3D View)

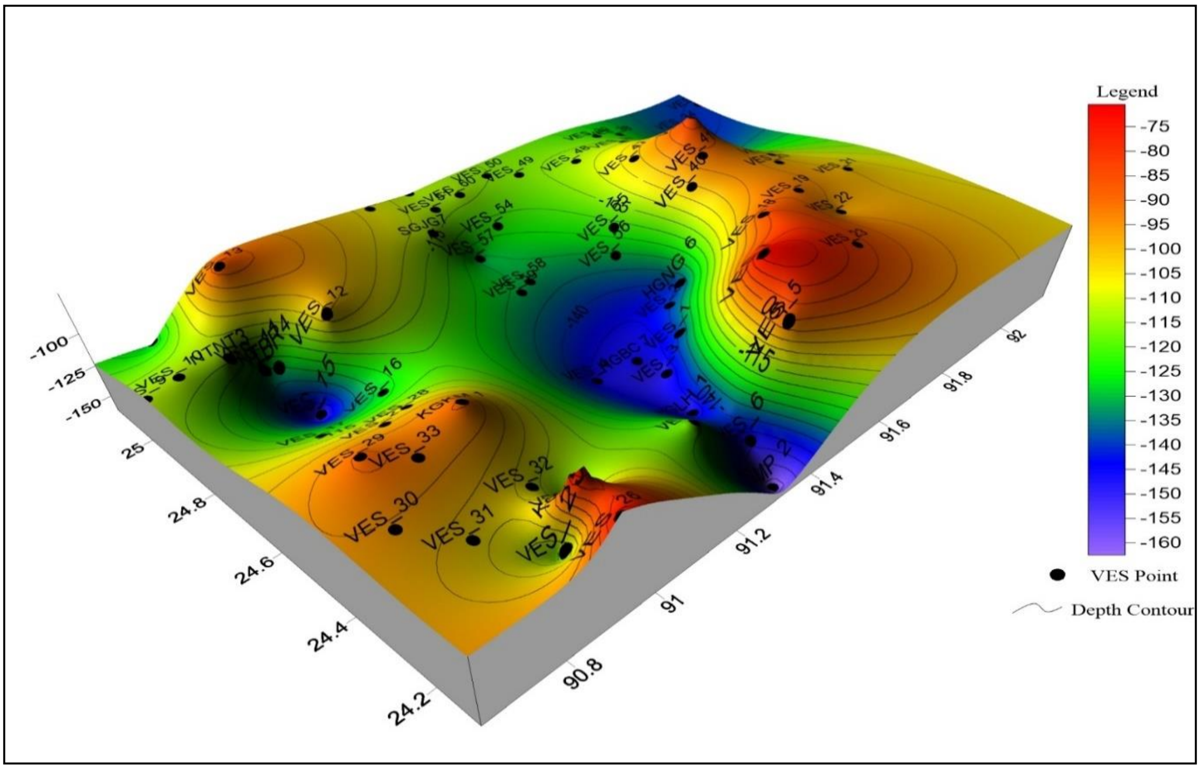


Figure 5-13: Depth Contour Map Along Lower Boundary of Aquifer-2 (3D View)

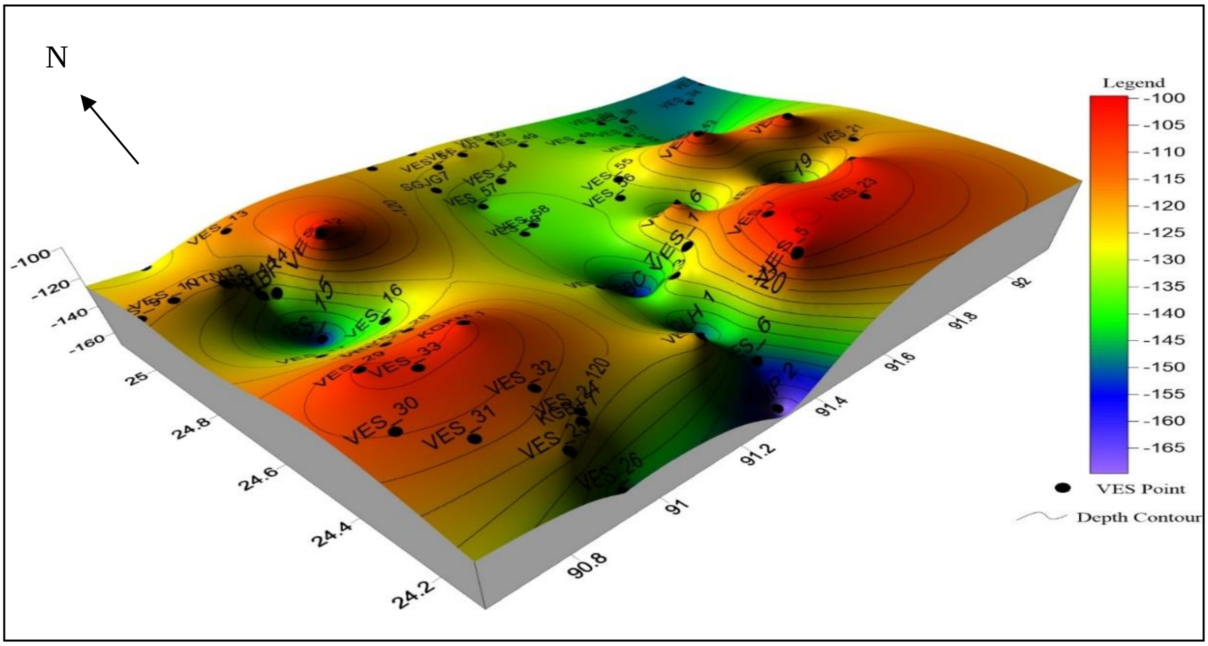


Figure 5-14: Depth Contour Map Along Upper Boundary of Aquifer-3 (3D View)

5.2.6 Contour Maps of the Thickness of Aquifer Units

The thickness contour map of Aquifer-1 in Figure 5-15 shows maximum thickness in the western part of the survey area. Maximum thickness of Aquifer-1 is about 104m at Atpara, Kishoreganj and minimum thickness is about 4m at Madan, Netrokona.

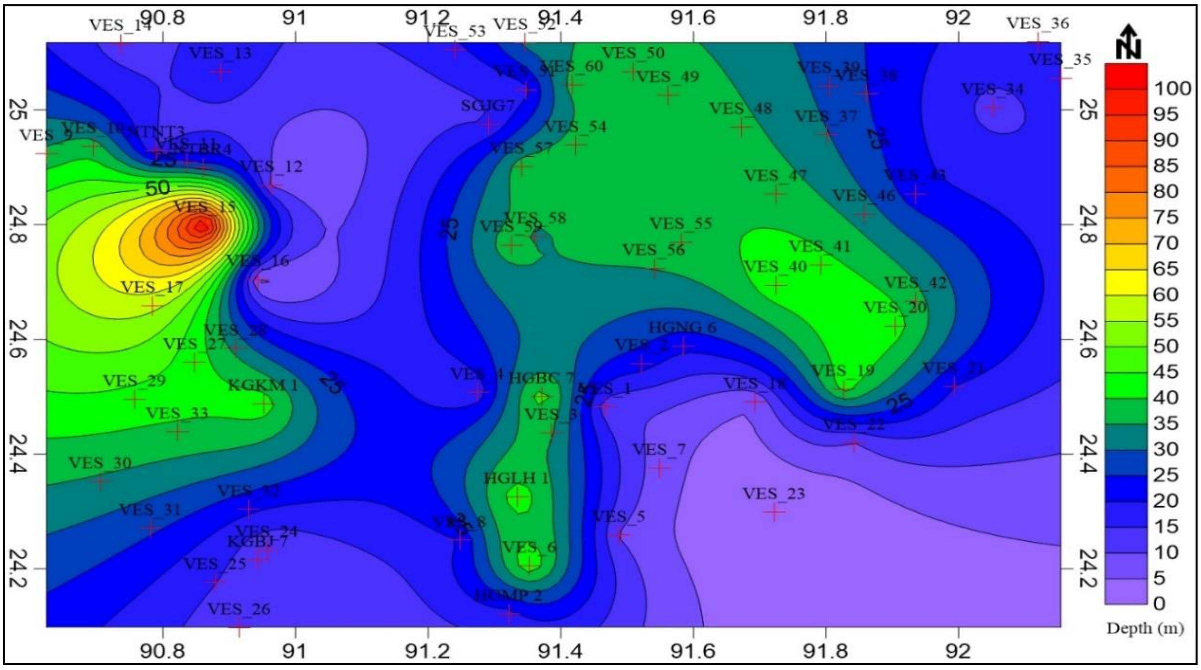


Figure 5-15: Thickness Contour Map of Aquifer-1

The thickness contour map of Aquifer-2 in Figure 5-16 shows maximum thickness in the southern part of the survey area. Maximum thickness of Aquifer-2 is about 134m at Madhabpur, Habiganj and minimum thickness is about 3m at Bajitpur, Kishoreganj.

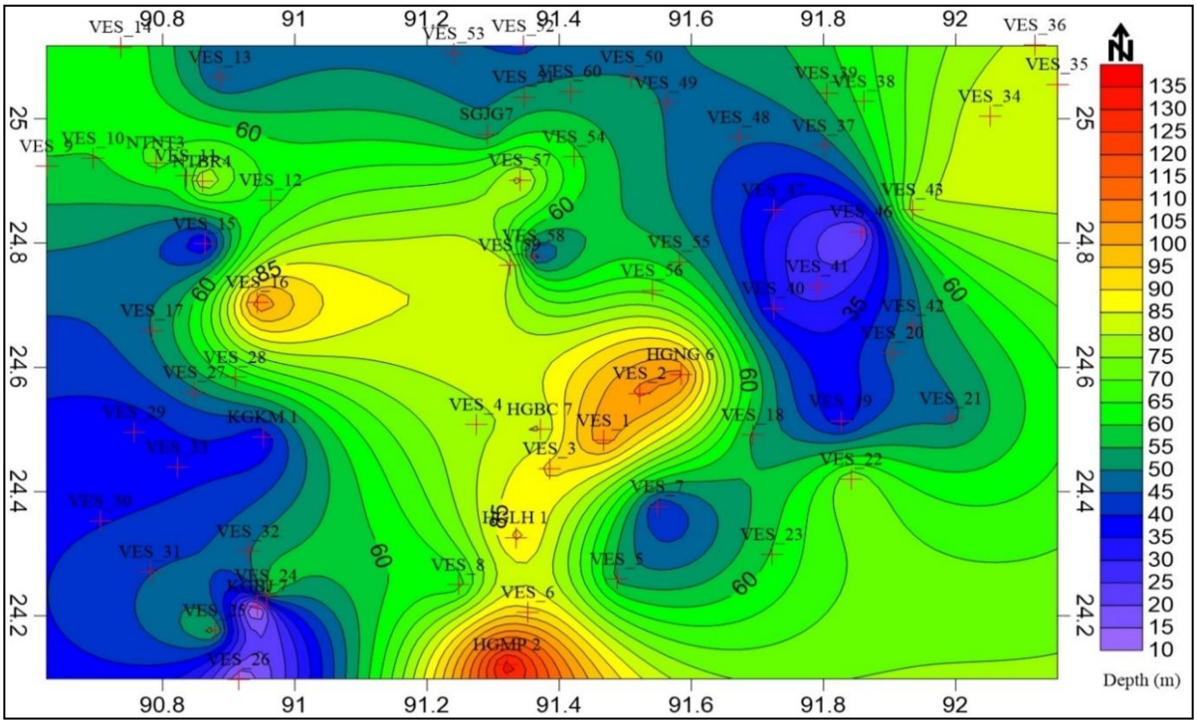


Figure 5-16: Thickness Contour Map of Aquifer-2

A fence diagram (Pseudo section) has been drawn to observe the aerial variation of Aquifer system vertically and laterally as show in Figure 5-17.

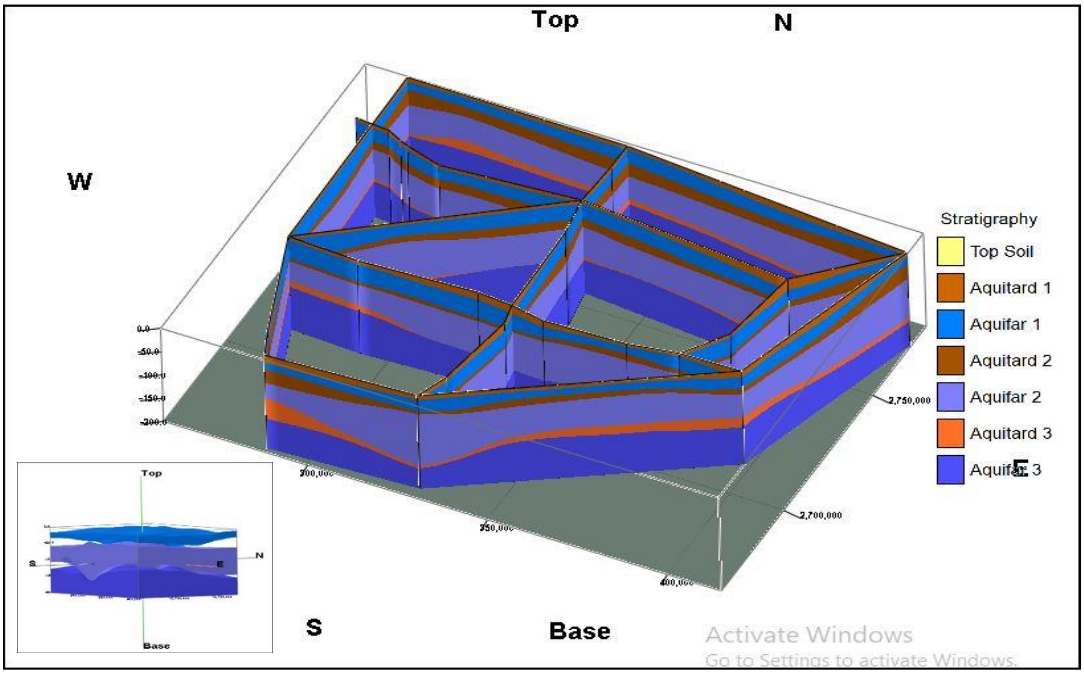


Figure 5-17: Pseudo Section (Fence Diagram) Showing the Aquifer Units of the Study Area

The details of Grophisical survey and anlysis is given in Volume-II, Appendix F.

5.3 Borehole Lithologic Logs

5.3.1 Aquifer System of Kishoreganj District

For the investigation of groundwater and understand the lithological variation, 98 borehole lithologs have been collected from different sources (such as BWDB, BADC and DPHE) and 7 exploratory drilling were conducted in seven upazilas upto the depth of 200 m. The depth range of all borelogs is 101.22 to 304.79 m. The detailed hydrogeological condition of the upazilas are described on the basis of the collected borelogs and analyzed the lithologic cross sections.

Depth of available borelog for Kuliar Char, Bajitpur, Katiadi, Pakundia, Hossainpur, Karimganj and Tarail upazilas varies from 111.28 to 271.27 m, 222.5 to 249.94 m, 198.17 to 304.79 m, 106.71 to 240.79 m, 101.22 to 198.17 m, 201.21 to 289.56 m and 201.21 to 240 m respectively. The generalized stratigraphic sections of Kishoreganj district in fence diagram are presented in Figure 5-18 and upazilawise description of aquifer system is presented in following paragraphs which are show in Figure 5-19 and Figure 5-20.

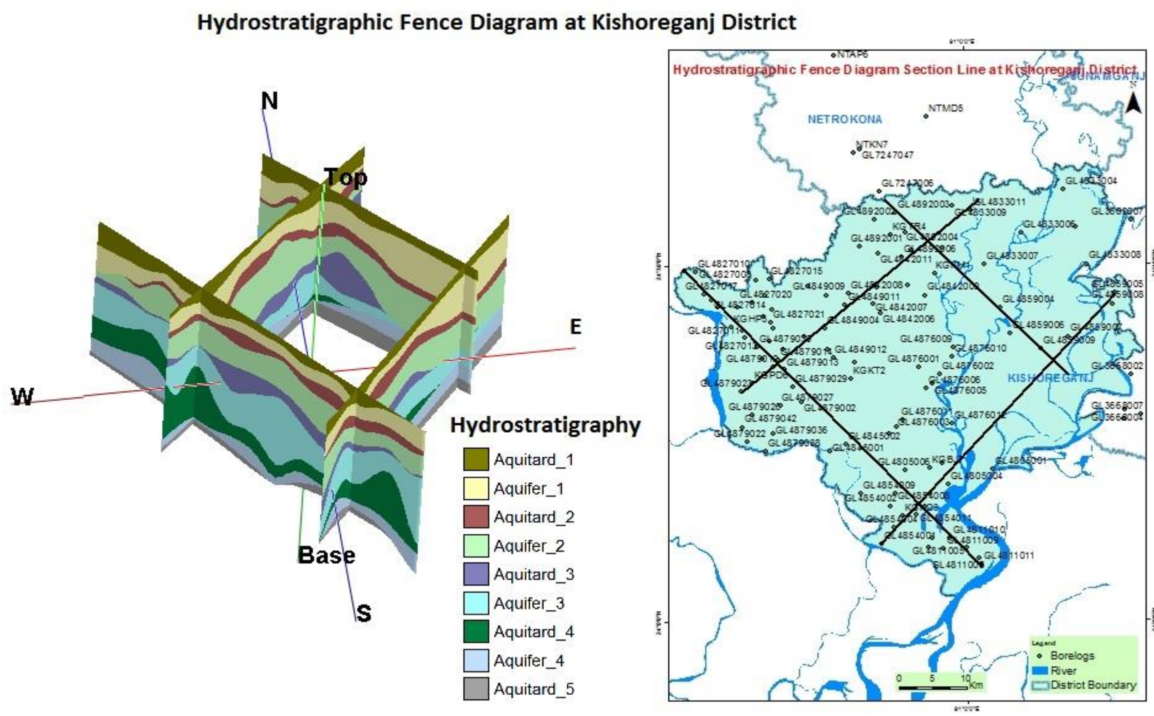


Figure 5-18: Hydrostratigraphic Fence Diagram of Kishoreganj District

Lithologic cross section along X-X′ in Figure 5-19 and Figure 5-20 represents the distribution of aquifer sediment of the Kuliar Char upazila down to about 270 m below ground surface. It reveals that top aquitard consist of clay, silt and very fine sand and the thickness varies from 0 to 60 m in place to place which increases in Faridpur union (GL4854001) area. In Ramdi union there is no aquitard present at the top of surface. Below this top clay and silty aquitard, a thick aquifer exists throughout the area with variable depths and the thickness ranges from 50 to 100 m. The aquifer is composed of medium sand and fine sand. Below this aquifer, there is an aquitard present throughout the area with variable thickness of 10 to 60 m in place to place. In Salua and Kuliar Char union the aquitard is only 5 m thick and underlain by a fine to medium sand aquifer encountered downto the depth of 230 m. In Faridpur and Ramdi union, deep aquifer is encountered at depth of 230 m with thickness of about 40 m, consisting of fine sand and medium sand.

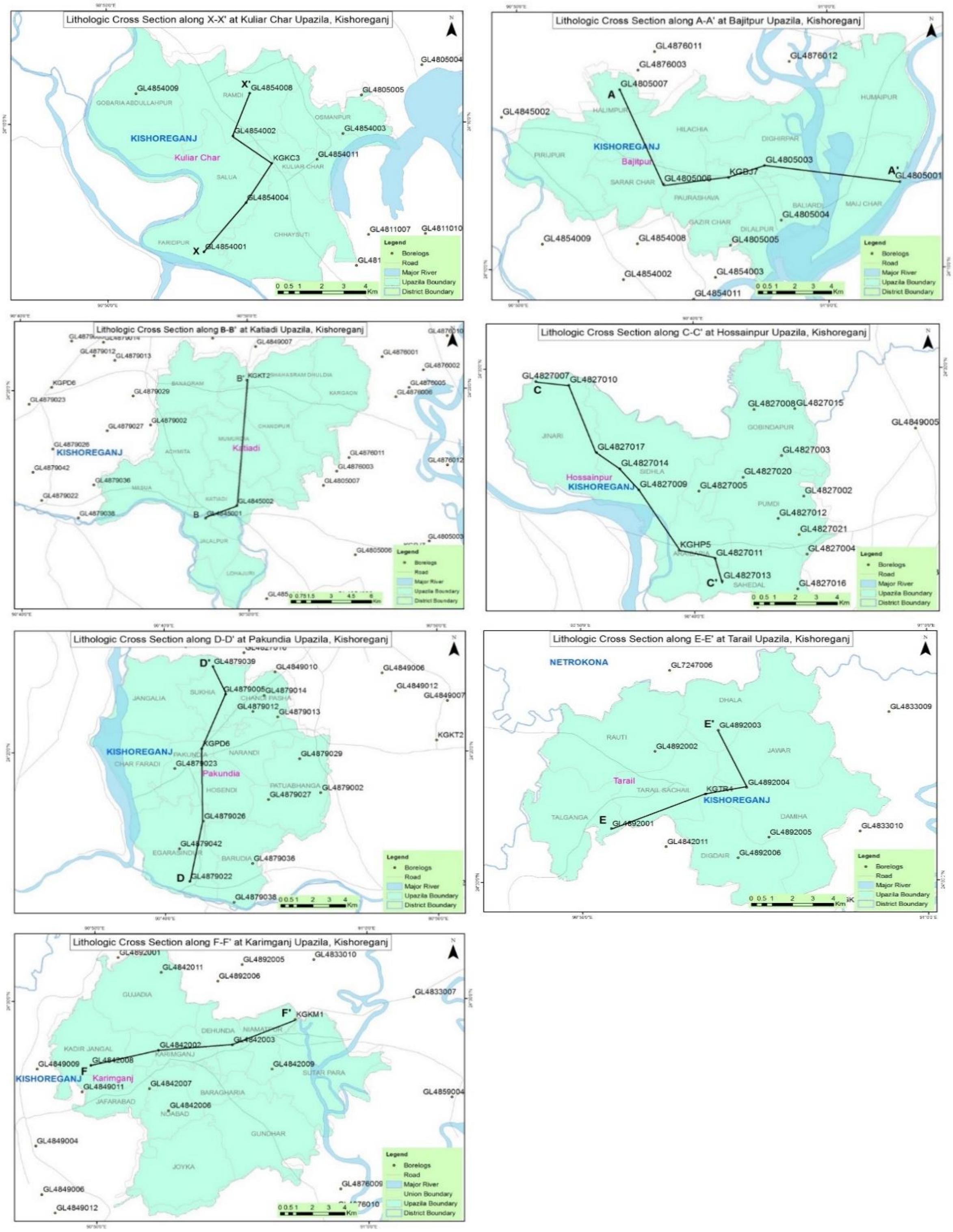


Figure 5-19: Borelog Distribution and Section Lines Under Kishoreganj District

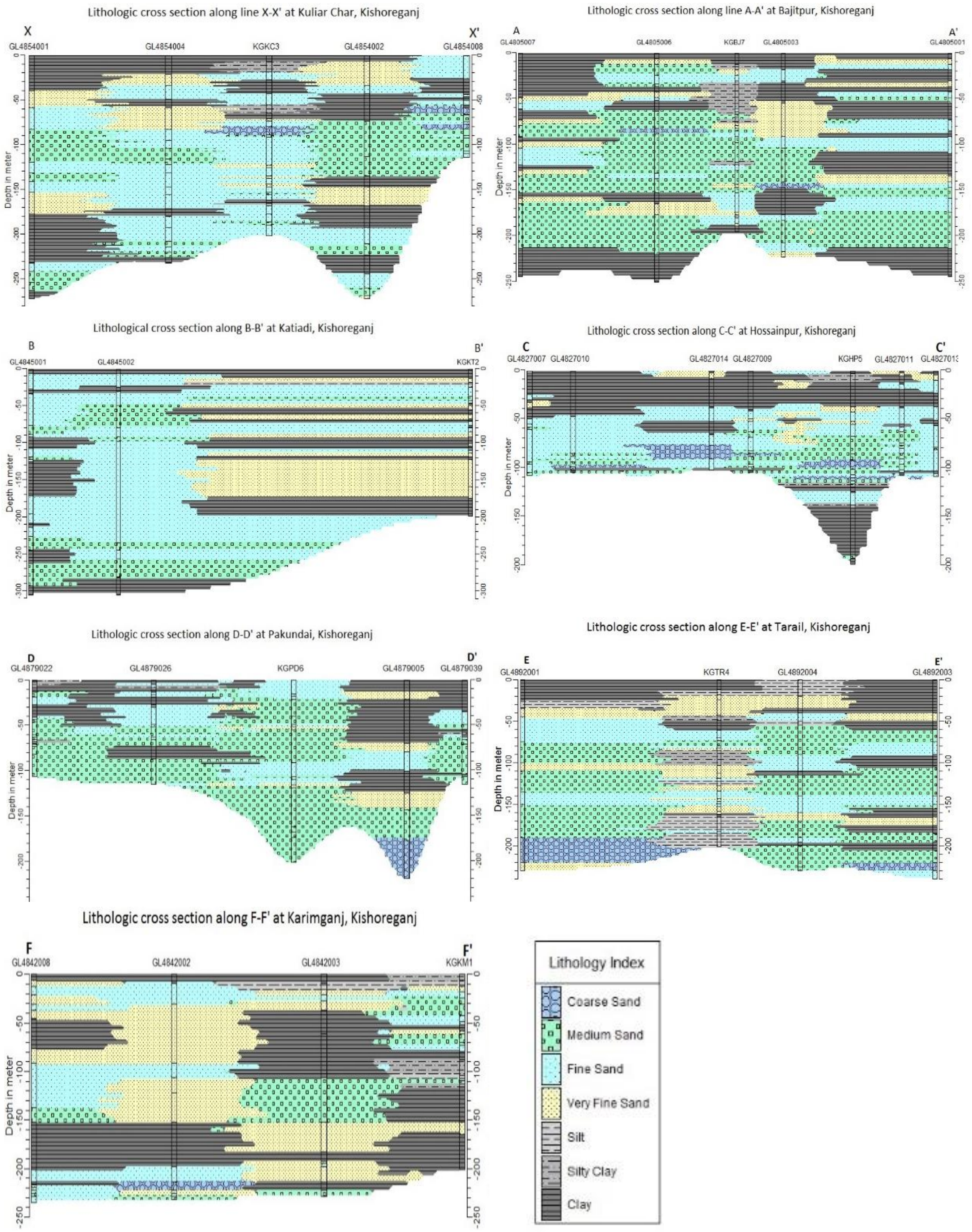


Figure 5-20: Lithologic Cross Sections Under Different Upazilas of Kishoreganj District

Lithologic cross section along A-A′ in Figure 5-19 and Figure 5-20 represents the layers distribution of the Bajitpur upazila. It reveals that top most aquitard consist of clay, silt and very fine sand and the thickness varies from 0-50 m in place to place which decrease in Sarar Char union (GL4805006) area. In Halimpur union (GL485007) there are four aquifers encounter from 78-90, 103-120, 134-151 and 165-213m separated with thin aquitard layer. In Sarar Char union

(GL4805006) three aquifers are exist from 12-36, 63-151 and 177-220 m upto the depth of 250m. From the project exploratory drilling (KGBJ7), it reveals that there is only one aquifer with interlayered with thin silt and very fine sand layer. There are three aquifers from 18-29, 90-145 and 176-214 m upto the depth of 224 m at Dighirpar union. Only one aquifer is encountered from 140-214m at Maij Char union upto depth of 245 m. The aquifers of the upazila are mostly composed of Medium sand and fine sand.

Lithologic cross section along B-B′ in Figure 5-19 and Figure 5-20 represents the layers distribution of the Katiadi upazila. The lithology of the Katiadi upazila is very complex. At Jalalpur union (GL4845001) there are three aquifers present at depth of 6-25, 33-89, 173-242 and 260-290 m where as there is one thick aquifer present from 33-280 m at Katiadi union (GL4845002). On the other hand at Shahasram Dhuldia (KGKT2) there are three thin aquifers present from 24-44, 70-84 and 109-113m upto the depth of 200m. The aquifers of the upazila are composed of fine sand and medium sand.

Lithologic cross section along C-C′ in Figure 5-19 and Figure 5-20 represents the layers distribution of the Hossainpur upazila. Form the lithologic section it reveals that there is only one aquifer upto the drilling depth of 198 m. The thickness of the aquifer varies from 35-80 m with variable depth in place to place throughout the upazila. From the project exploratory drilling (KGHP5) it also reveals that below the aquifer there is an aquitard present upto the depth of 198 m. The aquifer consists of mainly fine sand and medium. At Aribaria union (KGHP5), the aquifer is composed of medium to coarse sand.

Lithologic cross section along D-D′ in Figure 5-19 and Figure 5-20 represents the layers distribution of the Pakundia upazila. From the exploratory drilling (KGPD6) under this project at Pakundai, it reveals that there is no aquitard upto the depth of 200 m. The productive aquifer extended from the top to the drilling depth of 200m. The aquifer is composed of mostly medium to coarse sand. At Sukhia union (GL4879005), the productive aquifer present from 113m to the drilling depth of 219m which is composed of coarse sand and medium sand. A thick aquitard present at the top of this productive aquifer which is composed of clay and very fine sand. There is one thick aquifer present from 40-105 m and 65-105m at Egarsindur (GL4879022) and Sukhia (Gl48790039) union respectively. At Egarsindur union (GL4879026), two aquifers found from 30-73 and 87-114 m upto the drilling depth of 114 m. The aquifers are consisting of medium sand and fine to medium sand and are separated with thin clay layer.

Lithologic cross section along E-E′ in Figure 5-19 and Figure 5-20 represents the layers distribution of the Tarail upazila. From the lithologic cross section it reveals that at Talganga union (GL4892001) there is a thick aquifer present from 45-220m which is composed of coarse to medium sand, medium sand and fine sand. At Damiha union (GL4892004), three aquifers present from 55-110, 115-195 and 200-230 m separated each other with 3-5 m thin clay layers. The aquifers are composed of medium sand, medium to fine sand and fine sand. At Tarail Sachail union (KGTR4), two thin aquifers are present from 24-45 and 70-85 m upto the drilling depth of 201.21 m. At Dhala union (GL4892003), aquifers are present from 60-90, 105-155 and 208-240 m. The aquifers are composed of coarse sand, medium sand and fine sand. The overall groundwater condition of the upazila is good except the Tarail Sachail union.

Lithologic cross section along F-F′ in Figure 5-19 and Figure 5-20 represents the layers distribution of the Karimganj upazila. From the project exploratory drilling (KGKM1) it reveals that there are two aquifer presents from 18-51 and 60-80m upto the depth of 201.21m at Niamatpur union. At Kadir Jangal union (GL4842008) two major aquifers present from 90-150 and 201-234 m which are consist of fine sand and fine to medium sand. At Karimganj union, the aquifers are present from 9-30, 91-106, 198-231 m upto the depth of 231 m separated from each other with very fine sand and clay layers. The aquifers are composed of fine sand, medium sand and coarse sand. There is only one productive aquifer present from 106-152 m which is composed of medium sand.

5.3.2 Aquifer System of Netrokona District

For the investigation of groundwater and understand the lithological variation, 16 borehole lithologs have been collected from different sources (such as BWDB, BADC and DPHE) and 7 exploratory drilling were conducted in seven upazilas downto the depth of about 201 m. The depth range of all borelogs is 54.90 to 262.2 m. The detail hydrogeological condition of the upazilas is described on the basis of collected borelogs and analyzed the lithologic cross section.

Depth of available borelog of Netrokona Sadar, Purbadhala, Atpara, Barhata, Durgapur, Kendua and Madan upazilas varies from 54.9 to 240.26 m, 54.9 to 240.26 m, 109.45 to 198.17 m, 109.76 to 201.21 m, 201.21 to 231.71 m, 115.24 to 222.56 m, and 85.98 to 262.2m respectively. The generalized stratigraphic sections of Netrokona district in fence diagram are presented in Figure 5-21 and upazilawise description of aquifer system is presented in following paragraphs as shown in Figure 5-22 and Figure 5-23.

Lithologic cross section along G-G′ in Figure 5-22 and Figure 5-23 represents the layers distribution of the Kendua upazila. At Muzaffarpur union (GL7247006) there are three aquifers present from 5-32, 55-87 and 104-116 m upto the drilling depth of 115 m. The aquifers are composed of fine sand, medium sand and coarse sand, which are separated from each other with thick clay layer. The aquifers are extended throughout the section area with variable depth and thickness. At Mashka union (NTKN7) one thick aquifer present from 31-167m which is composed of mostly fine sand and medium sand. At Kandiura union (GL7247047) four aquifers present from 6-82, 85-103, 109-173 and 183-216 m upto the drilling depth of 222.56 m. The aquifers are separated with 3-10 m thick clay layers. The 1st, 2nd and 3rd aquifers are composed of fine sand and the 4th aquifer consists of medium sand.

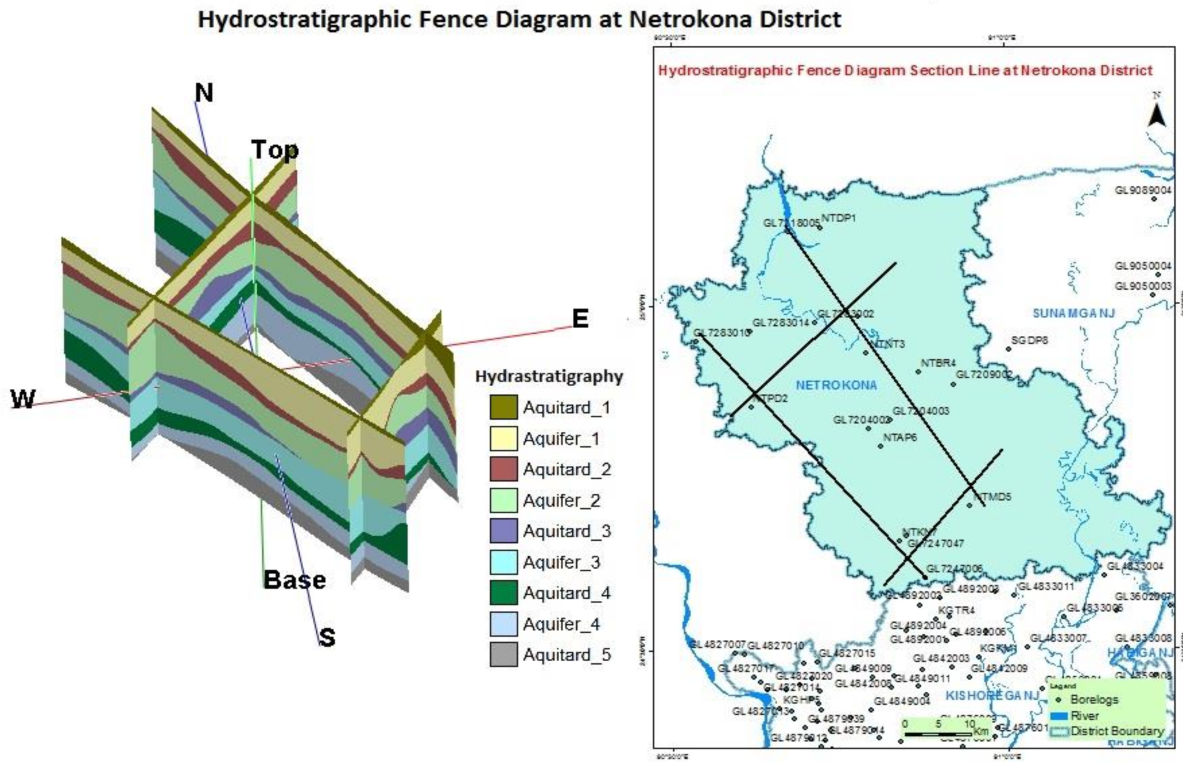


Figure 5-21: Hydrostratigraphic Fence Diagram of Netrokona District

Lithologic cross section along H-H′ in Figure 5-22 and Figure 5-23 represents the layers distribution of the Madan upazila. At Kaitail union (GL7256001) there are two aquifers present from 0-34, 36-85m upto the drilling depth of 85 m. The 1st aquifer is composed of fine sand and the 2nd aquifer is composed of medium sand and coarse sand. The aquifers are separated from each other with thin clay layer. At Jhangirpur union (NTMD5) three aquifers present from 39-61, 103-127 and 142-201 m. The aquifers are composed of mostly fine sand. From another borehole lithology at Jhangirpur union (GL7256004) shows that there are three aquifers present from 63-118,141-163 and 192-247 m upto the drilling depth of 262.2m. The aquifers are separated with 22-30 m thick clay layers. The 1st and 2nd aquifers are composed of fine sand and the 3rd aquifer is composed of fine and medium sand.

Lithologic cross section along I-I′ in Figure 5-22 and Figure 5-23 represents the layers distribution of the Atpara upazila. From the lithologic cross section it reveals that at Abhypasha (NTAP6) there are three aquifers present from 10-115, 119-134 and 155-175 m upto the depth of 200 m. The aquifers are separated with a thin clay layer (less than 5m). The aquifers are composed of mostly fine sand. At Ghagra (GL7204002) and Jalalpur (GL7204003) there are three aquifers present with variable thickness and depth in the areas. The thickness of the 2nd aquifer is 16 m which is extended throughout the section areas with variable depth. The aquifer is composed of mostly medium sand. Below this aquifer, a clay layer exists at Ghagra and Jalalpur areas with variable thickness from 4-17 m. The thickness of the 3rd aquifer varies from 26-48 m with variable depth in Ghagra and Jalalpur. The aquifer is composed of medium and coarse sand which is prolific aquifer for these areas.

Lithologic cross section along J-J′ in Figure 5-22 and Figure 5-23 represents the layers distribution of the purbadhala upazila. From the lithologic cross section it reveals that at Narandia union (NTPD2) there are two thick aquifers present from 40-100 m and 110-155 m upto the depth of 200m, separated with a thin silty clay layer. Among the aquifers, first aquifer is mostly composed of coarse sand and medium sand which is prolific aquifer for this area. First aquifer is extended with variable thickness and depth at Purbadhala (GL7283014) and Dhala mulgaon (GL7283002) union, where it separated with a thin clay layer. The aquifers are composed of coarse sand.

Lithologic cross section along K-K′ in Figure 5-22 and Figure 5-23 represents the layers distribution of the Netrokona upazila. From the lithologic cross section it reveals that in Kailati union (GL7274002) there are two aquifers present from 2-30 and 62-98 m separated with a thick clay layer. The aquifers are composed of fine sand, fine to medium sand and Medium sand. At Singhar Bangla union (GL7274004) the first aquifer is present from 3-35m and composed of fine sand interbedded with very fine sand layers. The second aquifer is present from 45-54 m which is composed of medium sand, separated from first aquifer with 10 m thick clay layer. At Thakurkona union there are five aquifers present at 12-45, 51-108, 119-135, 149-173 and 179-202 m upto the drilling depth of 204.26 m. The aquifers are consisting of fine sand and medium sand.

Lithologic cross section along L-L′ in Figure 5-22 and Figure 5-23 represents the layers distribution of the Barhata upazila. From the lithologic cross section it reveals that at Roypur union (GL7209003) there are two aquifers present upto the depth of 109.76 m. The 2nd aquifer exists from 70-104 m which is composed of coarse sand and medium sand. At Sahata union (NTBR4), four aquifers present from 9-36, 48-103, 109-129 and 136-187 m separated each other with 3-10 m thin clay layers. The aquifers are composed of fine sand, medium sand and coarse sand. At Barhata union (GL7209002), three aquifers are present from 0-29, 45-74 and 79-116 m upto the drilling depth of 116 m. The aquifers are composed of coarse sand, medium sand and fine sand.

Lithologic cross section along M-M′ in Figure 5-22 and Figure 5-23 represents the layers distribution of the Durgapur upazila. At Birisiri union (GL7218005) there are four aquifers present at depth from 3-29, 34-91, 94-148 and 183-205m. The top three aquifers are separated from each other with 3m thin clay layer. The 3rd aquifer is prolific for this area which is composed of mostly coarse sand. The 4th aquifer is composed of very fine sand. At Chandigarh union (NTDP1) there are three aquifers present from 20-27, 88-109 and 117-128m upto the depth of 201.21 m. The aquifers of the area are composed of fine sand.

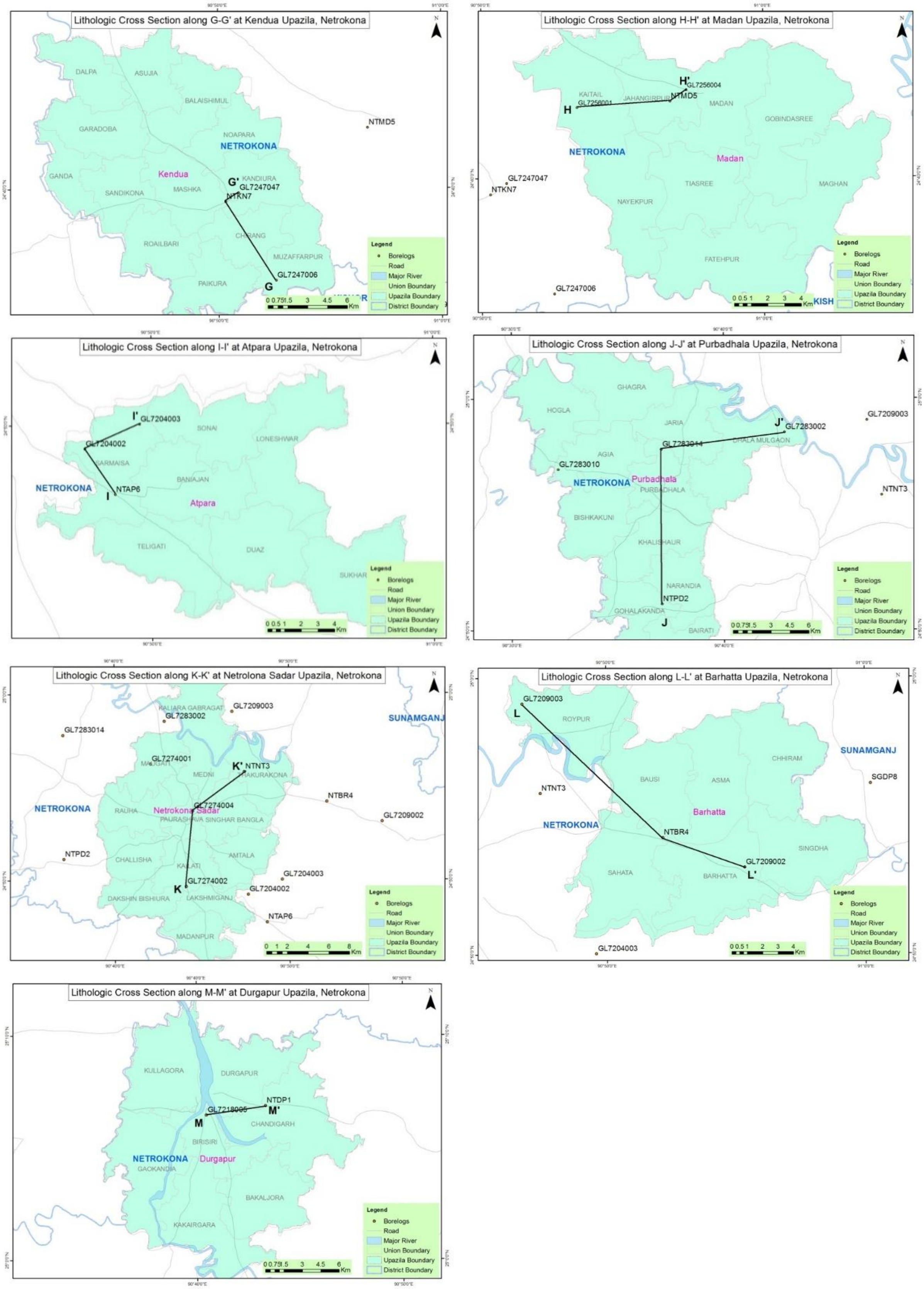


Figure 5-22: Borelog Distribution and Section Lines under Netrokona District

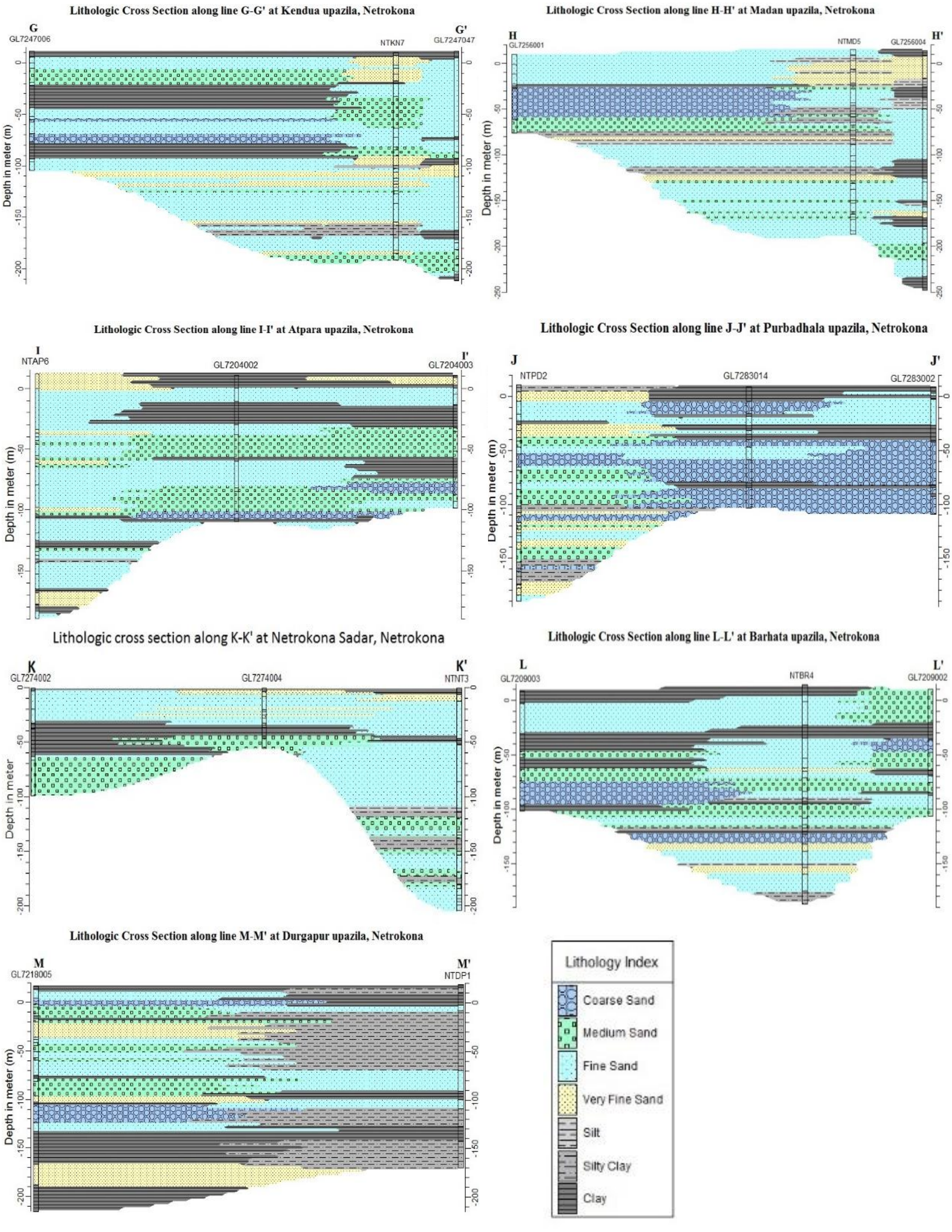


Figure 5-23: Lithologic Cross Sections under Different Upazilas of Netrokona District

5.3.3 Aquifer System of Sylhet District

For the investigation of groundwater and understand the lithological variation, 48 borehole lithologs have been collected from different sources (such as BWDB, BADC and DPHE) and

6 exploratory drilling were conducted in six upazilas downto the depth of about 198 m. The depth range of all borelogs is 115.85 to 304.79 m. The detail hydrogeological condition of the upazilas is described on the basis of collected borelogs and analyzed the lithologic cross sections.

Depth of available borelogs of Balaganj, Beani Bazar, Dakshin Surma, Golapganj, Jaintiapur and Kanaighat varies from 134.15 to 286.59 m, 198 to 301 m, 151 to 198 m, 164 to 222 m, 195 to 217 m and 115 to 198 m respectively. The generalized stratigraphic sections of Sylhet district in fence diagram are presented in Figure 5-24 and upazilawise description of aquifer system is presented in following paragraphs which are shown in Figure 5-25 and Figure 5-26 respectively.

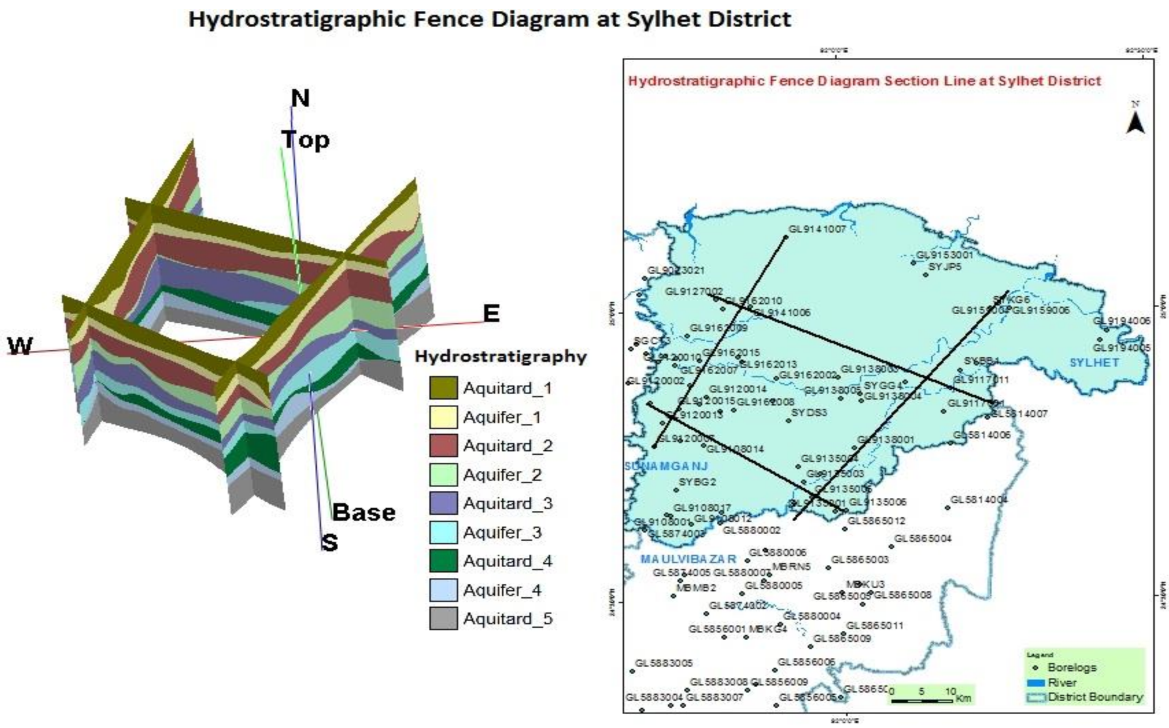


Figure 5-24: Hydrostratigraphic Fence Diagram of Sylhet District

Lithologic cross section along A-A′ in Figure 5-25 and Figure 5-26 represents the layers distribution of the Balaganj upazila. At Dayamir union (GL9108014) there are four thin aquifers present from 42-48 m, 61-67 m, 128-137 m and 170-183 m upto the drilling depth of 183 m. The aquifers are composed of fine sand and coarse to medium sand. There is a thick clay layer (42 m) present at the top of the area which is extended throughout the Balaganj upazila except Paschim Pailanpur (GL 9108001). At Goula Bazar union (SYBG2) there are three thin aquifers present from 67-79 m, 106-112 m and 149-179 m upto to drilling depth of 198 m. The aquifers are composed of very fine to fine sand which is not suitable for groundwater development. Only hand tubewell can be used for drinking water supply. At Paschim Pailanpur union (GL 9108001) there is a thin clay layer present at the top of the area. Bleow this aquitard there are two aquifers present from 7-28m and 62-99 m separated with 34m thick clay layer. Below these aquifers there is a thick clay layer present upto drilling depth of 286 m which is alarming for this area. The scenario is same for another drilling borehole (GL9108017) where there is one suitable aquifer present from 73-100 m upto the drilling depth of 256 m which is composed of very fine to fine sand. On the other hand, at Purba Pailanpur union (GL9108012) three aquifers present from 54-73 m, 82-100 m and 112-137 m upto the depth of 143m, separated from each other with thin clay layer. The aquifers are consisting of fine sand and medium sand.

Lithologic cross section along B-B′ in Figure 5-25 and Figure 5-26 represents the layers distribution of the Dakshin Surma upazila. From the exploratory boring at Lala Bazar (GL9162008) union it reveals that below a 140 m thick clay layer, there is only one aquifer present from 140-151 m upto drilling depth of 151 m. The extension of the aquifer is limited. The aquifer is composed of medium sand which is confined in nature. At Silam (GL9162004) union, only one aquifer is encountered from 27-48 m which extended in Mogla Bazar union with variable depth and thickness. Below this aquifer, a thick clay aquitard exists upto the depth of 182 m. The aquifer is composed of fine sand. At Mogla Bazar union (SYDS3), three aquifers are present from 42-57 m, 109-167 m and 173-182 m. The aquifers are consisting of very fine sand, fine sand and medium sand.

Lithologic cross section along C-C′ in Figure 5-25 and Figure 5-26 represents the layers distribution of the Golapganj upazila. At Bagha union (GL9138003), two fine sand aquifers are present from 48-64 m and 88-103 m, separated with clay materials. From the project exploratory drilling at Golabganj union (SYGG4), it is observed that there are two thin aquifers exist from 115-131 m and 161-182 m down to the depth of 200 m. The aquifers are consisting of very fine to fine sand which is not considered as a good aquifer for water abstraction. There is a thick aquitard, consists of clay extended from the surface to the depth of 115.85 m. Another drilling at Golabganj union (GL9138004) shows that there are three thin fine sand aquifers exist at depth of 24-30 m, 51-60 m and 115-123 m down to the investigated depth of 222 m. At Bhadeshwar union (GL9138001), there are two aquifers present from 37-93 m and 95-101 m separated from each other with thick clay aquitard. The aquifers are consisting of very fine to fine sand and fine sand to medium sand.

Lithologic cross section along D-D′ in Figure 5-25 and Figure 5-26 represents the layers distribution of the Beani Bazar upazila. At Dobhag union (GL9117010) two thick aquifers present from 6-103m and 121-207 m upto the drilling depth of 213 m. 1st aquifer is mostly composed of very fine sand and 2nd aquifer is composed fine sand and medium sand. On the top of the 1st aquifer there is clay layer present with variable thickness throughout the area. The northern part of Sheola union (SYBB1) there are three thin aquifers present from 24-30m, 115-121m and 140-146m, separated from each other with thick aquitard upto the drilling depth of 200 m. Groundwater source is limited in this area for drinking purpose. The aquifers are consisting of fine sand and medium sand. At southern of Sheola union (GL9117011), two major aquifers present from 42-146 m and 170-207 m upto drilling depth of 207m, are extended throughout the Beani Bazar union with variable depth and thickness. Among them the 1st aquifer consists of very fine sand and medium sand and the 2nd aquifer consists of mostly medium sand and coarse sand. At Beani Bazar union (GL9117001), there are three thick fine sand aquifers present up the drilling depth of 301m, are separated from each other with 8-10m thick clay layer.

Lithologic cross section along E-E′ in Figure 5-25 and Figure 5-26 represents the layers distribution of the Kanaighat upazila. At Kanaighat upazila, there is a thick aquifer present upto drilling depth of 198 m, interlayered with some clay and silty clay lenses. The thickness of the aquifer ranges from 90-165 m which is extended throughout the section line with variable depth. The aquifer consists of fine sand, fine to medium sand, medium sand and medium to coarse sand with some gravel lenses.

Lithologic cross section along F-F′ in Figure 5-25 and Figure 5-26 represents the distribution of aquifer sediments under Jaintiapur upazila. At Nijpat union (GL9153001) two thick fine sand aquifers are present from 54-66 m and 71-78 m separated from each other with thin clay layer. Below these aquifers there is a thick clay aquitard present down to the drilling depth of 217m. In Darbasta union (SYJP5) under Jaintiapur upazila, it is observed that there is only one thin aquifer exist from 9-21m, which is only source of water for drinking purpose down to the investigated depth of 200 m. The aquifer consists of fine to medium sand and medium sand.

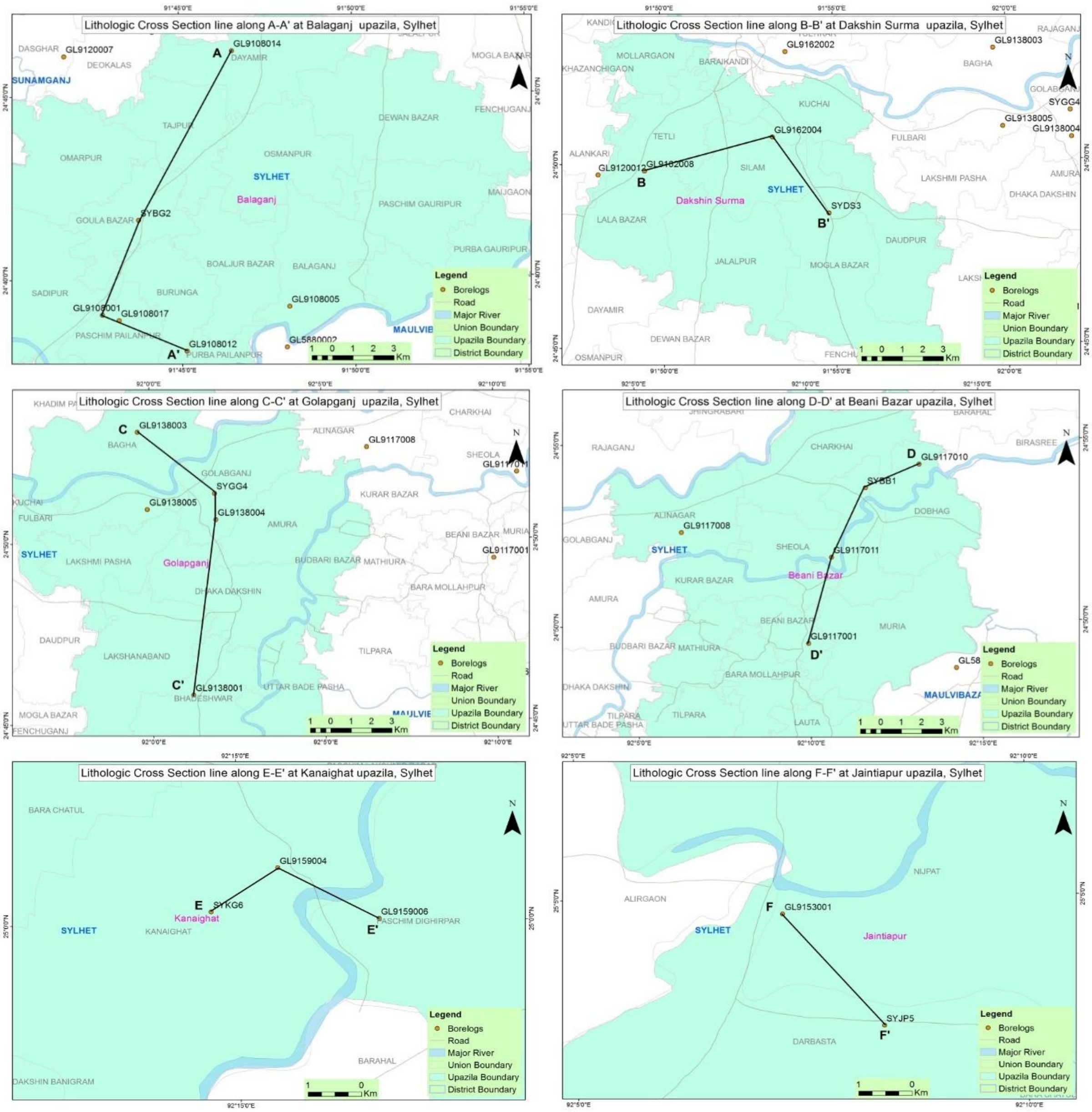


Figure 5-25: Borelog Distribution and Section Lines under Sylhet District

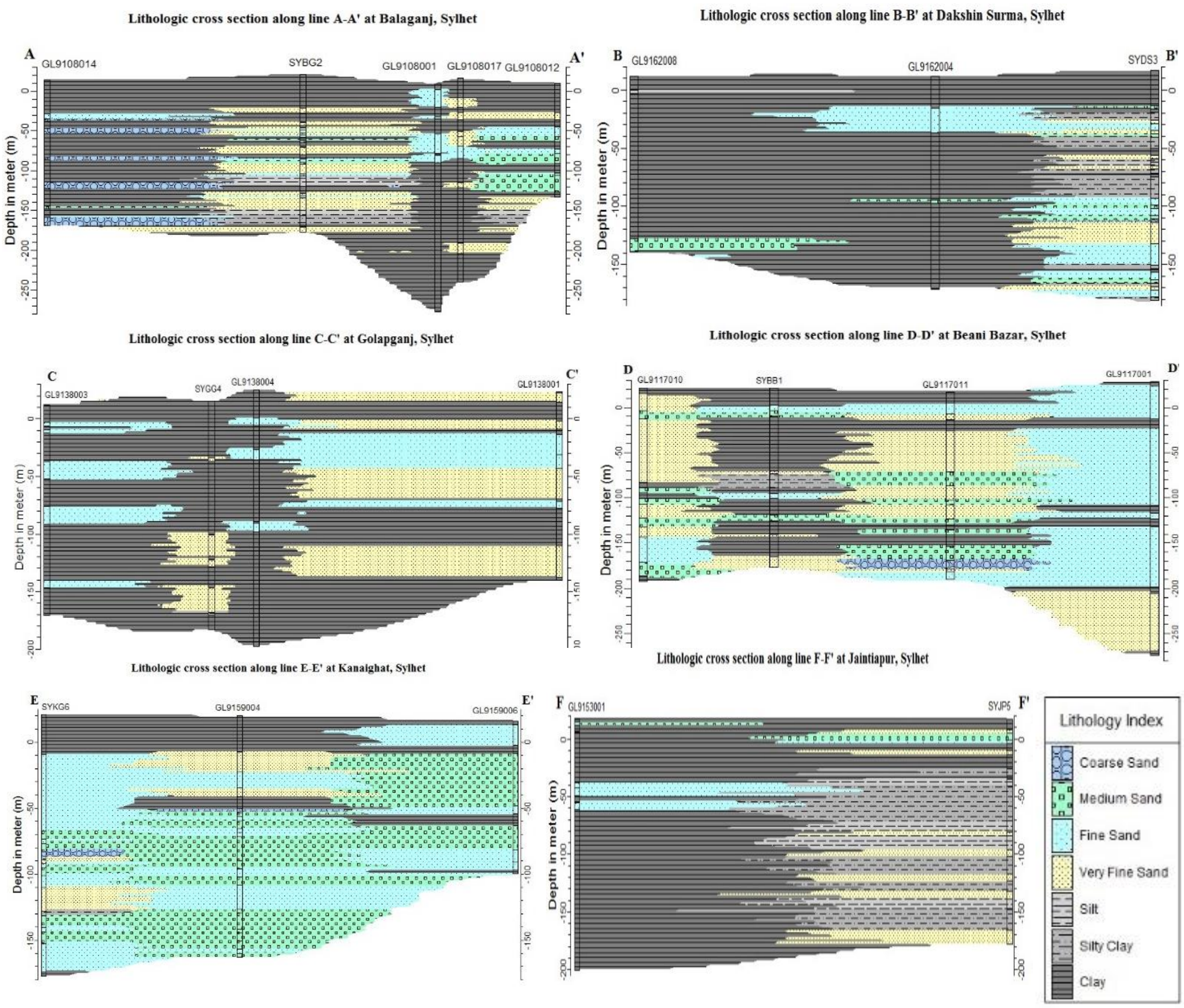


Figure 5-26: Lithologic Cross Sections under Different Upazilas of Sylhet District

5.3.4 Aquifer System of Maulavibazar District

For the investigation of groundwater and understand the lithological variation, 39 borehole lithologs have been collected from different sources (such as BWDB, BADC and DPHE) and 5 exploratory drilling were conducted in five upazilas upto the depth of about 201 m. The depth range of all borelogs is 118.9 to 307.83 m. The detail hydrogeological condition of the upazilas is described on the basis of collected borelogs and analyzed the lithologic cross sections.

Depth of available borelogs of Kamalganj, Kulaura, Maulavibazar Sadar, Rajnagar, and Sreemangal upazilas varies from 118.9 to 201.22 m, 167 to 207 m, 182 to 307 m, 198 to 214 m, and 185 to 225 m respectively. The generalized stratigraphic sections of Maulavibazar district in fence diagram are presented in Figure 5-27 and upazilawise description of aquifer system is presented in following paragraphs which are shown in Figure 5-28 and Figure 5-29 respectively.

Lithologic cross section along U-U′ in Figure 5-28 and Figure 5-29 represents the layers distribution of the Sreemangal upazila. The aquifer system throughout section line is same except Ashidron union. At Mirzapur, Sreemangal and Sindurkhan unions, there is only one prolific aquifer present from 204-216 m, 204-213 m and 207-219 m respectively. The aquifer is composed of coarse sand materials. On the other hand at Ashidron union (MBSM1), there is a 91 m thick aquifer present at top of the area. The aquifer is composed of fine sand, medium sand and medium to coarse sand materials. Below this aquifer a thick clay layer present from 91-146 m, interlayered with fine and very fine sand. The 2nd aquifer is encountered from 146 to 182 m, inter-bedded with silty clay aquitard lenses.

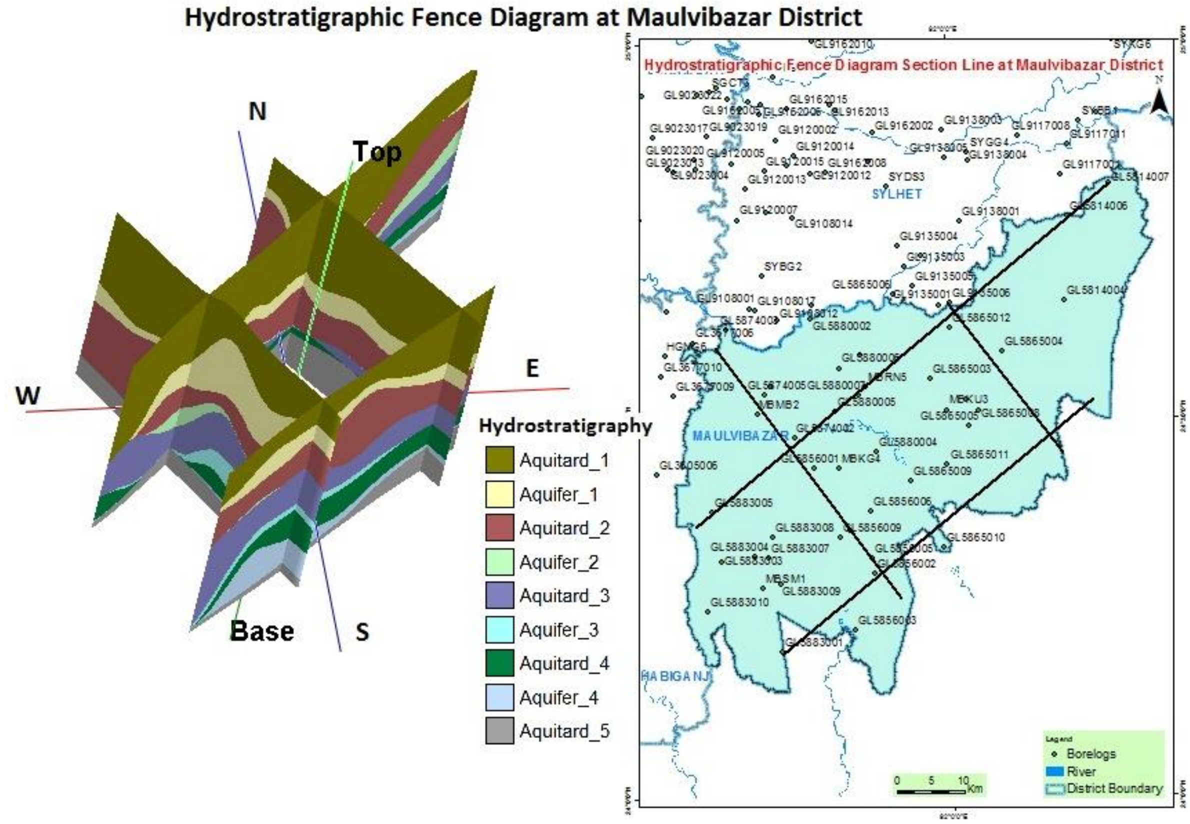


Figure 5-27: Hydrostratigraphic Fence Diagram of Maulavibazar District

Lithologic cross section along V-V′ in Figure 5-28 and Figure 5-29 represents the layers distribution of the Kamalganj upazila. At Rahimpur union (MBKG4), there is a thick aquifer present from 120-177 m interlayered with clay lenses upto drilling depth of 201.22 m. The aquifer is extended throughout the Kamalganj union with some variable in depth and thickness. The aquifer consists of fine sand, medium sand to fine sand, coarse to medium sand and coarse sand. At Kamalganj union (GL5856004), the aquifer is present from 91-146 m which is composed of fine and medium sand. The aquifer is only source of groundwater for the area upto the drilling depth of 182 m. At Alinagar union (GL5856005), there is only one aquifer present from 51-88 m upto the drilling depth of 182 m. The aquifer is composed of fine sand and coarse sand. At the same union (GL5856002), apart from the previous litholog, it is observed that there are three thin aquifer present upto drilling depth of 169 m. The thickness of the aquifers ranges from 2-3 m, which are not suitable for groundwater abstraction. Whereas at Islampur union (GL5856003), there are three aquifers present from 12-47 m, 60-76 m and

100-108 m, separated with thick clay layer upto the investigated depth of 118 m. The aquifers are composed of mainly coarse sand.

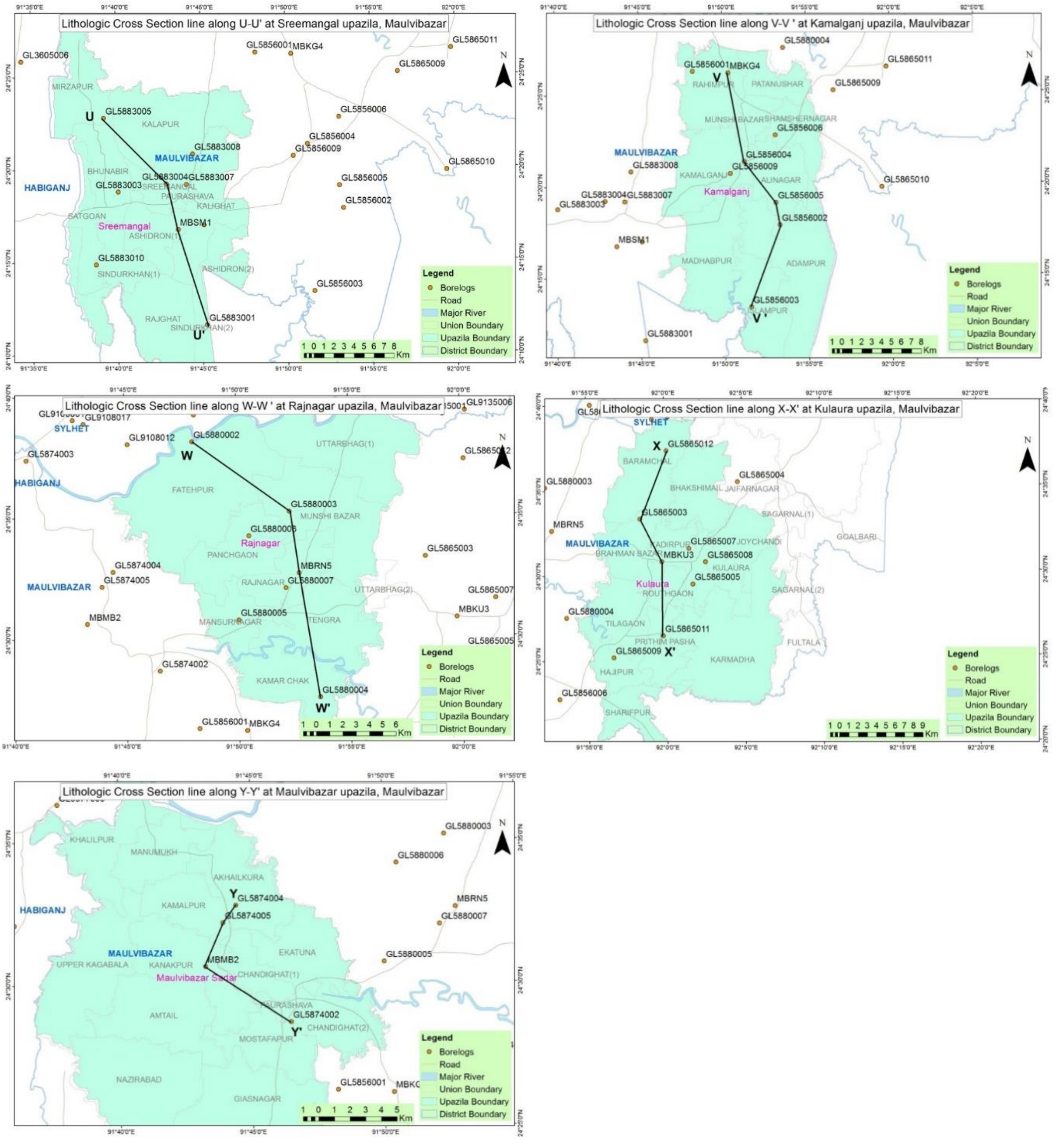


Figure 5-28: Borelogs Distribution and Section Lines under Maulavibazar District

Lithologic cross section along W-W′ in Figure 5-28 and Figure 5-29 represents the layers distribution of the Rajnagar upazila. At Fatehpur union (GL5880002), there are two thin aquifers are present from 106-112 m and 204-214 m upto the investigated depth of 214m, are composed of fine sand and coarse sand respectively. At Munshi Bazar union (GL5880003), there is a prolific aquifer present from 179-188 m, composed of coarse sand materials. The aquifer layer is continuous throughout the section line at Rajnagar and Kamar Chak union with variable depth of thickness. At Rajnagar union (MBRN5), the thickness of the aquifers varies from 3 to 9 m, are separated with clay layer upto the drilling depth of 201 m. There is a productive aquifer present from 185-198 m upto the investigated depth of 210 m at Kamar Chak union (GL5880004). The aquifer consists of coarse sand.

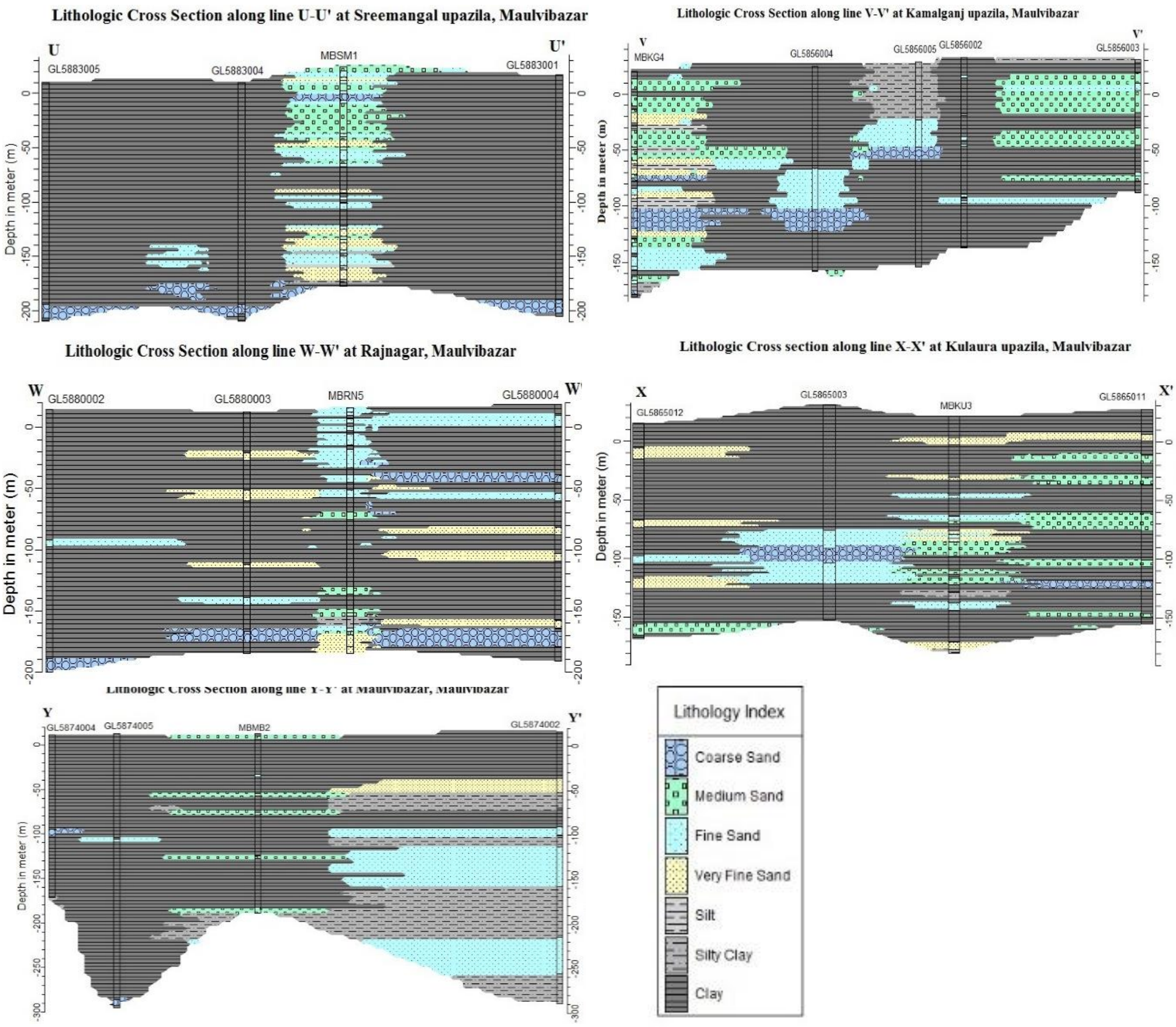


Figure 5-29: Lithologic Cross Sections under Different Upazilas of Maulavibazar District

Lithologic cross section along X-X′ in Figure 5-28 and Figure 5-29 represents the layers distribution of the Kulaura upazila. At Baramchal union (GL5865012), there are two thin aquifers present from 112-118 m and 169-179 m, separated with thick clay layer upto the investigated depth of 182 m. The 1st and 2nd aquifers are composed of fine sand and medium sand respectively. The 1st aquifer is continuous throughout the section area with variable depth and thickness. At Brahman Bazar union (GL5865003), there is one prolific aquifer present from 103-152 m, below a thick clay aquitard layer at the top. The aquifer consists of fine sand and medium sand. On the other hand, at Kadirpur union (MBKU3), there are many thin aquifers present upto the depth of 201 m interlayered with clay and silt layer. The thickness of the aquifers varies from 3-25 m, are consist of medium sand and medium to coarse sand. The abstraction of water from these aquifers is problematic due to interlayer with clay aquitard. The lithologic condition of the union Prithim Pasha (GL5865011) is same as Kadirpur union, where the thin aquifers are separated with thick clay layer. The aquifers are present from 39-45 m, 57-64 m, 88-103 m, 128-134 m, 146-152 m and 173-176 m. The aquifers are mostly dominated by medium to fine sand and coarse sand

Lithologic cross section along Y-Y′ in Figure 5-28 and Figure 5-29 represents the layers distribution of the Maulvibazar upazila. At Akhailkura union (GL5874004) there is only one aquifer present from 106-114 m upto the drilling depth of 182m which is alarming for this area. The aquifer is composed of coarse sand materials, which is only source of groundwater for this area upto the investigated depth of 182m. Same situation is present in the Kamalpur union (GL5874005) where two thin aquifers are present from 118-121 m and 298-304 m upto the drilling depth of 307 m, separated with thick clay layer. The 1st and 2nd aquifers are composed of fine sand and coarse sand respectively. At Kanakpur union (MBMB2), there are six thin aquifers present upto the depth of 201 m, are separated with thick clay aquitard layer. The thickness of the aquifers varies from 3-6 m, are mostly composed of medium to fine sand and medium sand materials. At Chandighat union (GL5874002) there are two thick aquifers are present from 129-173 m and 230-271 m upto the drilling depth of 305 m. The aquifers consist of fine to medium sand.

5.3.5 Aquifer System of Habiganj District

For the investigation of groundwater and understand the lithological variation, 55 lithologs have been collected from different sources (such as BWDB, BADC and DPHE) and 7 exploratory drilling were conducted in seven upazilas upto the depth of 201.21 m. The depth range of the borelogs is 103 to 305 m. The hydrogeological condition of the upazilas is described on the basis of collected borelogs and analyzed the lithologic cross section.

Depth of available borelogs of Bahubal, Baniachong, Chunarughat, Habiganj Sadar, Lakhai, Madhabpur, Nabiganj varies from 182 to 202 m, 182 to 202 m, 152 to 243m, 155 to 240m, 107 to 305 m, 107 to 304 m respectively. The generalized stratigraphic sections of Habiganj district in fence diagram are presented in Figure 5-30 and upazilawise description of aquifer system is presented in following paragraphs which are shown in Figure 5-31 and Figure 5-32.

Lithologic cross section along N-N′ in Figure 5-31 and Figure 5-32 represents the distribution of aquifer sediment of the Madhabpur upazila. At Madhabpur union (GL3671003), there are three aquifers present from 42-109m, 121-146m and 185-225m upto the investigated depth of 305m, are separated with clay aquitard layer. The Aquifers are mostly composed of fine sand and medium sand materials. Another borelog at Madhabpur union (GL3671002) shows that there is thick fine sand aquifer present from 6-237m upto the drilling depth of 304m, interlayered with clay layers. Other side of Madhabpur union (HGMP2) there is one aquifer presents from 48-201m, which is composed of coarse sand, medium sand and fine sand materials. At Shahjahanpur union (GL3671014), there is one aquifer presents from upto the drilling depth of 107m, which is composed of coarse sand, medium sand and fine sand.

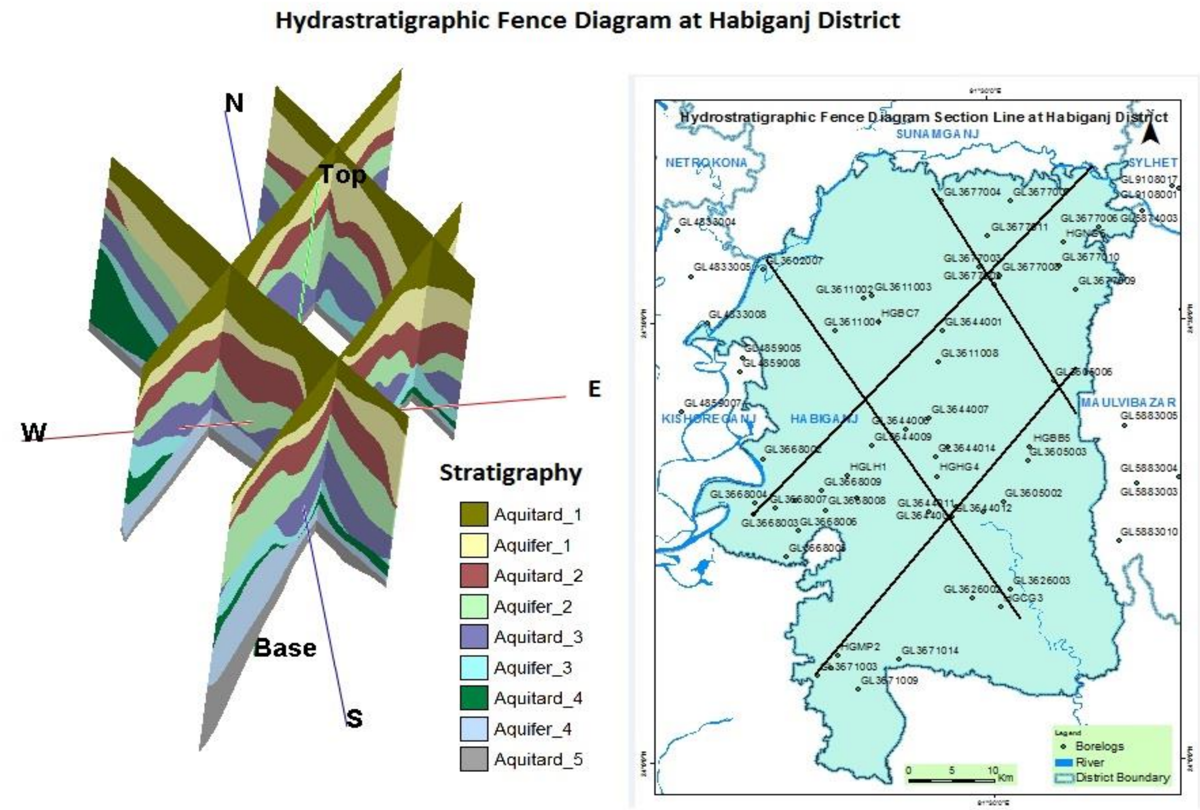


Figure 5-30: Hydrostratigraphic Fence Diagram of Habiganj District

Lithologic cross section along O-O′ in Figure 5-31 and Figure 5-32 represents the layers distribution of the Chunarughat upazila. At Paik Para union (GL3626002), an aquifer present from 123m to the drilling depth of 152m, is composed of medium sand. A thick aquifer present at Deorgacha union (HGCG3) from 24-178m, interlayered with silty clay layers. The aquifer is predominantly composed of fine to very fine sand materials. At Chunarughat union (GL3626003), a thick aquifer present from top surface to the depth of 134m, is composes of mostly fine sand and medium sand. Below this aquifer, there is a thick aquitard present upto the drilling depth of 243m. The aquitard is composed of clay materials.

Lithologic cross section along P-P′ in Figure 5-31 and Figure 5-32 represents the layers distribution of the Habiganj Sadar upazila. At Tegharia union (GL3644007), there are many aquifer lenses are present within the thick clay aquitard upto the depth of 237m. The thickness varies from 3-9m, are composed of fine sand, medium sand and coarse sand. At Gopaya union (GL3644014), two thick aquifers are present from 9-30m and 155-170m, are separated with thick clay layers. The aquifers are composed of coarse sand and medium sand respectively. Another lithologs at Gopaya union (HGHG4) shows that there is a thick major aquifer present from 112-167m, is composed of fine to medium sand and medium to coarse sand. At Saistaganj union, from the litholog (GL3644004) reveals that three aquifers are present from 18-27m, 121-134m and 192-207m upto the investigated depth of 208m. The aquifers are consisted of fine sand and coarse sand. From another litholog in the same union shows that three major aquifers are present from 45-60m, 155-167m and 176-198m, separated with clay layers. The aquifers are consisted of predominantly fine sand and medium to fine sand. The aquifers are not continuous throughout the section line area.

Lithologic cross section along Q-Q′ in Figure 5-31 and Figure 5-32 represents the layers distribution of the Lakhai upazila. From the cross sectional view, it reveals that at Bamai and Bulla union (GL3668007, GL3668001 and GL3668009) there are mostly three aquifers present with variable depth and thickness below a thick clay aquitard at the top or surface of the areas. The aquifers are mostly composed of medium sand and coarse sand materials, separated with thick clay aquitard layer. At Lakhai union (GL3668003) there are two aquifers present from 85-115 m and 158-176 m, are composed of fine sand materials. On the other hand, at Karab union (HGLH1), there is a thick aquifer present from 30-137 m, interlayered with very fine sand and clay layer.

Lithologic cross section along R-R′ in Figure 5-31 and Figure 5-32 represents the layers distribution of the Bahubal upazila. At Mirpur union (GL3605002), three aquifers are present from 36-48 m, 57-94 m and 149-167 m upto the drilling depth of 182 m. The 1st and 2nd aquifers are continuous with variable depth and thickness throughout the section line at Bahubal and Satkapan union. The aquifers are composed of fine and coarse sand. At Bahubal union (GL3605003), four aquifers are present from 21-39 m, 54-82 m, 118-131 m and 170-179 m, are composed of fine and coarse sand materials. At Satkapan union (HGBB5), there aquifers are present from 21-70 m, 100-137 m and 182-201 m upto the investigated depth of 201m. The aquifers are composed of fine to medium sand and medium to coarse sand. On the other hand, there is only one aquifer present from 67-128m upto the drilling depth of 182m, is composed of fine sand and coarse sand.

Lithologic cross section along S-S′ in Figure 5-31 and Figure 5-32 represents the layers distribution of the Baniachong upazila. At Uttar Purba Baniachong union (GL3611002), there is a prolific aquifer present from 118-143 m, which is composed of fine sand and coarse sand materials. There are two thick aquifers present from 67-109 m and 118-146 m upto the drilling depth of 201 m at Dakhin Purba Baniachong union (HGBC7). The aquifers are composed of fine to medium sand, medium sand, medium to coarse sand and coarse sand materials. At Pukhra union (GL3611008), a thick aquifer present from 73 m to the investigated depth of 182 m, is composed of mostly fine sand.

Lithologic cross section along T-T′ in Figure 5-31 and Figure 5-32 represents the layers distribution of the Nabiganj upazila. At Paschim Bara Bahkhair (GL3677004) and Purba Bara Bahkhair (GL3677007) unions, there are three aquifers present upto drilling depth of 220 m. The aquifers are continuous throughout the section area with variable depth and thickness except Kurshi union. The first two aquifers are composed of fine and medium sand materials and the third aquifer is composed of coarse and medium sand. At Kurshi union there is an aquifer present from 33-112 m, interlayered with some very fine sand layer upto investigated depth of 204 m.

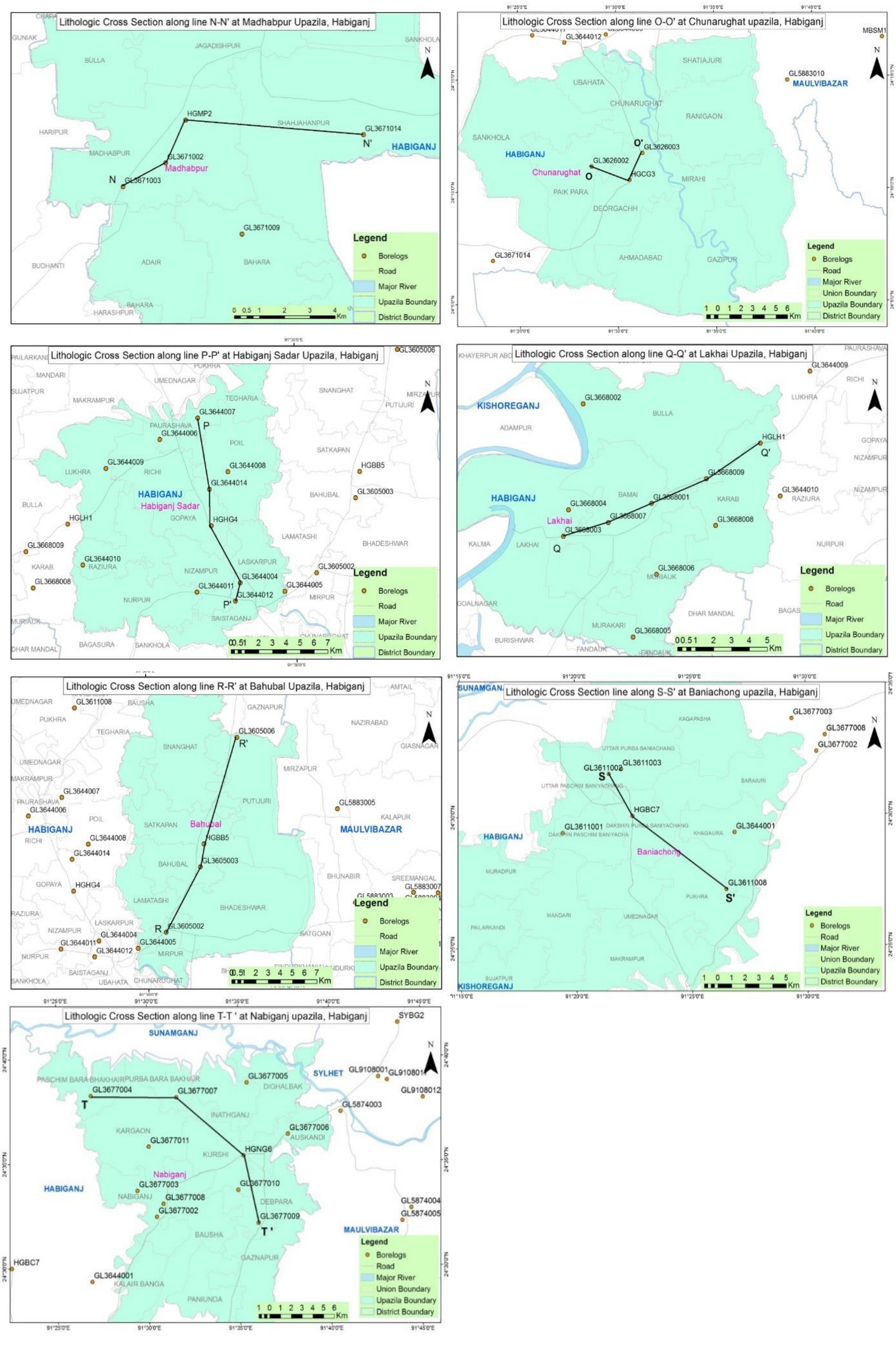


Figure 5-31: Borelogs Distribution and Section Lines under Habiganj District

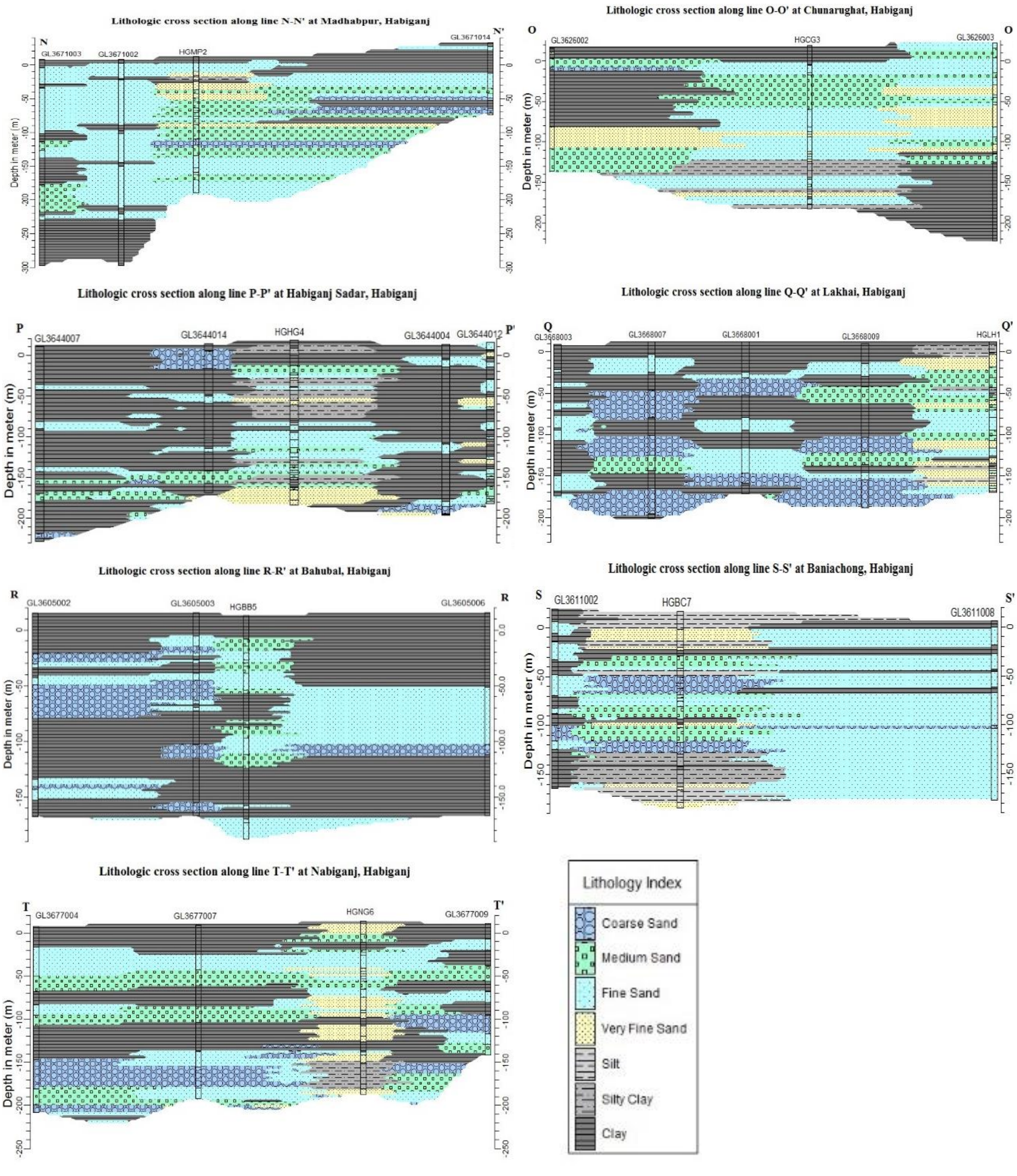


Figure 5-32: Lithologic Cross Sections under Different Upazilas of Habiganj District

5.3.6 Aquifer System of Sunamganj District

For the investigation of groundwater and understand the lithological variation, 25 borehole lithologs have been collected from different sources (such as BWDB, BADC and DPHE) and 8 exploratory drilling were conducted in eight upazilas upto the depth of about 201 m. The depth range of all borelogs is 112 to 250 m. The detail hydrogeological condition of the upazilas is described on the basis of collected borelogs and analyzed the lithologic cross section.

Depth of available borelog of Bishwambarpur, Chhatak, Derai, Dharmapasha, Dowarabazar, Jagannathpur, Jamalganj, and Sunamganj Sadar upazilas is 198 m, 138 to 216 m, 201.21 m, 201.21 m, 112 m, 198 to 250 m, 162 to 201 m, 149 to 207 m respectively. The generalized stratigraphic sections of Sunamganj district in fence diagram are presented in Figure 5-33 and upazilawise description of aquifer system is presented in following paragraphs which are shown in Figure 5-34 and Figure 5-35.

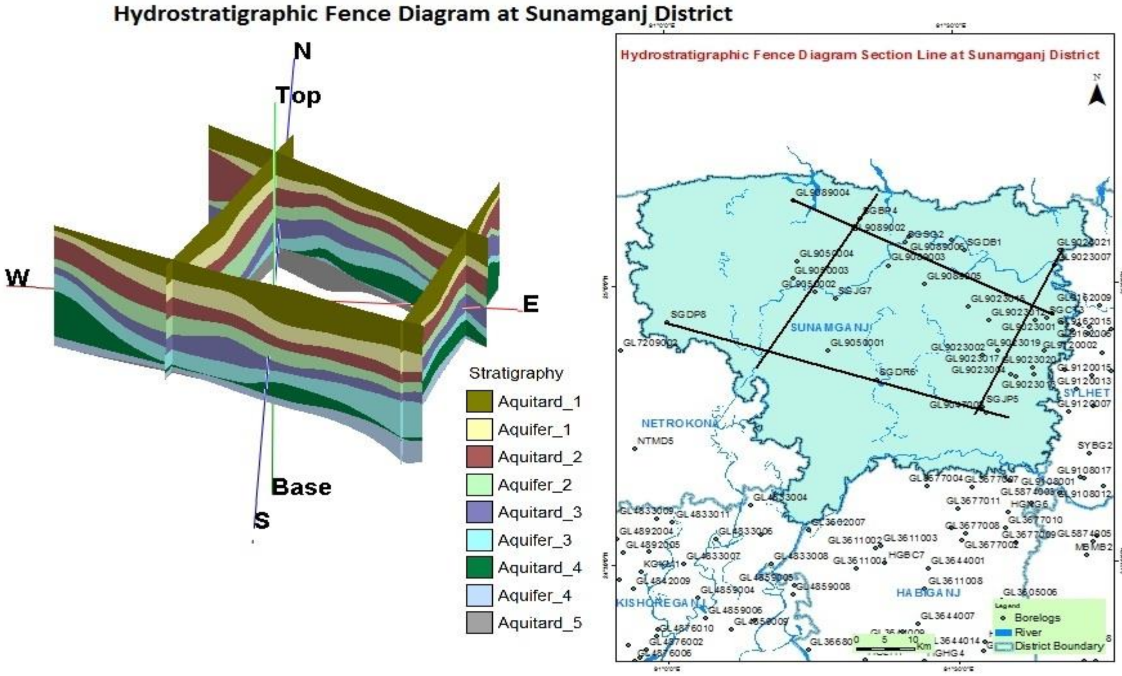


Figure 5-33: Hydrostratigraphic Fence Diagram of Sunamganj District

Lithologic cross section along G-G′ in Figure 5-34 and Figure 5-35 represents the layers distribution of the Chhatak upazila. There are two thin aquifers present upto drilling depth of 216m, which are continuous throughout the section area with variable depth and thickness except Dular Bazar (GL9023020). The aquifers are mostly composed of medium sand materials. At Dular Bazar there are three thick aquifers are present from 54-68, 118-128 and 164-188 m. The aquifers are separated with thick clay aquitard. The aquifers are mostly composed of medium and coarse sand materials.

Lithologic cross section along H-H′ in Figure 5-34 and Figure 5-35 represents the layers distribution of the Jagannathpur upazila. At one part of Jagannathpur union (SGJP5), there are two aquifers present upto drilling depth of 198 m, which are continuous throughout the section area with variable depth, thickness and materials. The aquifers are mostly composed of fine sand materials. Another part of Jagannathpur union (GL9047002), there are four aquifers present from 54-82, 91-103, 128-201 and 207-250 m. First two aquifers are composed of medium sand and coarse sand materials and second two aquifers are composed of very fine to fine sand, fine sand and medium sand materials. There is a thick aquitard present at the top of the surface.

Lithologic cross section along I-I′ in Figure 5-34 and Figure 5-35 represents the layers distribution of the Jamalganj upazila. At Beheli union (GL9050004) there is one aquifer present from 120-194 m, below a thick clay or silty clay aquitard. The aquifer is composed of fine sand and medium sand. At Jamalganj union (GL9050003), two aquifers are encounted at depth of 80-120 and 150-162 m upto the drilling depth of 162 m. The aquifers are not continuous throughout the area and are separated with clay aquitard. At Bhimkahli union (GL9050002), there is one prolific aquifer encounted at depth from 170m to 192m. The aquifer is composed of fine sand and medium sand. Another part of Bhimkahli union (SGJG7), three aquifers are present from 128-149 m, 152-179 m and 189-201 m, separated with thin clay aquitard layer. The aquifers are composed of fine sand, medium to fine sand and coarse sand. A thick aquitard present at the surface of the area except Beheli union.

Lithologic cross section along J-J′ in Figure 5-34 and Figure 5-35 represents the layers distribution of the Sunamganj Sadar upazila. At one part of Sunamganj Sadar union (GL9089003), there is one thick aquifer present from 162-204 m. The aquifer is composed of fine sand and medium sand. On the other hand, another part of Sunamganj Sadar union (SGSG2), there are four aquifer encounted from 21-33, 91-109, 131-152 and 185-195 m, are separated with clay or silty clay aquitard layer. The aquifers are consisted of Medium sand and coarse sand materials. At Aftabnagar union (GL9089002), two aquifers are encounted at depth of 60-76 and 121-146 m, are separated with thick clay aquitard. The aquifers are composed of medium sand and coarse sand. At Ranger Char union (GL9089006), there are three aquifers present from 60-70, 80-96 and 147-157 m, are separated with clay aquitard layer. The aquifers are consisted of medium sand and coarse sand materials.

From the striplog (SGBP4) of Bishwambarpur it observed that there are two thick aquifers present from 42-64 and 91-109 m. The first aquifer is composed of fine and medium sand and the second aquifer is coarse sand materials. The aquifers are separated with thick clay or silty clay aquitard.

From the striplog (SGDR6) of Derai it observed that there is one thick aquifer present from 64-91 m. The aquifer is composed of fine sand and fine to medium sand and medium to coarse sand materials. The aquifers are separated with thick silty clay or silt aquitard.

From the striplog (SGDP8) of Dharmapasha it observed that there are many thin aquifers present upto the drilling depth of 201 m, which are separated with silty clay or silt aquitard. The aquifers are mostly composed of fine sand and medium sand materials.

From the striplog (SGDB1) of Dowarabazar it observed that there is one thick aquifer present from 42-112 m. The aquifer is composed of fine sand, medium sand and coarse sand materials.

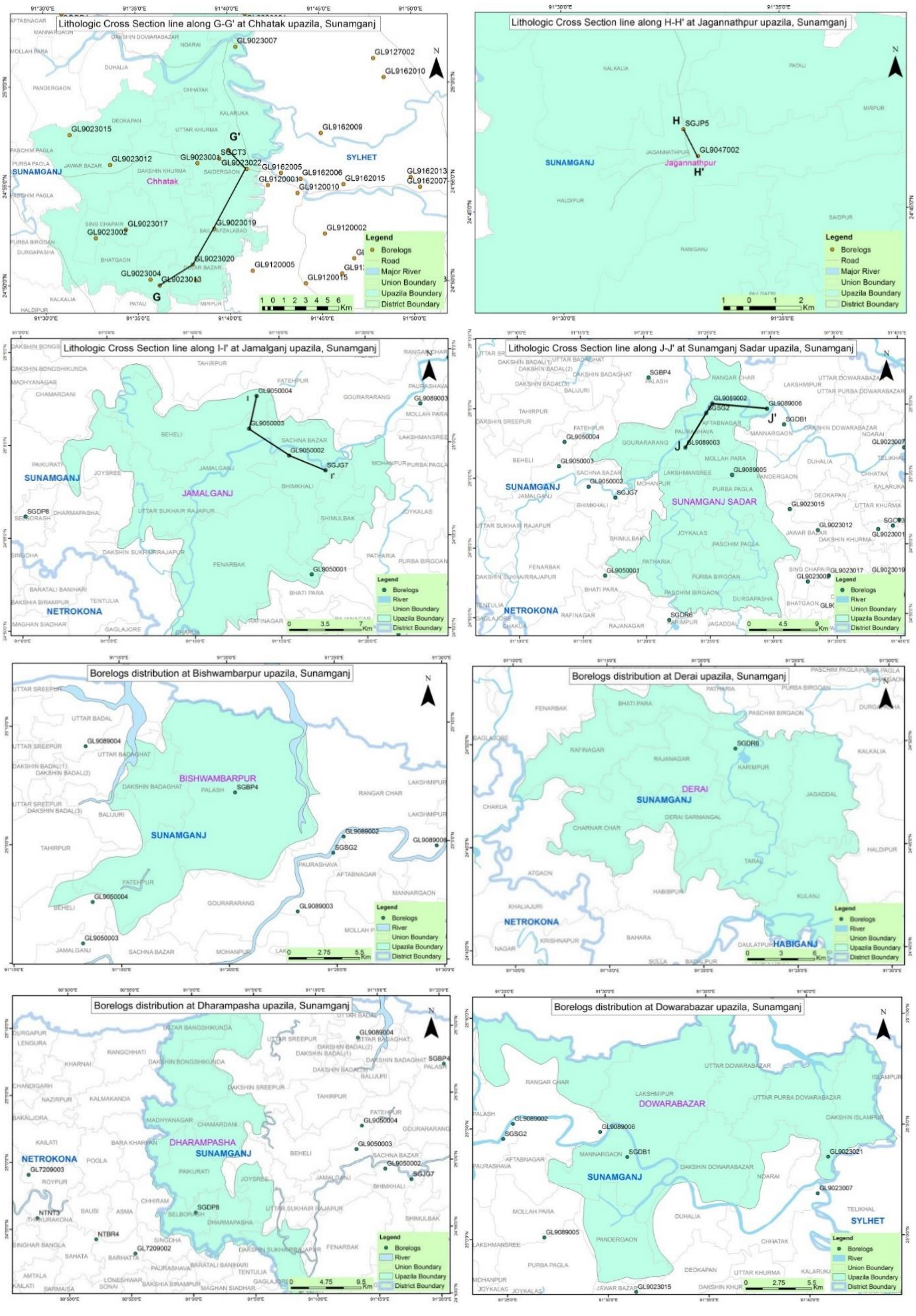


Figure 5-34: Borelogs Distribution and Section Lines under Sunamganj District

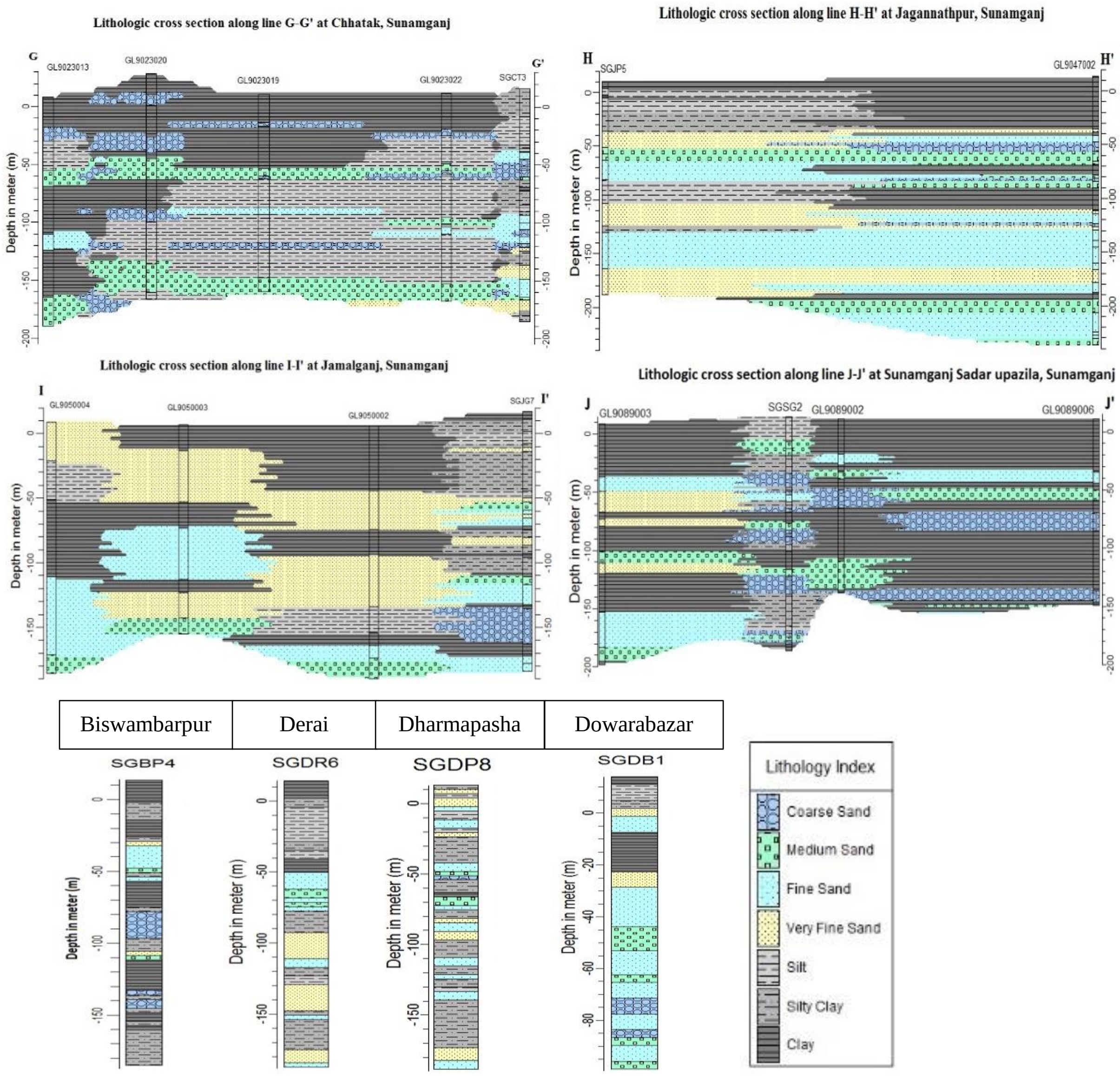


Figure 5-35: Lithologic Cross Sections under Different Upazilas of Sunamganj District

6 POTENTIAL OF AQUIFERS BASED ON HYDRAULIC PROPERTIES

6.1 Aquifer Pump Test

In designing the pumping test and depth of observation wells, a general background of the geology and lithologic conditions were considered. Basic geologic information was obtained from other borehole lithologic logs, wells drilled in the area. Lithologic log of drilled observation well was considered to design production well. To monitor the response of pumping i.e. to measure drawdown, observation wells were installed both in pumping aquifer and aquifer units above it. The lithology of the observation well reflects the conditions of the aquifer to be developed or the hydraulic properties of the aquifer. If there are additional objectives, such as vertical connections or gradients between shallow and deep systems, then nested wells were installed. The distance of observation wells from the pumping well should also reflect a basic understanding of the geologic conditions already mentioned above and whether the aquifer is confined or unconfined. Confined aquifers can have observation points literally miles away. It is also a function of the time of pumping. Short-duration tests may require that monitoring wells be placed closer than those being tested at longer pumping times. If delayed yield is expected in the time or drawdown response curve, an observation well close enough to the pumping well to observe this is necessary. This is usually on the order of 10 ft (3m) or so, but distances of approximately 10 times that much have been observed. Once again it depends on the duration of pumping and aquifer properties.

Table 6-1: Hydraulic Properties from Aquifer Pump Tests Conducted by Installing Production Wells

SL No.	District	Upazila	Latitude	Longitude	Well Depth (m)	Strainer Position (m)	Transmissivity (m^2/day)	Storage Coefficient/ Storativity
1	Habiganj	Bahubal	24.32082	91.529585	60.98	35.67-53.35	380	1.9108
2	Sylhet	Balaganj	24.750651	91.826652	145.43	123.78-143.90	347	6.79
3	Sunamganj	Bishwambarpur	25.109018	91.331422	100	79.87-96.95	70.86	0.000133
4	Sunamganj	Chhatak	24.959974	91.674454	80.49	60.37-77.44	1241.76	0.000373
5	Sunamganj	Dowarabazar	25.061507	91.513586	79.27	54.88-76.21	996.7	0.0000501
6	Netrokona	Kendua	24.650789	90.73543	121.95	99.09-119.51	2697.28	0.0000414
7	Habiganj	Madhabpur	24.133174	91.317786	132.93	117.07-131.71	982.7	0.00015
8	Netrokona	Netrokona Sadar	24.92976	90.78699	146.74	126.02-143.7	1090.03	0.0001268
9	Kishoreganj	Pakundia	24.33247	90.68894	94.88	68.67-91.84	1059.86	0.00020025
10	Kishoreganj	Kuliar Char	24.151159	90.931561	118.9	92.68-115.85	1128.90	0.0001842
11	Maulvibazar	Kamalganj	24.431566	91.842153	108.23	78.96-104.57	270.68	0.000091
12	Maulvibazar	Kulaura	24.531552	92.035999	150.3	128-148	853.06	0.00002235

Table 6-2: Hydraulic Properties from Aquifer Pump Tests Conducted by Existing Production Wells

SL No.	District	Upazila	Latitude	Longitude	Well Depth (m)	Strainer Position (m)	Transmissivity (m^2/day)	Storage Coefficient/ Storativity
1	Kishoreganj	Hossainpur	24.384963	90.670189	24.39	9.45-24.39	976.33	0.10678
2	Kishoreganj	Pakundai	24.347127	90.680394	18.29	9.45-18.29	2906.00	0.00086785
3	Kishoreganj	Hossainpur	24.431675	90.686672	27.44	16.77-27.44	381.33	0.5589
4	Kishoreganj	Pakundai	24.317144	90.714931	18.29	4.87-18.29	1268.33	0.0013337
5	Kishoreganj	Katiadi	24.244321	90.824074	18.29	8.17-18.29	1116.33	0.0024635
6	Kishoreganj	Katiadi	24.338581	90.830665	19.81	9.14-19.81	452.67	0.34775
7	Kishoreganj	Kishoreganj	24.42832	90.743163	28.96	12.07-28.96	673.33	0.078415
8	Netrokona	Kendua	24.659028	90.83409	21.34	5.18-21.34	988.33	2.0765
9	Kishoreganj	Kuliar Char	24.150566	90.902424	21.34	14.33-21.34	647.00	0.50085
10	Netrokona	Purbadhala	24.847156	90.624749	17.37	3.65-17.37	3093.00	0.000230578
11	Netrokona	Barhatta	24.88526	90.888705	20.42	4.57-20.42	1120.67	0.004729567
12	Netrokona	Barhatta	24.902348	90.82222	26.82	10.36-26.82	498.33	0.36275
13	Netrokona	Atpara	24.793216	90.805503	21.34	15.24-21.34	263.67	0.04604

6.1.1 Aquifer Properties of Kishoreganj District

Aquifer Pump Test at Modho Pakundia

The step drawdown test and constant discharge aquifer pump test were conducted at Pakundai upazila under Kishoreganj district. One production well and 4 nos. observation wells are installed for conducting aquifer tests. Step drawdown test was performed in production well by three steps with the discharge rates of 40, 50 and 60 m^3/h respectively. The analysis of step drawdown test data was not done due to high rates of drawdown. The depth of production well is 94.88 m having screen length of 23.17 m at the bottom above 3 m bail plug. The depths of 4 nos. observation wells are 83.84, 83.84, 83.84 and 28.96 m. Observation wells are located 3, 30, 90 and 4.5 m apart from the production well. Layout plan of the aquifer pump test setup is shown in Figure 6-1.

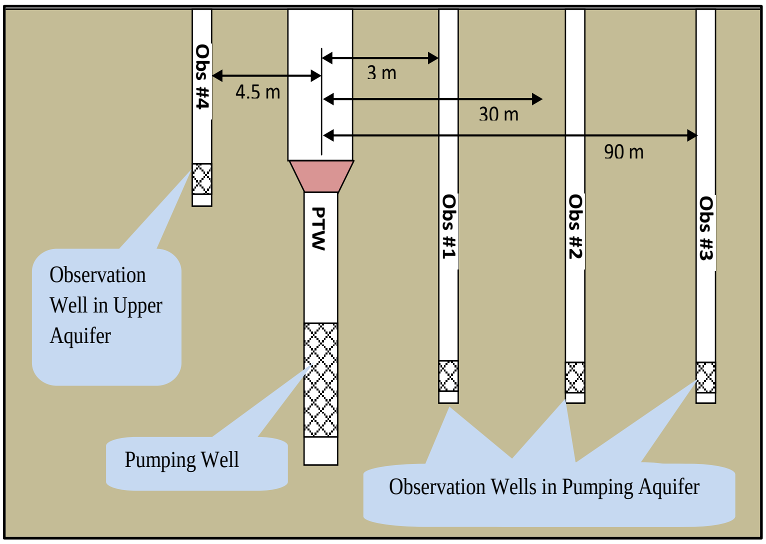


Figure 6-1: Location of Observation Wells and Pumping Well in Vertical Section

The constant discharge aquifer pump test was conducted for the time duration of 34 hours at Pakundia. The pumping rate was monitored using circular orifice pipe and manometer. The height of the water column in a manometer attached to the side of the pumping well discharge tube was measured at 72.39 cm (28.5 inch). A flow rate of 50 m^3/h was determined using standard tables for the discharge pipe diameter. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. Measurement of water levels after the pump stopped (recovery data) are extremely valuable for recovery test. So after the continuous pumping the recovery data have been collected at a fixed time interval. Initial water table was 3.00 m and maximum drawdown recorded as 7.47 m at pumping well.

During test, water level in upper aquifer observation well 4 showed no effect from pumping in the deep aquifer. But Groundwater levels in the deep aquifer observation wells (1, 2 and 3) responded to the withdrawal of water from the pumping well.

The aquifer test data of Pakundia production well was analyzed by AQTESOLV software in three methods; Theis's method, Cooper- Jacob's method and Theis's Recovery method. For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from 1024 to 1104 m^2/day and from 0.0000189 to 0.0003385 respectively. Storage- coefficient values and geological section indicate that the aquifer might be leaky confined to confined in nature. Transmissivity values indicate that the aquifer has moderate potential for groundwater abstraction. However, water quality patameters need to be considered. The results are given in Table 6-3.

Table 6-3: Summary of Aquifer Properties from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)	Permeability, K (m/day) appprox.
Theis	Obs#1	1024	0.0001511	0.00020025	1059.86	23.17
Cooper-Jacob	Obs#1	1031.3	0.0000189			
Theis	Obs#2	1051.5	0.0003385			
Cooper-Jacob	Obs#2	1104	0.0002925			
Theis Recovery	Main Well	1088.5	--			

Area i.e. zone of influence due to pumping has been determined by plotting the water level of pumping well and observation well nos. 1, 2 and 3. From the graphical representation it is observed that the area of influence of pumping is about 200 meter approximately surrounding the pump with pumping rate of 50 m^3/h. Maintaining proper well spacing, under moderate discharge rate i.e. upto 50 m^3/h, few hours of pumping per day can be done for potable water supply. Irrigation abstraction from the deep aquifer is not recommended.

Aquifer Pump Test at Tarakandi, Pakundia

The aquifer pump test was conducted at Tarakandi, Pakundia upazila under Kishoreganj district using existing production well. 2 nos. observation wells are installed for conducting aquifer test. The depth of production well is 18.29 m having screen length of 8.54 m. The depths of 2 nos. observation wells are 16.76 and 16.76 m. Observation wells are located 1.5 and 15.24 m apart from the production well respectively. Layout plan of aquifer pump test setup is shown in Figure 6-2.

The constant discharge aquifer pump test was conducted for the time duration of 7 hours at Tarakandi under Pakundia upazila. The pumping rate was monitored using Bucket and Stopwatch method. The flow rate of 17 m^3/h was determined using this method. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. Measurement of water levels after the pump stopped (recovery data) are extremely valuable for recovery test. So after the continuous pumping the recovery data have been collected at a fixed time interval. Initial water table was 2.79 m and maximum drawdown recorded as 0.80 m.

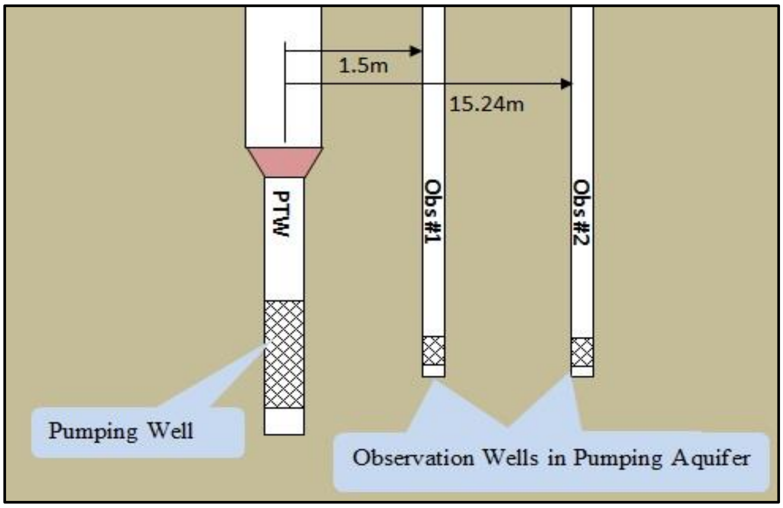


Figure 6-2: Location of Observation Wells and Pumping Well in Vertical Section

During test, Groundwater levels in the shallow aquifer observation wells (1 and 2) responded to the withdrawal of water from the pumping well.

The aquifer test data of existing production well was analyzed by AQTESOLV software in three methods; Theis's method, Cooper-Jacob method and Theis's Recovery methods. For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from 2820.7 to 3068.3 m^2/day and from 0.0007337 to 0.001002 respectively. Storage- coefficient values and geological section indicate that the aquifer might be semi confined in nature. Transmissivity values indicate that this shallow aquifer has high potential for groundwater abstraction. However, water quality patameters need to be considered. The results are given in Table 6-4.

Table 6-4: Summary of all Results from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)
Theis	Obs#1	2820.7	0.001002	0.1067	2906.76
Cooper-Jacob	Obs#1	2831.3	0.0007337		
Theis Recovery	Main Well	3068.3	--		

Area i.e. zone of influence due to pumping has been determined by plotting the pumping water level of main well and observation well nos. 1 and 2. From the graphical representation it is observed that the area of influence of pumping is about 35 meter approximately surrounding the pump with pumping rate of 17 m^3/h. Maintaining proper well spacing, few hours of pumping per day can be done from this shallow aquifer for both potable and irrigation water supply. Irrigation abstraction from the deep aquifer is not recommended.

Aquifer Pump Test at Pusindi, Pakundia

The aquifer pump test was conducted at Pusindi, Pakundia upazila under Kishoreganj district using existing production well. 2 nos. observation wells are installed for conducting aquifer test. The depth of production well is 18.29 m having screen length of 12.20 m. The depths of 2 nos. observation wells are 15.24 and 15.24 m. Observation wells are located 1.5 and 15.24 m apart from the production well respectively. Layout plan of the aquifer pump test setup is shown in Figure 6-3.

The constant discharge aquifer pump test was conducted at Pusindi under Pakundia upazila for the time duration of 6 hours. The pumping rate was monitored using Bucket and Stopwatch method. The flow rate of 17 m^3/h was determined using this method. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. Measurement of water levels after the pump stopped (recovery data) are extremely valuable for recovery test. So, after the continuous pumping the recovery data have been collected at a fixed time interval. Initial water table was 2.57 m and maximum drawdown recorded as 1.19 m.

Duing test, Groundwater levels in the shallow aquifer observation wells (1 and 2) responded to the withdrawal of water from the pumping well.

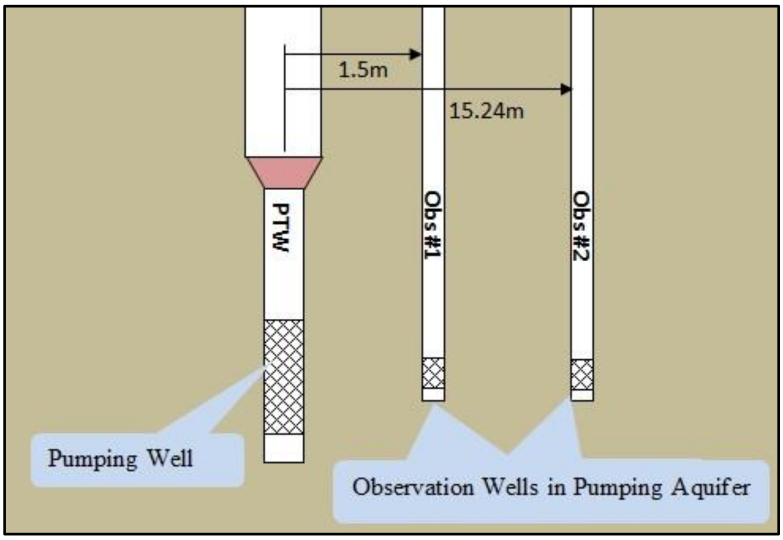


Figure 6-3: Location of Observation Wells and Pumping Well in Vertical Section

The aquifer test data of the existing production well was analyzed by AQTESOLV software in three methods; Theis's method, Cooper-Jacob method and Theis's Recovery method. The results are given in Table 6-5.

Table 6-5: Summary of all Results from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)
Theis	Obs#1	1158.3	0.001842	0.001333	1268.86
Cooper-Jacob	Obs#1	1149.6	0.0008254		
Theis Recovery	Main Well	1498.7	--		

For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from 1149.6 to 1498.7 m^2/day and from 0.0008254 to 0.001842 respectively. Storage-coefficient values and geological section indicate that the aquifer might be semi confined to leaky confined in nature. Transmissivity values indicate that this shallow aquifer has moderate to high potential for groundwater abstraction. However, water quality patameters need to be considered.

Area of influence due to pumping has been determined by plotting the pumping water level of main well and observation well nos. 1 and 2. From the graphical representation it is observed that the area of influence of pumping is about 23 meter approximately surrounding the pump with pumping capacity of 17 m^3/h. Maintaining proper well spacing, few hours of pumping per day can be done from this shallow aquifer for both potable and irrigation water supply. Irrigation abstraction from the deep aquifer is not recommended.

Aquifer Pump Test at Basurchar, Hossainpur

The aquifer pump test was conducted at Basurchar, Hossainpur upazila under Kishoreganj district using existing production well. 2 nos. observation wells are installed for conducting aquifer test. The depth of production well is 24.39 m having screen length of 12.19 m. The depths of 2 nos. observation wells are 21.33 and 21.33 m. Observation wells are located 1.5 and 15.24 m away from the production well. Layout plan of the aquifer pump test setup is shown in Figure 6-4.

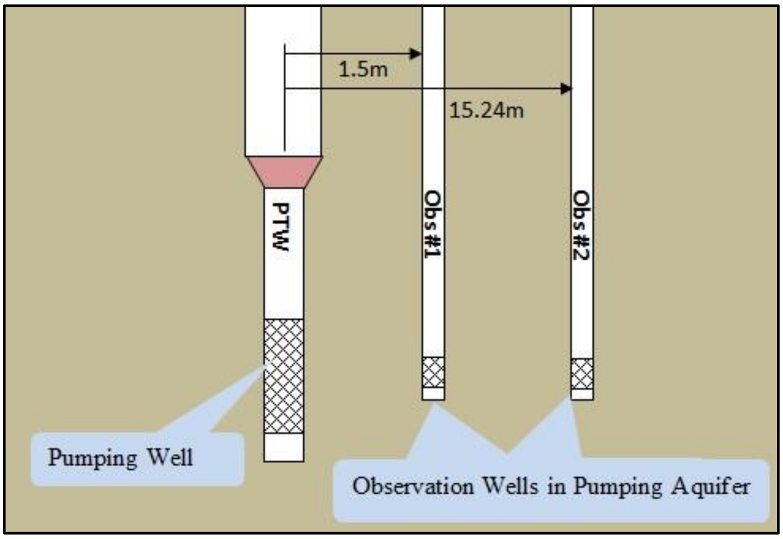


Figure 6-4: Location of Observation Wells and Pumping Well in Vertical Section

The constant discharge aquifer pump test was conducted for the time duration of 6 hours at Basurchar under Hossainpur upazila. The pumping rate was monitored using Bucket and Stopwatch method. The flow rate of 16 m^3/h was determined using this method. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. Measurement of water levels after the pump stopped (recovery data) are extremely valuable for recovery test. So after the continuous pumping the recovery data have been collected at a fixed time interval. Initial water table was 4.27 m and maximum drawdown recorded as 1.30 m.

During test, Groundwater levels in the shallow aquifer observation wells (1 and 2) responded to the withdrawal of water from the pumping well.

The aquifer test data of Hossainpur existing production well was analyzed by AQTESOLV software in three methods; Theis's method, Cooper-Jacob method and Theis's Recovery method. For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from 853 to 1082.4 m^2/day and from 0.07116 to 0.1424 respectively. Storage-coefficient values and geological section indicate that the aquifer might be semi confined in nature. Transmissivity values indicate that this shallow aquifer has moderate potential for groundwater abstraction. However, water quality patameters need to be considered. The results are given in Table 6-6.

Table 6-6: Summary of all Results from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)
Theis	Obs#1	994.8	0.1424	0.1067	976.73
Cooper-Jacob	Obs#1	853	0.07116		
Theis Recovery	Main Well	1082.4	--		

Area of influence due to pumping has been determined by plotting the pumping water level of main well and observation well nos. 1 and 2. From the graphical representation it is observed that the area of influence of pumping is about 25 meter approximately surrounding the pump with pumping capacity of 16 m^3/h. Maintaining proper well spacing, few hours of pumping per day can be done from this shallow aquifer for both potable and irrigation water supply. Irrigation abstraction from the deep aquifer is not recommended.

Aquifer Pump Test at Pusdi, Hossainpur

The aquifer pump test was conducted at Pusdi, Hossainpur upazila under Kishoreganj district using existing production well. 2 nos. observation wells are installed for conducting aquifer pump test. The depth of production well is 27.43 m having screen length of 9.15 m. The depths of 2 nos. observation wells are 24.39 and 24.39 m. Observation wells are located 1.5 and 15.24 m away from the production well respectively. Layout plan of the production well setup is shown in Figure 6-5.

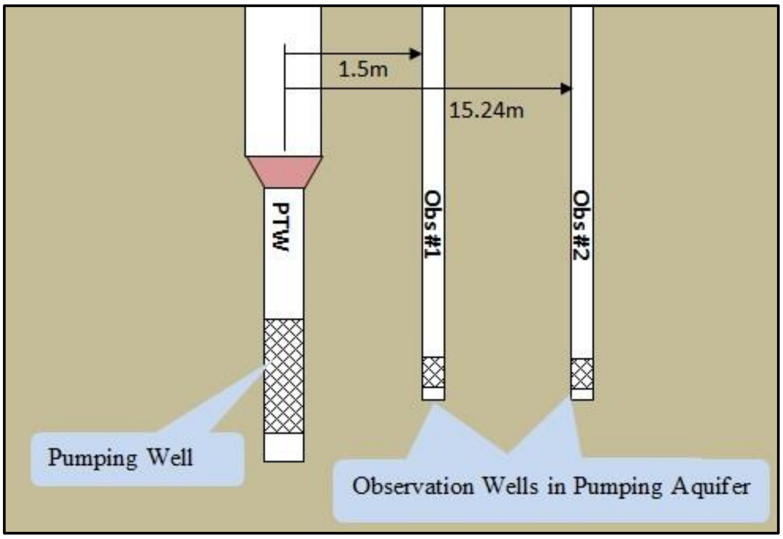


Figure 6-5: Location of Observation Wells and Pumping Well in Vertical Section

The constant discharge aquifer pump test, for the time duration of 6 hours, was conducted at Pusdi under Hossainpur upazila. The pumping rate was monitored using Bucket and Stopwatch method. The flow rate of 17 m^3/h was detected using this method. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. Measurement of water levels after the pump stopped (recovery data) are extremely valuable for recovery test. Therefore, the recovery data have also been measured at a fixed time interval. Initial water table was 7.14 m and maximum drawdown recorded as 2.53 m.

During test, groundwater levels in the shallow aquifer observation wells (1 and 2) responded to the withdrawal of water from the pumping well.

The aquifer test data of Hossainpur existing production well was analyzed by AQTESOLV software in three methods; Theis's method, Cooper-Jacob method and Theis's Recovery method. For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from 363.3 to 418.9 m^2/day and from 0.4942 to 0.6236 respectively. Storage-coefficient values and geological section indicate that the aquifer might be semi confined to unconfined in nature. Transmissivity values indicate that this shallow aquifer has low potential for groundwater abstraction. The results are given in Table 6-7.

Table 6-7: Summary of all Results from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)
Theis	Obs#1	418.9	0.6236	0.5589	381.86
Cooper-Jacob	Obs#1	363.3	0.4942		
Theis Recovery	Main Well	363.4	--		

Area of influence due to pumping has been determined by plotting the pumping water level of main well and observation well nos. 1 and 2. From the graphical representation it is observed that the area of influence of pumping is about 35 meter approximately surrounding the pump with pumping capacity of 17 m^3/h. Maintaining proper well spacing, few hours of pumping per day can be done from this shallow aquifer for potable water supply.

Aquifer Pump Test at Baraddia, Katiadi

The constantdischarge aquifer pump test was conducted at Baraddia, Katiadi upazila under Kishoreganj district using existing production. 2 nos. observation wells are installed for conducting aquifer test. The depth of production well is 18.29 m having screen length of 9.15 m. The depths of 2 nos. observation wells are 15.24 and 15.24 m. Observation wells are located

1.5 and 15.24 m apart from the production well respectively. Layout plan of the aquifer pump test setup is shown in Figure 6-6.

The aquifer pump test was conducted for the time duration of 6 hours. The constant discharge was monitored using Bucket and Stopwatch method. The flow rate of 17 m^3/h was determined using this method. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. The recovery data have also been collected at a fixed time interval. Initial water table was 4.05 m and maximum drawdown recorded as 1.185 m.

During test, Groundwater levels in the shallow aquifer observation wells (1 and 2) responded to the withdrawal of water from the pumping well.

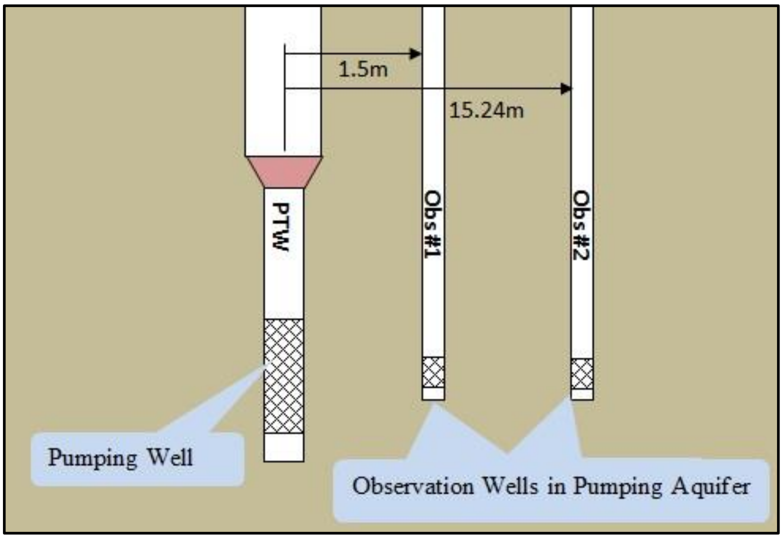


Figure 6-6: Location of Observation Wells and Pumping Well in Vertical Section

The aquifer pump test data was analyzed by AQTESOLV software in three methods; Theis's method, Cooper-Jacob method and Theis's Recovery method. For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from 1055.5 to 1187.7 m^2/day and from 0.002202 to 0.002725 respectively. Storage- coefficient values and geological section indicate that the aquifer might be semi confined to leaky confined in nature. Transmissivity values indicate that this shallow aquifer has moderate potential for groundwater abstraction. The results are given in Table 6-8.

Area of influence due to pumping has been determined by plotting the pumping water level of main well and observation wells. From the graphical representation it is observed that the area of influence of pumping is about 65 meter approximately surrounding the pump with pumping capacity of 17m^3/h. Maintaining proper well spacing, few hours of pumping per day can be done from this shallow aquifer both for potable and irrigation water supply.

Table 6-8: Summary of all Results from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)
Theis	Obs#1	1107	0.002202	0.002463	1116.73
Cooper-Jacob	Obs#1	1055.5	0.002725		
Theis Recovery	Main Well	1187.7	--		

Aquifer Pump Test at Gochihata, Katiadi

The constant discharge aquifer pump test was conducted at Gochihata, Katiadi upazila under Kishoreganj district using existing production well. 2 nos. observation wells are installed for conducting the test. The depth of production well is 21.34 m having screen length of 9.15 m. The depths of 2 nos. observation wells are 19.81 and 19.81 m. Observation wells are located 1.5 and 15.24 m apart from the production well respectively. Layout plan of the aquifer pump test setup is shown in Figure 6-7.

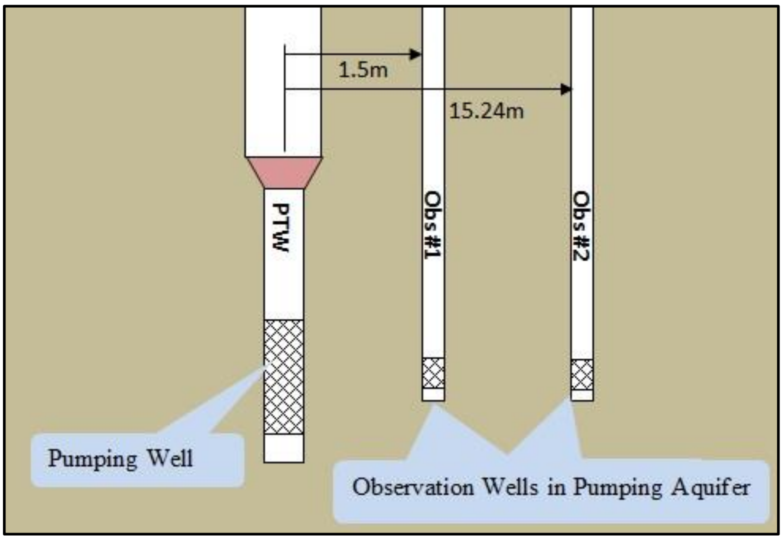


Figure 6-7: Location of Observation Wells and Pumping Well in Vertical Section

The aquifer test was conducted for the time duration of 6 hours at Gochihata under Katiadi upazila. The pumping rate was monitored using Bucket and Stopwatch method. The flow rate of $16m^3/h$ was determined using this method. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. The recovery data have also been measured at a fixed time interval. Initial water was 4.13 m and maximum drawdown recorded as 1.785 m.

During test, Groundwater levels in the shallow aquifer observation wells (1 and 2) responded to the withdrawal of water from the pumping well.

The aquifer test data of Gochihata test was analyzed by AQTESOLV software in three methods; Theis's method, Cooper-Jacob method and Theis's Recovery method. For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from 436.8 to 475.2 m^2/day and from 0.2594 to 0.4361 respectively. Storage- coefficient values and geological section indicate that the aquifer might be semi confined to unconfined in nature. Transmissivity values indicate that this shallow aquifer has moderate to low potential for groundwater abstraction.

Storage- coefficient values and geological section indicate that the aquifer might be semi confined in nature. The results are given in Table 6-9.

Table 6-9: Summary of all Results from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)
Theis	Obs#1	475.2	0.4361	0.34775	453.06
Cooper-Jacob	Obs#1	447.2	0.2594		
Theis Recovery	Main Well	436.8	--		

Area of influence due to pumping has been determined by plotting the pumping water level of main well and observation well nos. 1 and 2. From the graphical representation it is observed that the area of influence of pumping is about 65 meter approximately surrounding the pump with pumping capacity of 16 m^3/h. Maintaining proper well spacing, few hours of pumping per day can be done from this shallow aquifer for potable water supply. Irrigation abstraction may be done with careful monitoring.

Aquifer Pump Test at Kilpara, Kishoreganj Sadar

The constant discharge aquifer pump test was conducted at Kilpara, Kishoreganj Sadar upazila under Kishoreganj district using existing production well and 2 nos. newly installed observation wells. The depth of production well is 28.96 m having screen length of 6.10 m. The depths of 2 nos. observation wells are 28.00 and 28.00 m. Observation wells are located 1.5 and 15.24 m apart from the production well respectively. Layout plan of the pump test setup is shown in Figure 6-8.

The constant discharge aquifer pump test was conducted at Kilpara under Kishoreganj Sadar upazila for the time duration of 6 hours. The pumping rate was monitored using Bucket and Stopwatch method. The flow rate of 14 m^3/h was determined using this method. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. The recovery data have also been measured at a fixed time interval. Initial water table was 12.52 m and maximum drawdown recorded as 4.005 m.

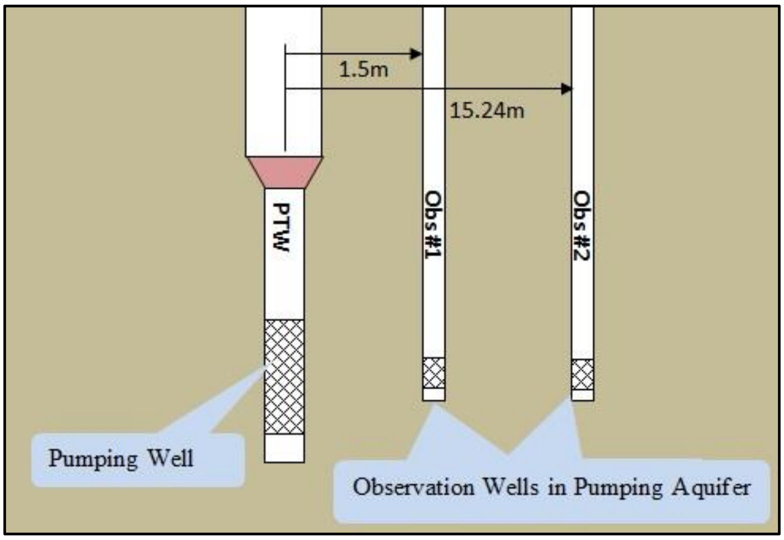


Figure 6-8: Location of Observation Wells and Pumping Well in Vertical Section

During test, Groundwater levels in the shallow aquifer observation wells (1 and 2) responded to the withdrawal of water from the pumping well.

The aquifer test data of Kilpara existing production well was analyzed by AQTESOLV software in three methods; Theis's method, Cooper-Jacob method and Theis's Recovery method. For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from 244.1 to 1281.8 m^2/day and from 0.01603 to 0.1408 respectively. Storage-coefficient values and geological section indicate that the aquifer might be semi confined in nature. Transmissivity values are highly variable and indicate that this shallow aquifer has moderate to low potential for groundwater abstraction. The results are given in Table 6-10.

Area of influence due to pumping has been determined by plotting the pumping water level of main well and observation well nos. 1 and 2. From the graphical representation it is observed that the area of influence of pumping is about 42 meter approximately surrounding the pump with pumping capacity of 14 m^3/h. Maintaining proper well spacing, few hours of pumping per day can be done from this shallow aquifer for both potable and irrigation water supply.

Table 6-10: Summary of all Results from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)
Theis	Obs#1	244.1	0.1408	0.07841	657.7
Cooper-Jacob	Obs#1	447.2	0.01603		
Theis Recovery	Main Well	1281.8	--		

Aquifer Pump Test at Singla, Kuliar Char

The constant discharge aquifer pump test was conducted at Kuliar Char under Kishoreganj district using existing production well. 2 nos. observation wells are installed for conducting aquifer test. The depth of production well is 24.39 m having screen length of 3.05 m. The depths of 2 nos. observation wells are 22.86 and 22.86 m. Observation wells are located 1.5 and 15.24 m apart from the production well respectively. Layout plan of the aquifer pump test setup is shown in Figure 6-9.

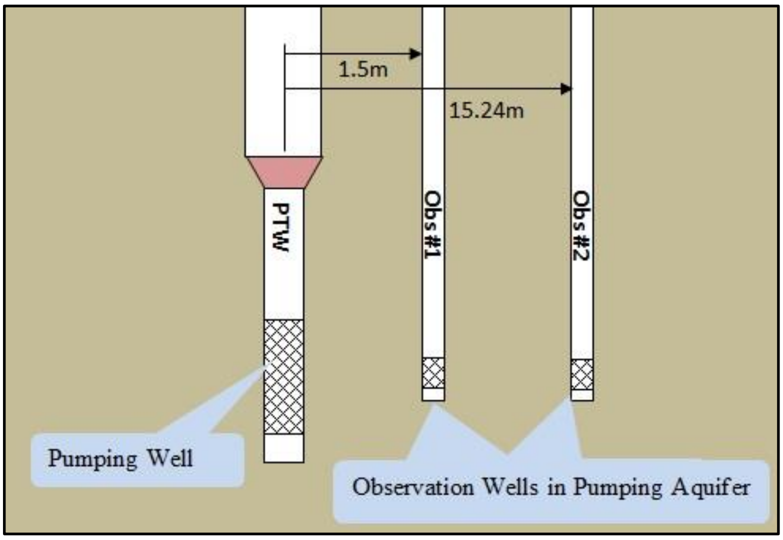


Figure 6-9: Location of Observation Wells and Pumping Well in Vertical Section

The aquifer pump test was conducted for the time duration of 5 hours at Kuliar Char upazila. The pumping rate was monitored using Bucket and Stopwatch method. The flow rate of 17 m^3/h was determined using this method. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. After the end of pumping, the recovery data have been collected at a fixed time interval. Initial water table was 4.11 m and maximum drawdown recorded as 2.14 m. Drawdown was measured using water level meter and measuring tapes attached with Avometers by the field personnel.

During test, Groundwater levels in the shallow aquifer observation wells (1 and 2) responded to the withdrawal of water from the pumping well.

The aquifer test data of Kuliar Char existing production well was analyzed by AQTESOLV software in three methods; Theis's method, Cooper-Jacob method and Theis's Recovery method. For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from 613.7 to 705.4 m^2/day and from 0.2914 to 0.7103 respectively. Storage-coefficient values and geological section indicate that the aquifer might be semi confined to unconfined in nature. Transmissivity values indicate that this shallow aquifer has moderate potential for groundwater abstraction. The results are given in Table 6-11.

Table 6-11: Summary of all Results from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)
Theis	Obs#1	623.5	0.7103	0.50085	647.53
Cooper-Jacob	Obs#1	613.7	0.2914		
Theis Recovery	Main Well	705.4	--		

Area of influence due to pumping has been determined by plotting the pumping water level of main well and observation well nos. 1 and 2. From the graphical representation it is observed that the area of influence of pumping is about 58 meter approximately surrounding the pump with pumping capacity of 17 m^3/h. Maintaining proper well spacing, few hours of pumping per day can be done from this shallow aquifer for potable and irrigation water supply.

Aquifer Pump Test at Kuliar Char

The step drawdown test and constant discharge aquifer pump test were conducted at Kuliar Char upazila under Kishoreganj district. One production well and 4 nos. observation wells are installed for conducting aquifer test as well as step drawdown test. Step drawdown test was performed in production well by three steps such as 40, 50 and 60 m^3/h. The interpretation of step drawdown test was not done due to high drawdown. The depth of production well is 118.90 m having screen length of 23.17 m. The depths of 4 nos. observation wells are 108.23, 108.23, 108.23 and 53.35 m. Observation wells are located 3, 30, 90 and 4.5 m apart from the production well respectively. Layout plan is shown in Figure 6-19.

The constant rate test for the time duration of 12 hours was conducted at Kuliar Char. The pumping rate was monitored using circular orifice pipe and manometer. The height of the water column in a manometer attached to the side of the pumping well discharge tube was measured at 72.39 cm (28.5 inch). A flow rate of 50 m^3/h was determined using standard tables for the discharge pipe diameter. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. Measurement of water levels after the pump stopped (recovery data) are extremely valuable for recovery test. So after the continuous pumping the recovery data have been collected at a fixed time interval. Initial water table was 6.20 m and maximum drawdown recorded as 7.42 m.

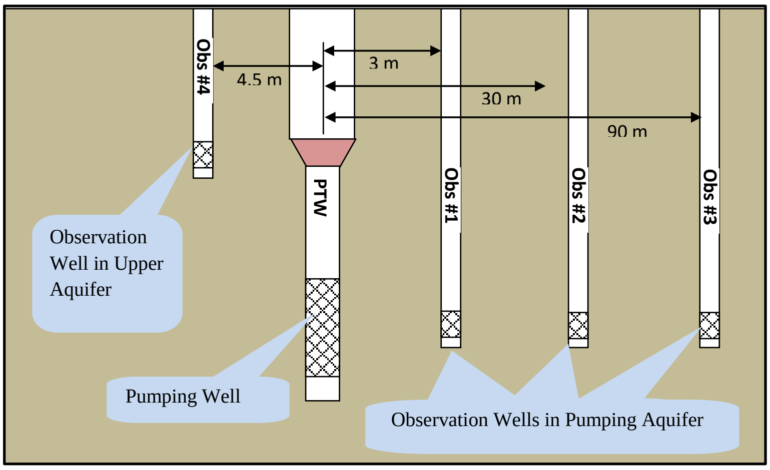


Figure 6-10: Location of Observation Wells and Pumping Well in Vertical Section.

During test, water level in upper aquifer observation well-4 showed no effect from pumping in the deep aquifer. But Groundwater levels in the deep aquifer observation wells (1 and 2) responded to the withdrawal of water from the pumping well.

The aquifer test data of Kuliar Char production well was analyzed by AQTESOLV software in three methods; Theis's method, Cooper-Jacob method and Theis's Recovery method. For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from 991 to 1313.1 m^2/day and from 0.00002174 to 0.000322 respectively. Storage- coefficient values and geological section indicate that the aquifer might be semi confined to confined in nature. Transmissivity values indicate that this aquifer has moderate potential for groundwater abstraction. However, water quality patameters need to be considered. The results are given in Table 6-12.

Area of influence due to pumping has been determined by plotting the pumping water level of main well and observation well nos. 1 and 2. From the graphical representation in Figure 6-10 it is observed that the area of influence of pumping is about 160 meter approximately surrounding the pump with pumping capacity of 50m^3/h. Maintaining proper well spacing, few hours of pumping per day can be done from this aquifer for potable use. Irrigation abstraction from the deep aquifer is not recommended.

Table 6-12: Summary of all Results from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)
Theis	Obs#1	1090.4	0.000161	0.0001842	1128.9
Cooper-Jacob	Obs#1	1313.1	0.00002174		
Theis	Obs#2	1087	0.000322		
Cooper-Jacob	Obs#2	1163	0.0002324		
Theis Recovery	Main Well	991	--		

6.1.2 Aquifer Properties of Netrokona District

Aquifer Pump Test at Kendua

Both of the step drawdown test and constant discharge aquifer pump test were conducted at Kendua upazila under Netrokona district. One production well and 4 nos. observation wells are installed for conducting constant discharge aquifer pump test as well as step drawdown test. The depth of production well is 121.95 m having screen length of 20.43 m. The depths of 4 nos. observation wells are 112.8, 112.8, 112.8and 47.25 m. Observation wells are located 3, 30, 90 and 4.5 m apart from the production well respectively. Layout plan is shown in Figure 6-11.

Step drawdown test was performed in three steps having the discharges of 40, 50 and 60 m^3/h for 2 (two) hours each and corresponding drawdowns were recorded as 5.43, 7.08 and 8.63 m respectively. By analyzing the drawdown data with IWM customized software, it is observed that well loss constant of the Kendua production well, Cw is 6.74E-07 and formation loss constant, Cf is 4.93E-03. Consideration of the well loss of the tube well and observed drawdown indicates that the design of the well is perfect. It is also observed that slight increment of discharge results in large drawdown. Well loss of this test production well is 14.33% only. Transmissivity is estimated as 247 m^2/day.

The constant discharge pump test was conducted for the time duration of 32 hours at Kendua. The pumping rate was monitored using circular orifice pipe and manometer. The height of the water column in a manometer attached to the side of the pumping well discharge tube was measured at 72.39 cm (28.5 inch). A flow rate of 50 m^3/h was determined using standard tables for the discharge pipe diameter. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. The recovery data have also been measured at a fixed time interval. Initial water table was 3.06 m and maximum drawdown recorded as 7.22 m.

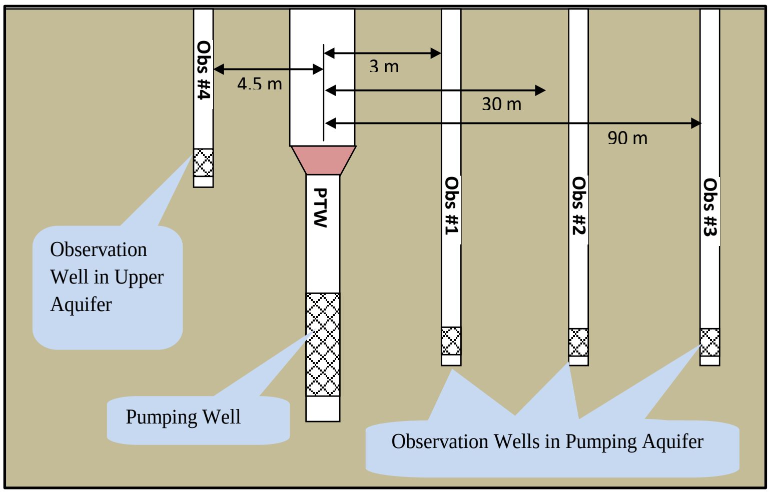


Figure 6-11: Location of Observation Wells and Pumping Well in Vertical Section

During test, water level in upper aquifer observation well-4 showed no effect from pumping in the deep aquifer. But Groundwater levels in the deep aquifer observation wells (1, 2 and 3) responded to the withdrawal of water from the pumping well.

The aquifer test data of Kendua production well was analyzed by AQTESOLV software in three methods; Theis method, Cooper-Jacob method and Theis's Recovery method. For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from 2621.1 to 2814.5 m^2/day and from 0.00000274 to 0.0000834 respectively. Storage- coefficient values and geological section indicate that the aquifer might be confined to leaky confined in nature. Transmissivity values indicate that this shallow aquifer has high potential for groundwater abstraction. However, water quality patameters need to be considered. The results are given in Table 6-13.

Table 6-13: Summary of all Results from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)	Permeability, K (m/day) appprox.
Theis	Obs#2	2621.1	0.00000545	0.0000414	2697.28	88.46
Cooper-Jacob	Obs#2	2814.5	0.00000274			
Theis	Obs#3	2748.3	0.00007404			
Cooper-Jacob	Obs#3	2667	0.0000834			
Theis Recovery	Main Well	2635.5	--			

Area of influence due to pumping has been determined by plotting the pumping water level of main well and observation well nos. 1, 2 and 3. From the graphical representation it is observed that the area of influence of pumping is about 220 meter approximately surrounding the pump with pumping capacity of 50 m^3/h. Maintaining proper well spacing, few hours of pumping per day can be done from this aquifer for both potable and irrigation water supply. Irrigation abstraction from the deeper aquifer is not recommended.

Aquifer Pump Test at Kamolpur, Kendua

The aquifer pump test was conducted at Kamolpur of Kendua upazila using existing production well. 2 nos. observation wells are installed for conducting aquifer test. The depth of production well is 21.34 m having screen length of 9.15 m. The depths of 2 nos. observation wells are 19.81 and 19.81 m. Observation wells are located 1.5 and 15.24 m apart from the production well respectively. Layout plan of the aquifer pump test setup is shown in Figure 6-12.

The constant discharge aquifer pump test was conducted for the time duration of 3 hours at Kamolpur under Kendua upazila. The pumping rate was monitored using Bucket and Stopwatch method. The flow rate of 17 m^3/h was determined using this method. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. The recovery data have also been collected immediately after completion of the pump test at a fixed time interval. Initial water table was 5.13 m and maximum drawdown recorded as 2.54 m.

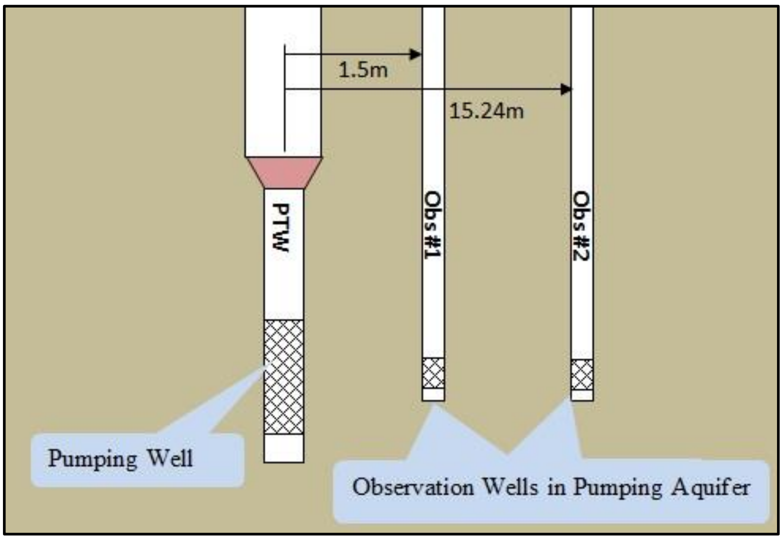


Figure 6-12: Location of Observation Wells and Pumping Well in Vertical Section

During test, Groundwater levels in the shallow aquifer observation wells (1 and 2) responded to the withdrawal of water from the pumping well.

The aquifer test data of Kamolpur existing production well was analyzed by AQTESOLV software in three methods; Theis's method, Cooper-Jacob method and Theis's Recovery method. For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from 736.1 to 1258 m^2/day and from 1.423 to 2.732 respectively. Storage-coefficient values and geological section indicate that the aquifer might be semi confined to unconfined in nature. Transmissivity values indicate that this shallow aquifer has moderate to high potential for groundwater abstraction. However, water quality patameters need to be considered. The results are given in Table 6-14.

Table 6-14: Summary of all Results from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)
Theis	Obs#1	1258	2.732	2.0775	988.46
Cooper-Jacob	Obs#1	736.1	1.423		
Theis Recovery	Main Well	971.3	--		

Area of influence due to pumping has been determined by plotting the pumping water level of main well and observation well nos. 1 and 2. From the graphical representation it is observed that the area of influence of pumping is about 80 meter approximately surrounding the pump with pumping capacity of 17 m^3/h. Maintaining proper well spacing, few hours of pumping per day can be done from this shallow aquifer for both potable and irrigation water supply.

Aquifer Pump Test at Netrokona Sadar

The step drawdown test and constant discharge aquifer pump test were conducted at Netrokona Sadar upazila. One production well and 4 nos. observation wells are installed for conducting aquifer test as well as step drawdown test. The depth of production well is 146.74 m having screen length of 17.68 m. The depths of 4 nos. observation wells are 139.32, 139.32, 139.32and 62.48 m. Observation wells are located 3, 30, 90 and 4.5 m apart from the production well respectively. Layout plan of aquifer pump test setup is shown in Figure 6-13.

Step drawdown test was performed in three steps. The pump was driven at 3 different stages: 40, 50 and 60 m^3/h for 2 (two) hours each and corresponding drawdowns were recorded as 3.62, 4.63 and 5.65 m respectively.

By analyzing the drawdown data with IWM customized software, it is observed that well loss constant of the Netrokona Sadar production well, Cw is 3.06E-07 and formation loss constant, Cf is 3.40E-03. Consideration of the well loss of the tube well and observed drawdown indicates that the design of the well is perfect. Well loss of this test production well calculated by IWM customized software is 9.91% only. Transmissivity is estimated as 358 m^2/day.

The constant discharge aquifer pump test was conducted for the time duration of 36 hours at Netrokona Sadar. The pumping rate was monitored using circular orifice pipe and manometer. The height of the water column in a manometer attached to the side of the pumping well discharge tube was measured at 72.39 cm (28.5 inch). A flow rate of 50 m^3/h was determined using standard tables for the discharge pipe diameter. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. The recovery data have been measured at a fixed time interval. Initial water table was 7.52 m and maximum drawdown recorded as 4.68 m.

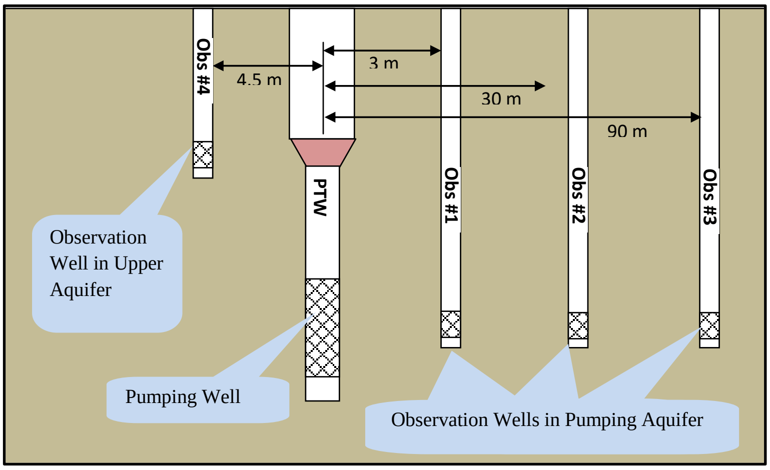


Figure 6-13: Location of Observation Wells and Pumping Well in Vertical Section

During test, water level in upper aquifer observation well-4 showed no effect from pumping in the deep aquifer. But Groundwater levels in the deep aquifer observation wells (1, 2 and 3) responded to the withdrawal of water from the pumping well.

The aquifer test data of Netrokona Sadar production well was analyzed by AQTESOLV software in three methods; Theis method, Cooper-Jacob method and Theis's Recovery method. For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from 1046.2 to 1137.5 m^2/day and from 0.0001161 to 0.0001375 respectively. Storage-coefficient values and geological section indicate that the aquifer might be confined to leaky confined in nature. Transmissivity values indicate that this aquifer has moderate to high potential for groundwater abstraction. However, water quality patameters need to be considered. The results are given in Table 6-15.

Table 6-15: Summary of all Results from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)	Permeability, K (m/day) appprox.
Theis	Obs#3	1086.4	0.0001375	0.0001268	1090.03	35.75
Cooper-Jacob	Obs#3	1137.5	0.0001161			
Theis Recovery	Main Well	1046.2	--			

Aquifer Pump Test at Purbadhala

The constant discharge aquifer pump test was conducted at Purbadhala under Netrokona district using existing production well. 2 nos. observation wells are installed for conducting aquifer test. The depth of production well is 17.37 m having screen length of 8.23 m. The depths of 2 nos. observation wells are 15.24 and 15.24 m. Observation wells are located 1.5 and 15.24 m apart from the production well respectively. Layout plan is shown in Figure 6-14.

The aquifer pump test was conducted at Purbadhala upazila for the time duration of 1 hour. The pumping rate was monitored using Bucket and Stopwatch method. The flow rate of 17 m^3/h was determined using this method. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. The recovery data have also been collected at a fixed time interval. Initial water table was 4.43 m and maximum drawdown recorded as 1.175 m.

During test, Groundwater levels in the shallow aquifer observation wells (1 and 2) responded to the withdrawal of water from the pumping well.

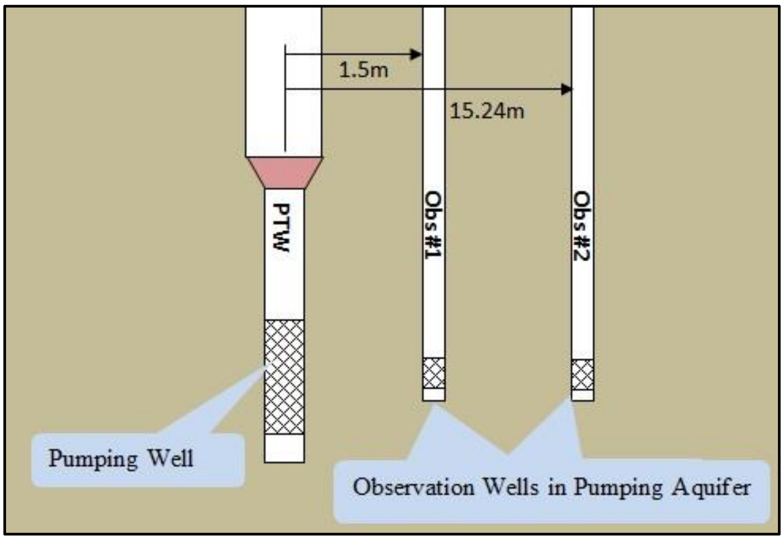


Figure 6-14: Location of Observation Wells and Pumping Well in Vertical Section

The aquifer test data of Purbadhala existing production well was analyzed by AQTESOLV software in three methods; Theis's method, Cooper-Jacob method and Theis's Recovery method. For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from 2691.1 to 3387.1 m^2/day and from 0.000000835 to 0.0004603 respectively. Storage- coefficient values and geological section indicate that the aquifer might be confined to leaky confined in nature. Transmissivity values indicate that this shallow aquifer has high potential for groundwater abstraction. However, water quality patameters need to be considered. The results are given in Table 6-16.

Table 6-16: Summary of all Results from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)
Theis	Obs#1	3201.8	0.0004603	0.00023	3093.33
Cooper-Jacob	Obs#1	3387.1	0.000000835		
Theis Recovery	Main Well	2691.1	--		

Area of influence due to pumping has been determined by plotting the pumping water level of main well and observation well nos. 1 and 2. From the graphical representation it is observed that the area of influence of pumping is about 20 meter approximately surrounding the pump with pumping capacity of 17 m^3/h. Maintaining proper well spacing, few hours of pumping per day can be done from this shallow aquifer for both potable and irrigation water supply.

Aquifer Pump Test at Bikailka, Barhatta

The aquifer pump test was conducted at Bikailka village, Barhatta under Netrokona district using existing production well. 2 nos. observation wells are installed for conducting aquifer test. The depth of production well is 20.42 m having screen length of 6.71 m. The depths of 2 nos. observation wells are 19.81 and 19.81 m. Observation wells are located 1.5 and 15.24 m apart from the production well respectively. Layout plan of the aquifer pump test setup is shown in Figure 6-15.

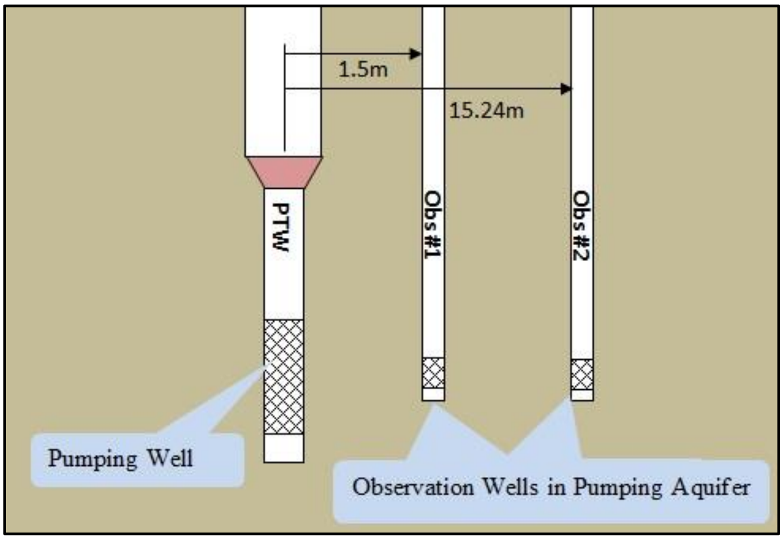


Figure 6-15: Location of Observation Wells and Pumping Well in Vertical Section

The constant discharge aquifer pump test was conducted for the time duration of 5 hours at Bikailka village under Barhatta upazila. The pumping rate was monitored using Bucket and Stopwatch method. The flow rate of 14 m^3/h was determined using this method. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. The recovery data have been collected at a fixed time interval. Initial water table was 5.31 m and maximum drawdown recorded as 2.065 m.

During test, Groundwater levels in the shallow aquifer observation wells (1 and 2) responded to the withdrawal of water from the pumping well.

The aquifer test data of Bikailka existing production well was analyzed by AQTESOLV software in three methods; Theis's method, Cooper-Jacob method and Theis's Recovery method. For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from 1093.6 to 1164.4 m^2/day and from 0.000000134 to 0.009459 respectively. Storage- coefficient values and geological section indicate that the aquifer might be semi confined to confined in nature. Transmissivity values indicate that this shallow aquifer has moderate to high potential for groundwater abstraction. However, water quality patameters need to be considered. The results are given in Table 6-17.

Table 6-17: Summary of all Results from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)
Theis	Obs#1	1093.6	0.009459	0.0047	1120.36
Cooper-Jacob	Obs#1	1103.1	0.000000134		
Theis Recovery	Main Well	1164.4	--		

Area of influence due to pumping has been determined by plotting the pumping water level of main well and observation well nos. 1 and 2. From the graphical representation it is observed that the area of influence of pumping is about 24 meter approximately surrounding the pump with pumping capacity of 14m^3/h. Maintaining proper well spacing, few hours of pumping per day can be done from this shallow aquifer for both potable and irrigation water supply.

Aquifer Pump Test at Dattogram, Barhatta

The constant discharge aquifer pump test was conducted at Dattogram village, Barhatta under Netrokona district using production well. 2 nos. observation wells are installed for conducting aquifer test. The depth of production well is 26.82 m having screen length of 14.63 m. The depths of 2 nos. observation wells are 25 and 25 m. Observation wells are located 1.5 and 15.24 m apart from the production well respectively. Layout plan of the aquifer pump test setup is shown in Figure 6-16.

The constant rate test for the time duration of 5 hours was conducted at Dattogram village under Barhatta upazila. The pumping rate was monitored using Bucket and Stopwatch method. The flow rate of 16 m^3/h was determined using this method. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. The recovery data have been collected at a fixed time interval. Initial water table was 5.07 m and maximum drawdown recorded as 1.405 m. Drawdown was measured using water level meter and measuring tapes attached with Avometers by the field personnel.

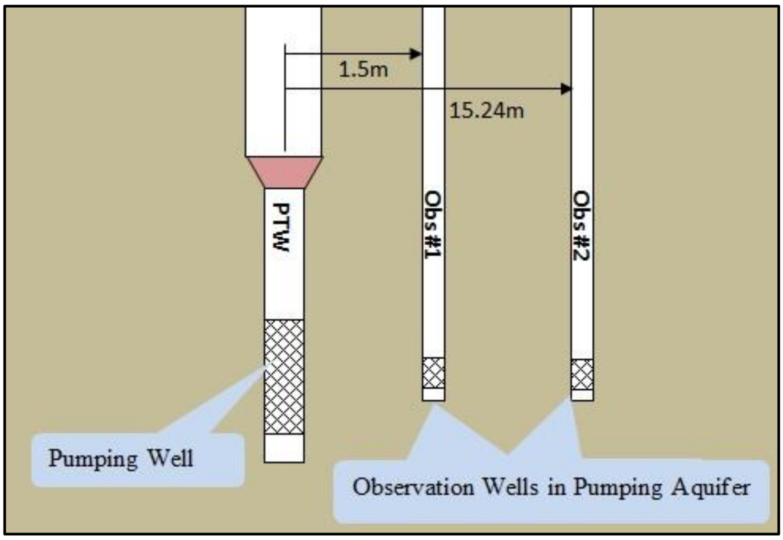


Figure 6-16: Location of Observation Wells and Pumping Well in Vertical Section

During test, Groundwater levels in the shallow aquifer observation wells (1 and 2) responded to the withdrawal of water from the pumping well.

The aquifer test data of Dattogram existing production well was analyzed by AQTESOLV software in three methods; Theis's method, Cooper-Jacob method and Theis's Recovery method. For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from 423.6 to 548 m^2/day and from 0.2581 to 0.4674 respectively. Storage-coefficient values and geological section indicate that the aquifer might be semi confined to unconfined in nature. Transmissivity values indicate that this shallow aquifer has moderate to low potential for groundwater abstraction. The results are given in Table 6-18.

Table 6-18: Summary of all Results from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)
Theis	Obs#1	548	0.4674	0.36275	498.6
Cooper-Jacob	Obs#1	524.2	0.2581		
Theis Recovery	Main Well	423.6	--		

Area of influence due to pumping has been determined by plotting the pumping water level of main well and observation well nos. 1 and 2. From the graphical representation it is observed that the area of influence of pumping is about 33 meter approximately surrounding the pump with pumping capacity of 16m^3/h. Maintaining proper well spacing, few hours of pumping per day can be done from this shallow aquifer for both potable and irrigation water supply.

Aquifer Pump Test at Atpara

The constant discharge aquifer pump test was conducted at Atpara under Netrokona district using existing production well. 2 nos. observation wells are installed for conducting aquifer test. The depth of production well is 22 m having screen length of 14.63 m. The depths of 2 nos. observation wells are 21.95 and 21.95 m. Observation wells are located 1.5 and 15.24 m apart from the production well respectively. Layout plan is shown in Figure 6-17.

The aquifer pump test was conducted at Atpara upazila for the time duration of 4 hours. The pumping rate was monitored using Bucket and Stopwatch method. The flow rate of 16 m^3/h was determined using this method. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. The recovery data have been collected at a fixed time interval. Initial water table was 5.67 m and maximum drawdown recorded as 3.21 m.

During test, Groundwater levels in the shallow aquifer observation wells (1 and 2) responded to the withdrawal of water from the pumping well.

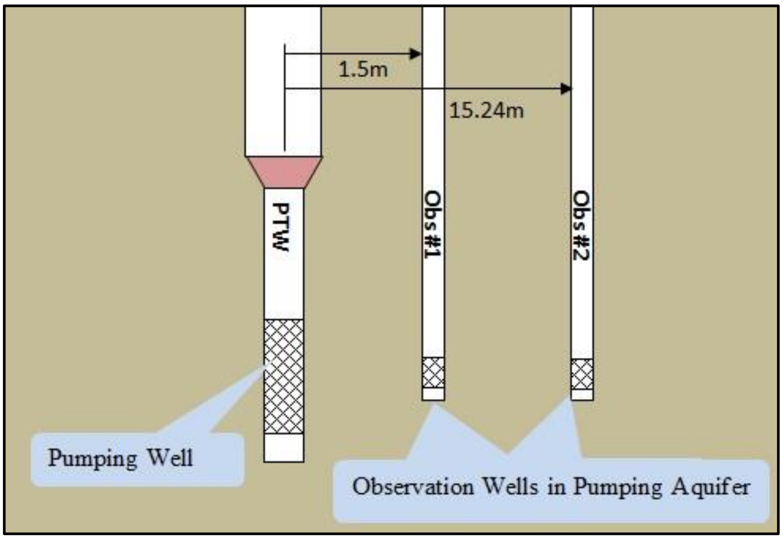


Figure 6-17: Location of Observation Wells and Pumping Well in Vertical Section

The aquifer test data of Atpara existing production well was analyzed by AQTESOLV software in three methods; Theis's method, Cooper-Jacob method and Theis's Recovery method. For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from 246.6 to 287.9 m^2/day and from 0.01001 to 0.08207 respectively. Storage- coefficient values and geological section indicate that the aquifer might be semi confined in nature.

Transmissivity values indicate that this shallow aquifer has low potential for groundwater abstraction. The results are given in Table 6-19.

Table 6-19: Summary of all Results from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)
Theis	Obs#1	246.6	0.08207	0.04604	264.7
Cooper-Jacob	Obs#1	287.9	0.01001		
Theis Recovery	Main Well	259.6	--		

Area of influence due to pumping has been determined by plotting the pumping water level of main well and observation well nos. 1 and 2. From the graphical representation it is observed that the area of influence of pumping is about 25 meter approximately surrounding the pump with pumping capacity of 16m^3/h. Maintaining proper well spacing, few hours of pumping per day can be done from this shallow aquifer for potable water supply. Irrigation abstraction from the aquifer may be done with careful monitoring.

6.1.3 Aquifer Properties of Sylhet District

Aquifer Pump Test at Balaganj

The step drawdown test and constant discharge aquifer pump test were conducted at Balaganj upazila under Sylhet district. One production well and 4 nos. observation wells are installed for conducting aquifer test as well as step drawdown test. Step drawdown test was performed in production well by three steps such as 40, 50 and 60 m^3/h. The interpretation of step drawdown test was not done due to high rate of drawdown. The depth of production well is 145.43 m having screen length of 20.12 m. The depths of 4 nos. observation wells are 138.72, 138.72, 138.72 and 86.89 m. Observation wells are located 3, 30, 90 and 4.5 m apart from the production well respectively. Layout plan of the aquifer pump test setup is shown in Figure 6-18.

The constant discharge pump test was conducted for the time duration of 34 hours at Balaganj. The pumping rate was monitored using circular orifice pipe and manometer. The height of the water column in a manometer attached to the side of the pumping well discharge tube was measured at 72.39 cm (28.5 inch). A flow rate of 50 m^3/h was determined using standard tables for the discharge pipe diameter. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. The recovery data have been collected at a fixed time interval. Initial water table was 7.27m and maximum drawdown recorded as 7.25 m.

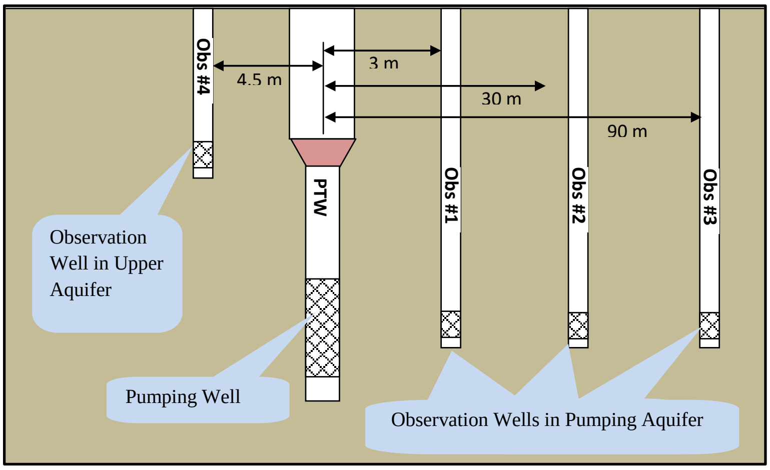


Figure 6-18: Location of Observation Wells and Pumping Well in Vertical Section

During test, water level in upper aquifer observation well-4 showed no effect from pumping in the deep aquifer. But Groundwater levels in the deep aquifer observation wells (1, 2 and 3) responded to the withdrawal of water from the pumping well.

The aquifer test data of Balaganj production well was analyzed by AQTESOLV software in three methods; Theis's method, Cooper-Jacob method and Theis's Recovery method. For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from 275 to 486 m^2/day and from 5.587 to 8.002 respectively. Storage- coefficient values and geological section indicate that the aquifer might be unconfined in nature. Transmissivity values indicate that this shallow aquifer has moderate to low potential for groundwater abstraction. The results are given in Table 6-20.

Table 6-20: Summary of all Results from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)	Permeability, K (m/day) appprox.
Theis	Obs#1	375	8.002	6.79	347	12
Cooper-Jacob	Obs#1	277	5.587			
Theis	Obs#3	486	--			
Cooper-Jacob	Obs#3	324	--			
Theis Recovery	Main Well	275	--			

Area of influence due to pumping has been determined by plotting the pumping water level of main well and observation well nos. 1, 2 and 3. From the graphical representation it is observed that the area of influence of pumping is about 150 meter approximately surrounding the pump with pumping capacity of 50 m^3/h. Maintaining proper well spacing, few hours of pumping per day can be done from this shallow aquifer for both potable and irrigation water supply.

6.1.4 Aquifer Properties of Habganj District

Aquifer Pump Test at Bahubal

The step drawdown test and constant discharge aquifer pump test were conducted at Bahubal upazila under Habiganj district. One production well and 4 nos. observation wells are installed for conducting aquifer test as well as step drawdown test. Step drawdown test was performed in production well by three steps such as 40, 50 and 60 m^3/h. The interpretation of step drawdown test was not done due to high drawdown. The depth of production well is 60.98 m having screen length of 17.68 m. The depths of 4 nos. observation wells are 47.26, 47.26, 47.26 and 25.95 m. Observation wells are located 3, 30, 90 and 4.5 m apart from the production well respectively. Layout plan is shown in Figure 6-19.

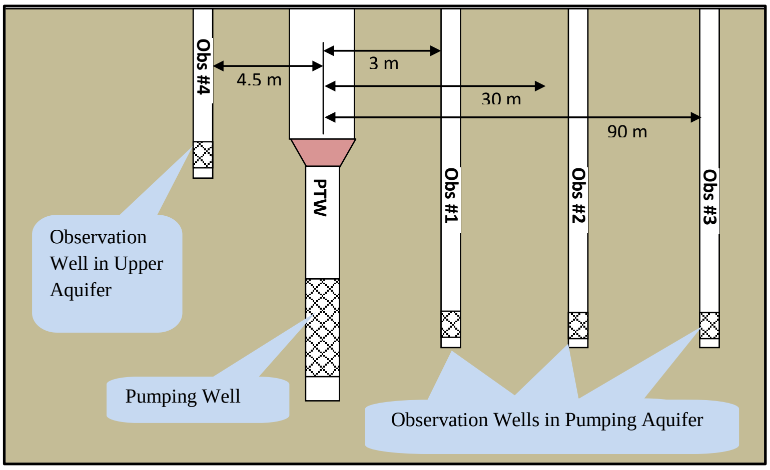


Figure 6-19: Location of Observation Wells and Pumping Well in Vertical Section

The constant discharge aquifer pump test was conducted at Bahubal for the time duration of 30 hours. The pumping rate was monitored using circular orifice pipe and manometer. The height of the water column in a manometer attached to the side of the pumping well discharge tube was measured at 72.39 cm (28.5 inch). A flow rate of 50 m^3/h was determined using standard tables for the discharge pipe diameter. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. The recovery data have been collected at a fixed time interval. Initial water table was 8.04 m and maximum drawdown recorded as 8.38m.

During test, Groundwater levels in the deep aquifer observation wells (1, 2 and 3) and shallow aquifer observation well 4 responded to the withdrawal of water from the pumping well.

The aquifer test data of Bhubal production well was analyzed by AQTESOLV software in three methods; Cooper-Jacob method, Neuman and Theis's Recovery method. For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from 357 to 394 m^2/day and from 0.8346 to 2.987 respectively. Storage- coefficient values and geological section indicate that the aquifer might be semi confined to unconfined in nature. Transmissivity values indicate that this aquifer has moderate to low potential for groundwater abstraction. However, water quality patameters need to be considered. The results are given in Table 6-21.

Table 6-21: Summary of all Results from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)	Permeability, K (m/day) appprox.
Cooper-Jacob	Obs#1	391	0.8346	1.9108	380	8.12
Neuman	Obs#1	357	2.987			
Theis Recovery	Main Well	394	--			

Area of influence due to pumping has been determined by plotting the pumping water level of main well and observation well nos. 1, 2 and 3. From the graphical representation it is observed that the area of influence of pumping is about 410 meter approximately surrounding the pump with pumping capacity of 50 m^3/h. Maintaining proper well spacing, few hours of pumping per day can be done from this aquifer for potable use. Irrigation abstraction from the deep aquifer is not recommended.

Aquifer Pump Test at Madhabpur

The step drawdown test and constant discharge aquifer pump test were conducted at Madhabpur upazila under Habiganj district. One production well and 4 nos. observation wells are installed for conducting aquifer test as well as step drawdown test.

Step drawdown test was performed in three steps. The pump was driven at 3 different stages: 40, 50 and 60 m^3/h for 2 (two) hours each and corresponding drawdowns were recorded as 4.28, 5.49 and 6.75 m respectively.

By analyzing the drawdown data with IWM customized software, it is observed that well loss constant of the Madhabpur production well, Cw is 4.59E-07 and formation loss constant, Cf is 3.92E-03. Consideration of the well loss of the tube well and observed drawdown indicates that the design of the well is perfect. Well loss of this test production well calculated by IWM customized software is 12.52% only. For optimum design of the supply well planners should keep in mind not only the well loss, he should also consider the formation loss of the screened aquifer which increases total drawdown. Transmissivity is determined as 311 m^2/day.

The Layout plan of aquifer pump test setup is shown in Figure 6-20. The depth of production well is 132.93 m having screen length of 14.63 m. The depths of 4 nos. observation wells are 129.59, 129.59, 129.59 and 53.35 m. Observation wells are located 3, 30, 90 and 4.5 m apart from the production well respectively.

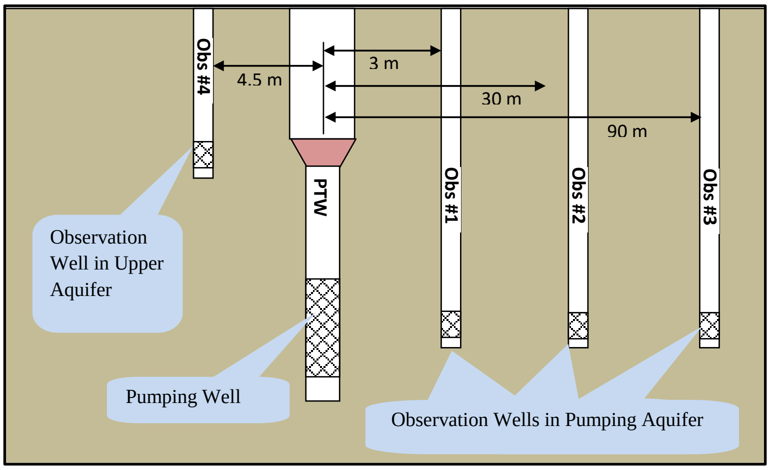


Figure 6-20: Location of Observation Wells and Pumping Well in Vertical Section

The constant discharge aquifer pump test was conducted at Madhabpur for the time duration of 26 hours. The pumping rate was monitored using circular orifice pipe and manometer. The height of the water column in a manometer attached to the side of the pumping well discharge tube was measured at 72.39 cm (28.5 inch). A flow rate of 50 m^3/h was determined using standard tables for the discharge pipe diameter. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. The recovery data have been collected at a fixed time interval. Initial water table was 0.15 m and maximum drawdown recorded as 5.67 m.

During test, water level in upper aquifer observation well-4 showed no effect from pumping in the deep aquifer. But Groundwater levels in the deep aquifer observation wells (1 and 2) responded to the withdrawal of water from the pumping well whereas no influence in water level shows in the observation well 3 located in 90m apart from the production well during the pumping.

The aquifer test data of Madhabpur production well was analyzed by AQTESOLV software in three methods; Theis method, Cooper-Jacob method and Theis's Recovery method. For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from 966.2 to 991.3 m^2/day and from 0.0001397 to 0.0001594 respectively. Storage- coefficient values and geological section indicate that the aquifer might be confined to leaky confined in nature. Transmissivity values indicate that this shallow aquifer has moderate potential for groundwater abstraction. However, water quality patameters need to be considered. The results are given in Table 6-22.

Table 6-22: Summary of all Results from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)	Permeability, K (m/day) appprox.
Theis	Obs#2	991.3	0.0001397	0.00015	982.7	40.29
Cooper-Jacob	Obs#2	966.2	0.0001594			
Theis Recovery	Main Well	990.6	--			

6.1.5 Aquifer Properties of Sunamganj District

Aquifer Pump Test at Biswambarpur

The step drawdown test and constant discharge aquifer pump test were conducted at Bishwambarpur upazila under Sunamganj district. One production well and 4 nos. observation wells are installed for conducting aquifer test as well as step drawdown test. Step drawdown test was performed in production well by three steps such as 40, 50 and 60 m^3/h. The interpretation of step drawdown test was not done due to high drawdown. The depth of production well is 100 m having screen length of 17.07 m. The depths of 4 nos. observation wells are 92.99, 92.99, 92.99 and 62.50 m. Observation wells are located 3, 30, 90 and 4.5 m apart from the production well respectively. Layout plan is shown in Figure 6-21.

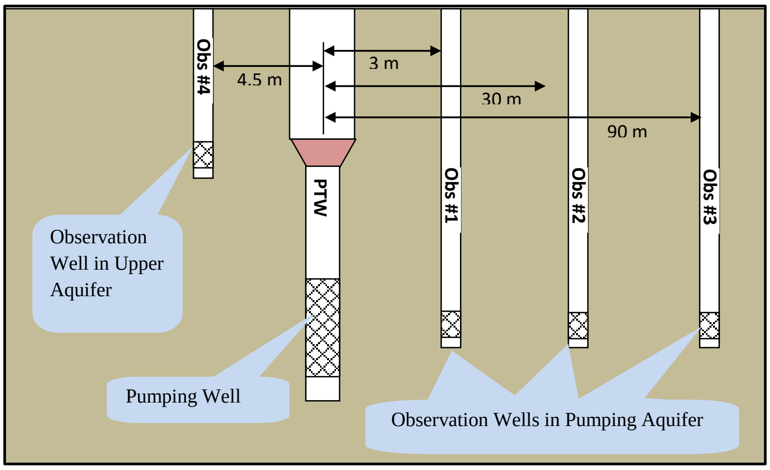


Figure 6-21: Location of Observation Wells and Pumping Well in Vertical Section

The constant discharge aquifer test was conducted at Bishwambarpur for the time duration of 34 hours. The pumping rate was monitored using circular orifice pipe and manometer. The height of the water column in a manometer attached to the side of the pumping well discharge tube was measured at 46.99 cm (18.5 inch). The flow rate of 40 m^3/h was determined using standard tables for the discharge pipe diameter. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. The recovery data have been collected at a fixed time interval. Initial water table was 7.16 m and maximum drawdown recorded as 12.74 m.

During test, water level in upper aquifer observation well-4 showed no effect from pumping in the deep aquifer. But Groundwater levels in the deep aquifer observation wells (1 and 2) responded to the withdrawal of water from the pumping well. Water level in observation well 3 was not able to measure due to technical problem.

The aquifer test data of Bishwambarpur production well was analyzed by AQTESOLV software in three methods; Theis's method, Cooper-Jacob method and Theis's Recovery method. For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from 63.86 to 81.23 m^2/day and from 0.0001245 to 0.0001412 respectively. Storage- coefficient values and geological section indicate that the aquifer might be confined to leaky confined in nature. Transmissivity values indicate that this shallow aquifer has very low potential for groundwater abstraction. The results are given in Table 6-23.

Table 6-23: Summary of all Results from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)	Permeability, K (m/day) appprox.
Theis	Obs#2	67.53	0.0001245	0.000133	70.86	1.79
Cooper-Jacob	Obs#2	63.86	0.0001412			
Theis Recovery	Main Well	81.23	--			

Aquifer Pump Test at Chattak

The step drawdown test and constant discharge aquifer pump test were conducted at Chhatak upazila under Sunamganj district. One production well and 4 nos. observation wells are installed for conducting aquifer test as well as step drawdown test. Step drawdown test was performed in production well by three steps such as 40, 50 and 60 m^3/h. The interpretation of step drawdown test was not done due to high drawdown. The depth of production well is 80.49 m having screen length of 17.07 m. The depths of 4 nos. observation wells are 71.65, 71.65, 71.65 and 32.01 m. Observation wells are located 3, 30, 90 and 4.5 m apart from the production well respectively. Layout plan of the aquifer test setup is shown in Figure 6-22.

The constant discharge test for the time duration of 32 hours was conducted at Chhatak. The pumping rate was monitored using circular orifice pipe and manometer. The height of the water column in a manometer attached to the side of the pumping well discharge tube was measured at 72.39 cm (28.5 inch). A flow rate of 50 m^3/h was determined using standard tables for the discharge pipe diameter. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. The recovery data have been collected at a fixed time interval. Initial water table was 8.15 m and maximum drawdown recorded as 3.50 m. Drawdown was measured using water level meter and measuring tapes attached with Avometers by the field personnel.

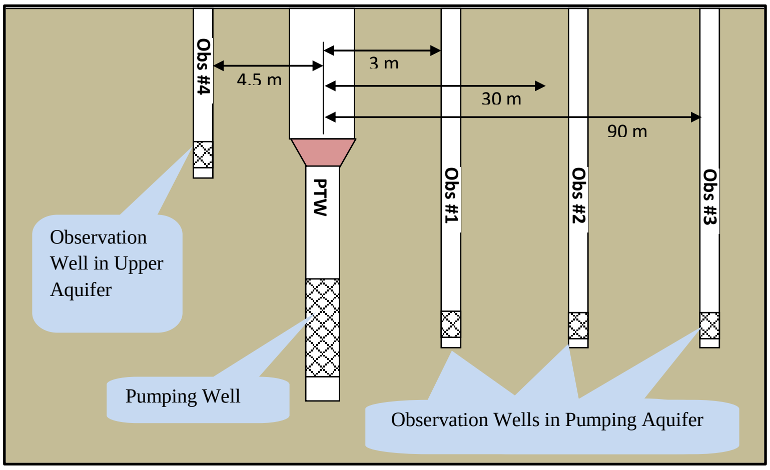


Figure 6-22: Location of Observation Wells and Pumping Well in Vertical Section

During test, water level in upper aquifer observation well 4 showed no effect from pumping in the deep aquifer. But Groundwater levels in the deep aquifer observation wells (1, 2 and 3) responded to the withdrawal of water from the pumping well.

The aquifer pump test data of Chhatak production well was analyzed by AQTESOLV software in three methods; Theis's method, Cooper-Jacob method and Theis's Recovery method. For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from 1145 to 1362.4 m^2/day and from 0.0001312 to 0.0009648 respectively. Storage- coefficient values and geological section indicate that the aquifer might be semi confined to leaky confined in nature. Transmissivity values indicate that this aquifer has moderate to high potential for groundwater abstraction. However, water quality patameters need to be considered. The results are given in Table 6-24.

Table 6-24: Summary of all Results from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)	Permeability, K (m/day) appprox.
Theis	Obs#1	1252.8	0.0009648	0.000373	1241.76	27.15
Cooper-Jacob	Obs#1	1145	0.0001312			
Theis	Obs#2	1281.3	0.0002373			
Cooper-Jacob	Obs#2	1362.4	0.0001608			
Theis Recovery	Main Well	1167.3	--			

Area of influence due to pumping has been determined by plotting the pumping water level of main well and observation well nos. 1, 2 and 3. From the graphical representation it is observed that the area of influence of pumping is about 640 meter approximately surrounding the pump with pumping capacity of 50 m^3/h. Maintaining proper well spacing, few hours of pumping per day can be done from this aquifer for both potable and irrigation water supply. Irrigation abstraction from the deep aquifer is not recommended.

Aquifer Pump Test at Dowarabazar

The step drawdown test and constant discharge aquifer pump test were conducted at Dowarabazar upazila under Sunamganj district. One production well and 4 nos. observation wells are installed for conducting aquifer test as well as step drawdown test.

Step drawdown test was performed in three steps. The pump was driven at 3 different stages: 40, 50 and 60 m^3/h for 2 (two) hours each and corresponding drawdowns were recorded as 5.64, 7.1 and 8.6 m respectively. Transmissivity is determined as 219 m^2/day.

By analyzing the drawdown data with IWM customized software, it is observed that well loss constant of the Dowarabazar production well, Cw is 1.95E-07 and formation loss constant, Cf is 5.56E-03. Consideration of the well loss of the tube well and observed drawdown indicates that the design of the well is perfect. It is also observed that slight increment of discharge results in large drawdown. Well loss of this test production well is calculated as 4.11% only. For optimum design of the supply well planners should keep in mind not only the well loss, he should also consider the formation loss of the screened aquifer which increases total drawdown.

Layout plan of the aquifer pump test is shown in Figure 6-23. The depth of production well is 79.27 m having screen length of 21.33 m. The depths of 4 nos. observation wells are 70.12, 70.12, 70.12and 22.87 m. Observation wells are located 3, 30, 90 and 4.5 m apart from the production well respectively.

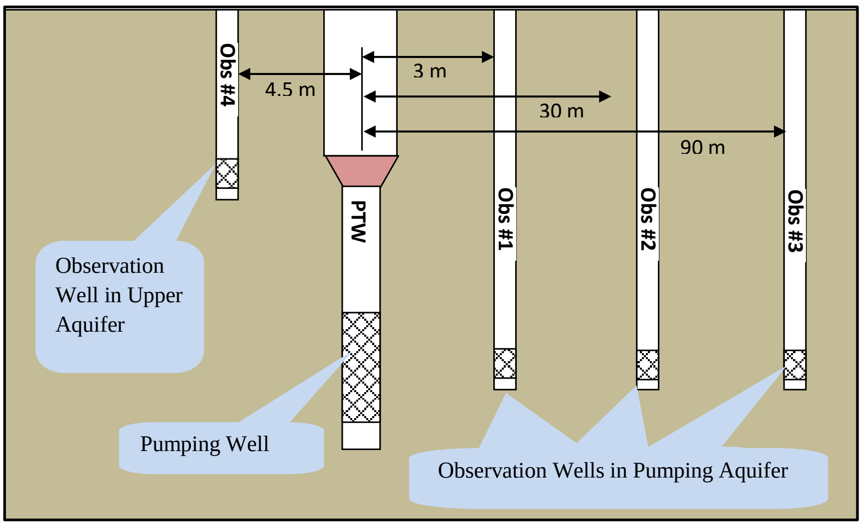


Figure 6-23: Location of Observation Wells and Pumping Well in Vertical Section

The aquifer pump test was conducted at Dowarabazar for the time duration of 26 hours. The pumping rate was monitored using circular orifice pipe and manometer. The height of the water column in a manometer attached to the side of the pumping well discharge tube was measured at 72.39 cm (28.5 inch). A flow rate of 50 m^3/h was determined using standard tables for the discharge pipe diameter. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. The recovery data have also been measured at a fixed time interval. Initial water table was 0.07 m and maximum drawdown recorded as 5.64 m. Drawdown was measured using water level meter and measuring tapes attached with Avometers by the field personnel.

During test, water level in upper aquifer observation well-4 as well as deep aquifer observation wells (1, 2 and 3) responded to the withdrawal of water from the pumping well.

The aquifer test data of Dawarabazar production well was analyzed by AQTESOLV software in three methods; Theis's method, Cooper-Jacob method and Theis's Recovery method. For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from 666.2 to 1446.6 m^2/day and from 0.000104 to 8.77E-11 respectively. Storage- coefficient values and geological section indicate that the aquifer might be leaky confined to confined in nature. Transmissivity values indicate that this aquifer has moderate to high potential for groundwater abstraction. However, water quality patameters need to be considered. The results are given in Table 6-25.

Table 6-25: Summary of all Results from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)	Permeability, K (m/day) appprox.
Theis	Obs#1	1190.4	0.000104	0.0000501	996.7	10.89
Cooper-Jacob	Obs#1	666.2	8.77E-11			
Theis	Obs#2	1446.6	0.0000965			
Cooper-Jacob	Obs#2	895.1	3.55E-8			
Theis Recovery	Main Well	785.2	--			

Area of influence due to pumping has been determined by plotting the pumping water level of main well and observation well nos. 1, 2 and 3. From the graphical representation it is observed that the area of influence of pumping is about 90 meter approximately surrounding the pump with pumping capacity of 50 m^3/h. Maintaining proper well spacing, few hours of pumping per day can be done from this aquifer for both potable and irrigation water supply. Irrigation abstraction from the deep aquifer is not recommended.

6.1.6 Aquifer Properties of Maulavibazar District

Aquifer Pump Test at Kamalganj

The step drawdown test and aquifer pump test were conducted at Kamalganj upazila under Maulvibazar district. One production well and 4 nos. observation wells are installed for conducting aquifer test as well as step drawdown test. Step drawdown test was performed in production well by three steps such as 40, 50 and 60 m^3/h. The interpretation of step drawdown test was not possible due to high in drawdown. The depth of production well is 108.23 m having screen length of 25.81 m. The depths of 4 nos. observation wells are 96.03, 96.03, 96.03 and 47.25 m. Observation wells are located 3, 30, 90 and 4.5 m apart from the production well respectively. Layout plan is shown in Figure 6-24.

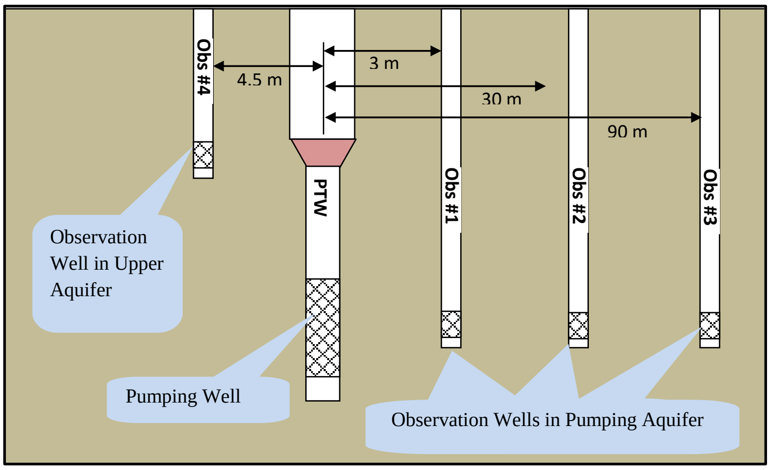


Figure 6-24: Location of Observation Wells and Pumping Well in Vertical Section.

The constant rate test for the time duration of 12 hours was conducted at Kamalganj. The pumping rate was monitored using circular orifice pipe and manometer. The height of the water column in a manometer attached to the side of the pumping well discharge tube was measured at 72.39 cm (28.5 inch). A flow rate of 50m^3/h was determined using standard tables for the discharge pipe diameter. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. Measurement of water levels after the pump stopped (recovery data) are extremely valuable for recovery test. So after the continuous pumping the recovery data have been collected at a fixed time interval. Initial water table was 2.05 m and maximum drawdown recorded as 14.24 m.

During test, water level in upper aquifer observation well-4 showed no effect from pumping in the deep aquifer. But Groundwater levels in the deep aquifer observation wells (1 and 2) responded to the withdrawal of water from the pumping well.

The aquifer test data of Kamalganj production well was analyzed by AQTESOLV software in three methods; Theis's method, Cooper-Jacob method and Theis's Recovery method. For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from

259 to 288.4 m^2/day and from 0.0000222 to 0.0001298 respectively. Storage- coefficient values and geological section indicate that the aquifer might be semi confined to confined in nature. Transmissivity values indicate that this aquifer has moderate to low potential for groundwater abstraction. However, water quality patameters need to be considered. The results are given in Table 6-26.

Table 6-26: Summary of all Results from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)
Theis	Obs#1	275.5	0.0000222	0.000091	270.68
Cooper-Jacob	Obs#1	288.4	0.0001058		
Theis	Obs#2	260.3	0.0001298		
Cooper-Jacob	Obs#2	270.2	0.0001088		
Theis Recovery	Main Well	259	--		

Area of influence due to pumping has been determined by plotting the pumping water level of main well and observation well nos. 1 and 2. From the graphical representation it is observed that the area of influence of pumping is about 165 meter approximately surrounding the pump with pumping capacity of 50m^3/h. Maintaining proper well spacing, few hours of pumping per day can be done from this aquifer for potable use. Irrigation abstraction from the deep aquifer is not recommended.

Aquifer Pump Test at Kulaura

The step drawdown test and aquifer pump test were conducted at Kulaura upazila under Maulvibazar district. One production well and 4 nos. observation wells are installed for conducting aquifer test as well as step drawdown test. Step drawdown test was performed in production well by three steps such as 40, 50 and 60 m^3/h. The interpretation of step drawdown test was not possible due to high in drawdown. The depth of production well is 150.30 m having screen length of 20 m. The depths of 4 nos. observation wells are 143.29, 150.91, 149.39 and 25.91 m. Observation wells are located 3, 30, 90 and 4.5 m apart from the production well respectively. Layout plan is shown in Figure 6-25.

The constant rate test for the time duration of 12 hours was conducted at Kulaura. The pumping rate was monitored using circular orifice pipe and manometer. The height of the water column in a manometer attached to the side of the pumping well discharge tube was measured at 72.39 cm (28.5 inch). The flow rate of 50 m^3/h was determined using standard tables for the discharge pipe diameter. The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. Measurement of water levels after the pump stopped (recovery data) are extremely valuable for recovery test. So after the continuous pumping the recovery data have been collected at a fixed time interval. Initial water table was 21.63 m and maximum drawdown recorded as 12.35 m.

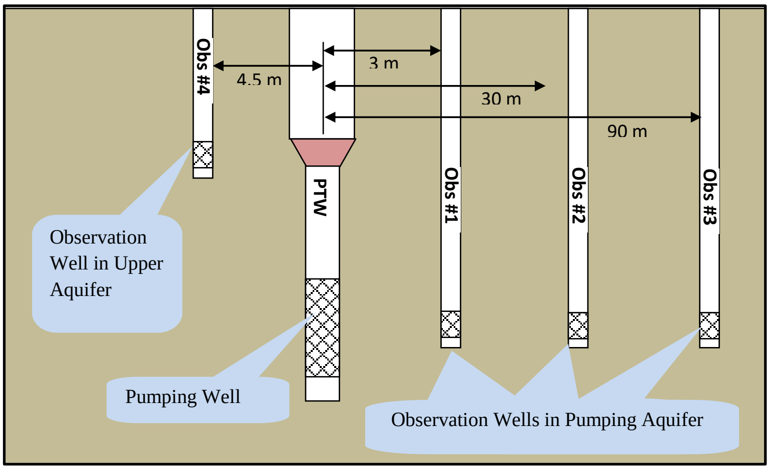


Figure 6-25: Location of Observation Wells and Pumping Well in Vertical Section.

During test, water level in upper aquifer observation well-4 showed no effect from pumping in the deep aquifer. But Groundwater levels in the deep aquifer observation wells 3 responded to the withdrawal of water from the pumping well. Water level in observation well 1 and 2 was not able to measure due to technical problem.

The aquifer test data of Kulaura production well was analyzed by AQTESOLV software in three methods; Theis's method, Cooper-Jacob method and Theis's Recovery method. For different methods of calculating transmissivity (T) and storage coefficient (S), values vary from 769.6 to 896.8 m^2/day and from 0.0000223 to 0.0000224 respectively. Storage- coefficient values and geological section indicate that the aquifer might be semi confined to confined in nature. Transmissivity values indicate that this aquifer has moderate potential for groundwater abstraction. However, water quality patameters need to be considered. The results are given in Table 6-27.

Table 6-27: Summary of all Results from Different Methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)	Permeability, K (m/day) appprox.
Theis	Obs#3	896.8	0.0000224	0.00002235	853.06	23.31
Cooper-Jacob	Obs#3	892.8	0.0000223			
Theis Recovery	Main Well	769.6	--			

Details analysis of aquifer test data is given in Volume-II, Appendix G.

6.2 Trend of Groundwater Table

On a regional basis the major components of groundwater flow are in vertical direction. These include the natural recharge from rainfall and flooding during the monsoon season, and the various discharges of water comprises mainly groundwater abstraction, during the dry season. Lateral groundwater movement is, on a regional scale, insignificant. Analysis of long-term water table data of BWDB piezometers installed in upper aquifers shows that hydrographs are very variable in different parts of the study area, and variations can be significant on a local scale as well (Figure 6-27, Figure 6-29, Figure 6-31, Figure 6-33, Figure 6-35, Figure 6-37). On the other hand, a degree of similarity is also found between different hydrographs and this is quite closely related to the physiography and geological characteristics of the aquifer system. The impact of increasing groundwater development can often be clearly observed from hydrographs. Groundwater recedes more during the dry season and the rise is often delayed. When abstraction is intensive, groundwater levels may fall towards a permanent new equilibrium state. However, seasonal water table fluctuation is noticed where groundwater irrigation is extensive, and this fluctuation is low with low abstraction of water. Use of deep groundwater is not potential for irrigation because of recharge constraint.

Table 6-28: Status of Exploratory Drilling and Installation of Monitoring Wells

Sl No.	Well ID	District	Upazila	Monitoring well Installation Depth (m)
1	HGBB5	Habiganj	Bahubal	50
2	HGBC7	Habiganj	Baniachong	88
3	HGCG3	Habiganj	Chunarughat	70
4	HGHG4	Habiganj	Habiganj Sadar	43
5	HGLH1	Habiganj	Lakhai	85
6	HGMP2	Habiganj	Madhabpur	117
7	HGNG6	Habiganj	Nabiganj	79
8	KGBJ7	Kishoreganj	Bajitpur	105
9	KGHP5	Kishoreganj	Hossainpur	101
10	KGKC3	Kishoreganj	Kuliar Char	90
11	KGKM1	Kishoreganj	Karimganj	79
12	KGKT2	Kishoreganj	Katiadi	46
13	KGPD6	Kishoreganj	Pakundia	128
14	KGTR4	Kishoreganj	Tarail	82
15	MBKG4	Maulvibazar	Kamalganj	82
16	MBKU3	Maulvibazar	Kulaura	116
17	MBMB2	Maulvibazar	Maulvibazar	73
18	MBRN5	Maulvibazar	Rajnagar	95
19	MBSM1	Maulvibazar	Sreemangal	64
20	NTAP6	Netrokona	Atpara	61
21	NTBH4	Netrokona	Barhata	98
22	NTDP1	Netrokona	Durgapur	110
23	NTKN7	Netrokona	Kendua	63
24	NTMD6	Netrokona	Madan	52

Sl No.	Well ID	District	Upazila	Monitoring well Installation Depth (m)
25	NTNT3	Netrokona	Netrokona	204
26	NTPD2	Netrokona	Purbadhala	79
27	SGBP4	Sunamganj	Bishwambarpur	64
28	SGCT3	Sunamganj	Chhatak	72
29	SGDB1	Sunamganj	Dowarabazar	70
30	SGDP8	Sunamganj	Dharampasha	67
31	SGDR6	Sunamganj	Derai	84
32	SGJG7	Sunamganj	Jamalganj	79
33	SGJP5	Sunamganj	Jagannathpur	76
34	SGSG2	Sunamganj	Sunamganj	113
35	SYBB1	Sylhet	Beanibazar	43
36	SYBG2	Sylhet	Balaganj	117
37	SYDS3	Sylhet	Dakhin Surma	125
38	SYGG4	Sylhet	Golapganj	128
39	SYJP5	Sylhet	Jaintiapur	21
40	SYKG6	Sylhet	Kanaighat	113

During the peak irrigation season in March and April, the hydrograph is fairly smooth since years and steepest rise in the hydrograph is observed immediately after the irrigation pumps are switched off (April to May). During monsoon, the hydrographs rise steadily until the levels are within about 1-2 m of the surface. Withdrawal by shallow irrigation wells may also influence the huge fluctuations in water levels in the main aquifer. These levels in the deeper part recover rapidly when seasonal pumping stops. This rapid recovery, parallel to water levels in shallow aquifer, reveals that shallow and main aquifers are hydraulically connected. However, with intensive abstraction, water levels may fall towards a new equilibrium state. Generally, groundwater withdrawal from the shallow aquifer for domestic and irrigation purposes during dry periods is balanced with the vertical percolation of rainwater and inflow from surrounding aquifers during monsoon when pumping is ceased. No permanent declining of water table is observed, except few areas.

6.2.1 Trend of Groundwater Table under Kishoreganj District

Depth to groundwater level/table below ground surface for the project installed observation wells of investigated upazilas under Kishoreganj district reveals that the minimum depth of water level is observed during August and maximum during March or April as shown in Figure 6-26. The minimum and maximum depths to water table ranges from 1.5 to 5.0 m and 4.5 to 11.0 m respectively. The fluctuation of water table ranges between 2.5 and 7.0 m. Groundwater level starts to decline in September and reaches to the maximum depth in March-April and then moves upward again in monsoon to regain the static water level in July-August. However, from both the long duration hydrographs and hydrographs from the project installed wells permanent declination of water level/table by few centimeters is noticed which might be due to increasing abstraction mainly for irrigation use.

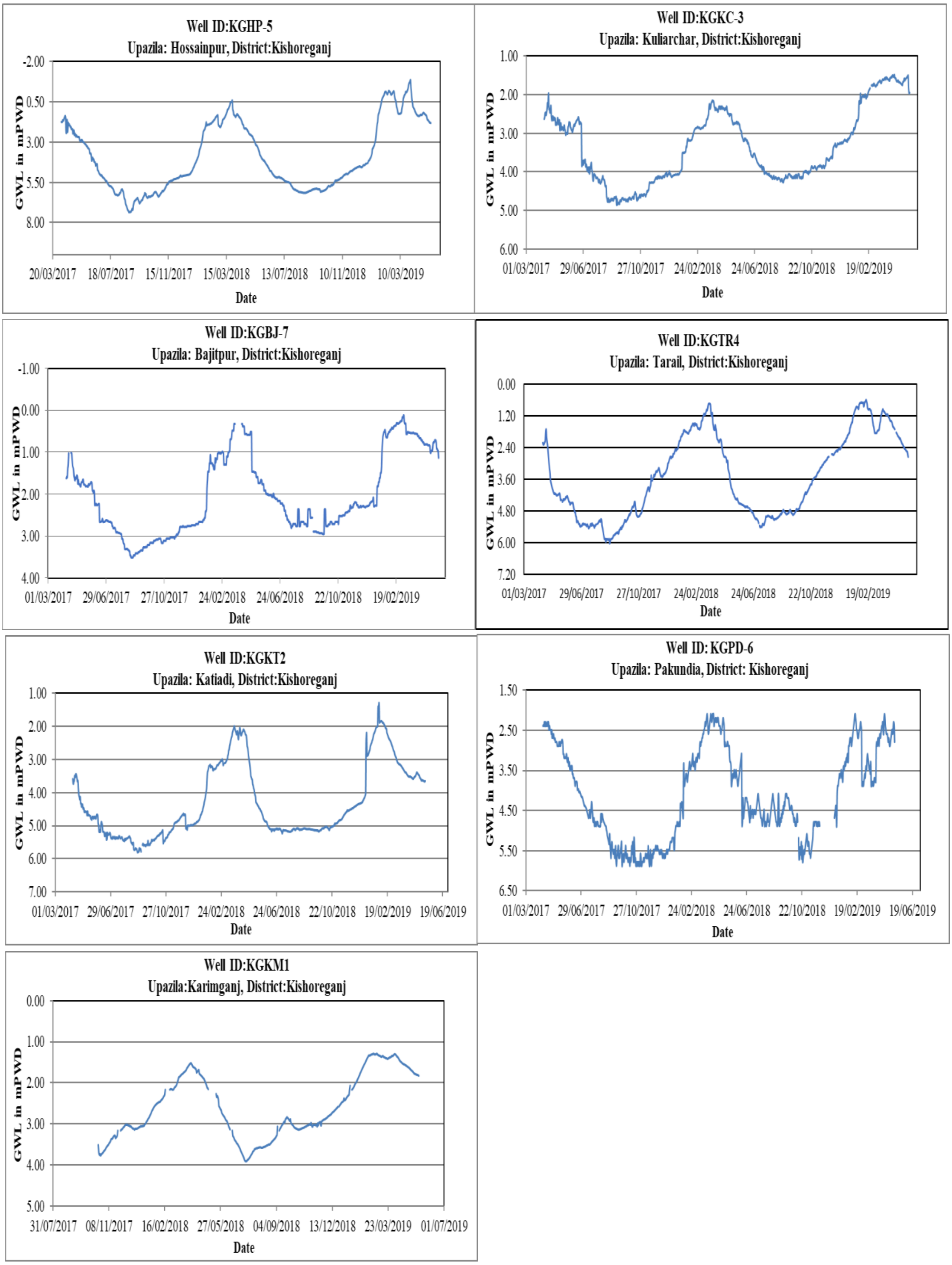


Figure 6-26: Groundwater Table Hydrographs of Different Upazilas under Kishoreganj District

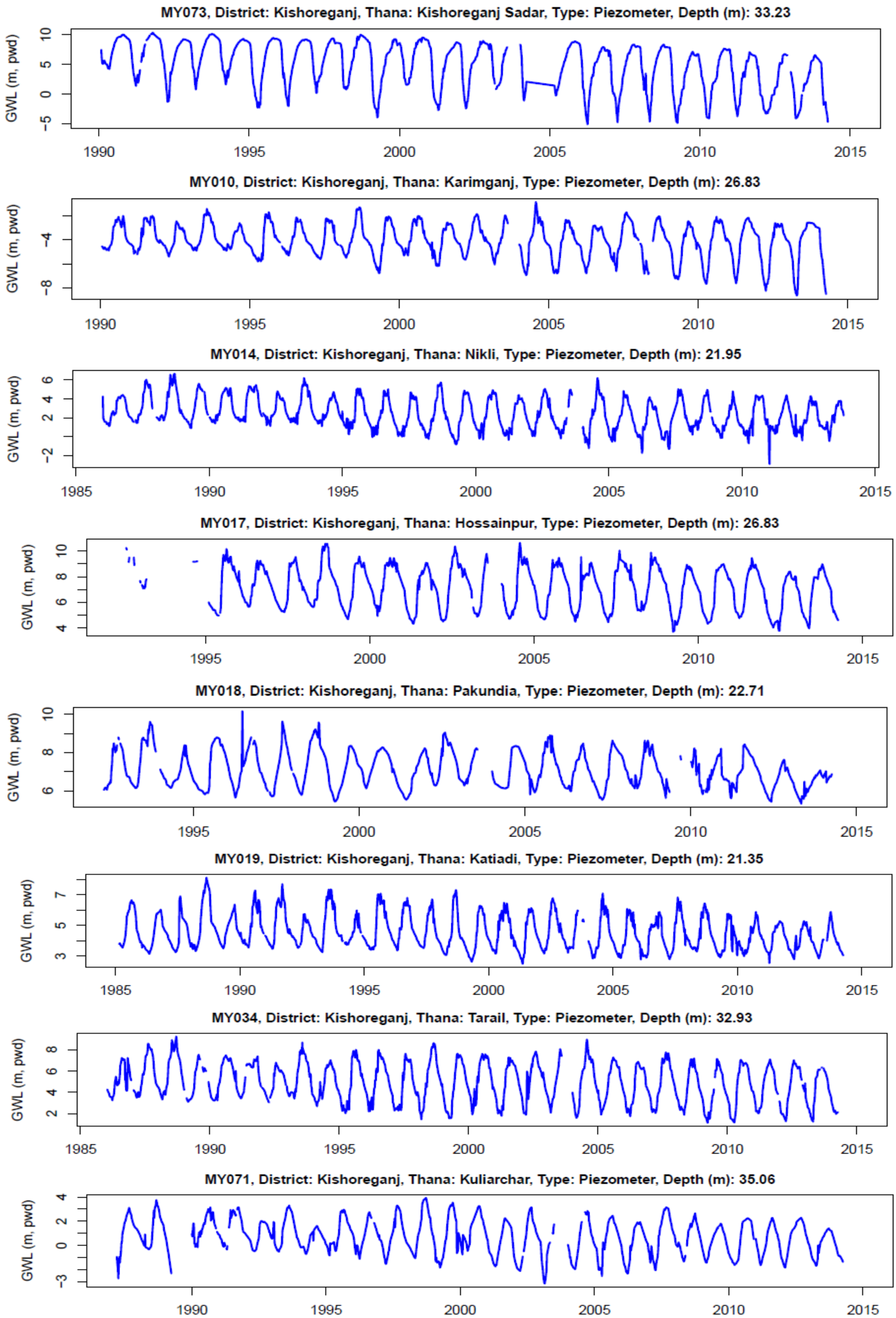


Figure 6-27: Long Duration Hydrographs of Groundwater Level of Different Upazilas under Kishoreganj District

6.2.2 Trend of Groundwater Table under Netrokona District

Depth to groundwater level/table below ground surface for the project installed observation wells of investigated upazilas under Netrokona district reveals that the minimum depth of water level is observed during August and maximum during March or April as shown in Figure 6-28. The minimum and maximum depths to water table ranges from 1.5 to 4.5 m and 4.5 to 11.0 m respectively, with an exceptional in Netrokona Sadar and Atpara where maximum depth is 16 and 24 m respectively which might be due to urban and irrigation abstraction. The fluctuation of water table ranges between 4.0 and 19.0 m. Groundwater level starts to decline in September and reaches to the maximum depth in March-April and then moves upward again in monsoon to regain the static water level in July-August. However, from both the long duration hydrographs and hydrographs from the project installed wells permanent declination of water level/table by few centimeters is noticed which might be due to increasing abstraction mainly for irrigation use.

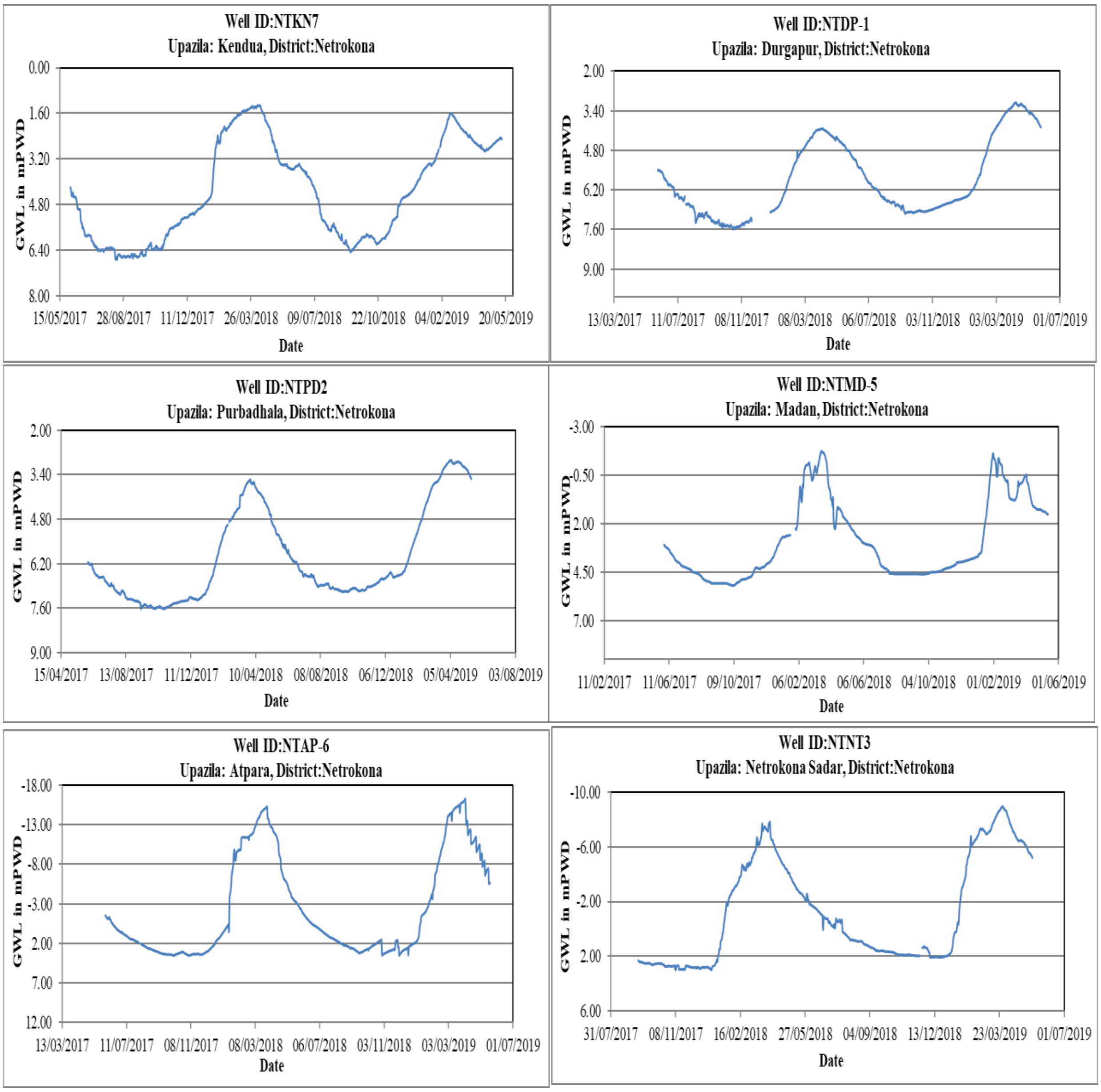


Figure 6-28: Groundwater Table Hydrographs of Different Upazilas under Netrokona District

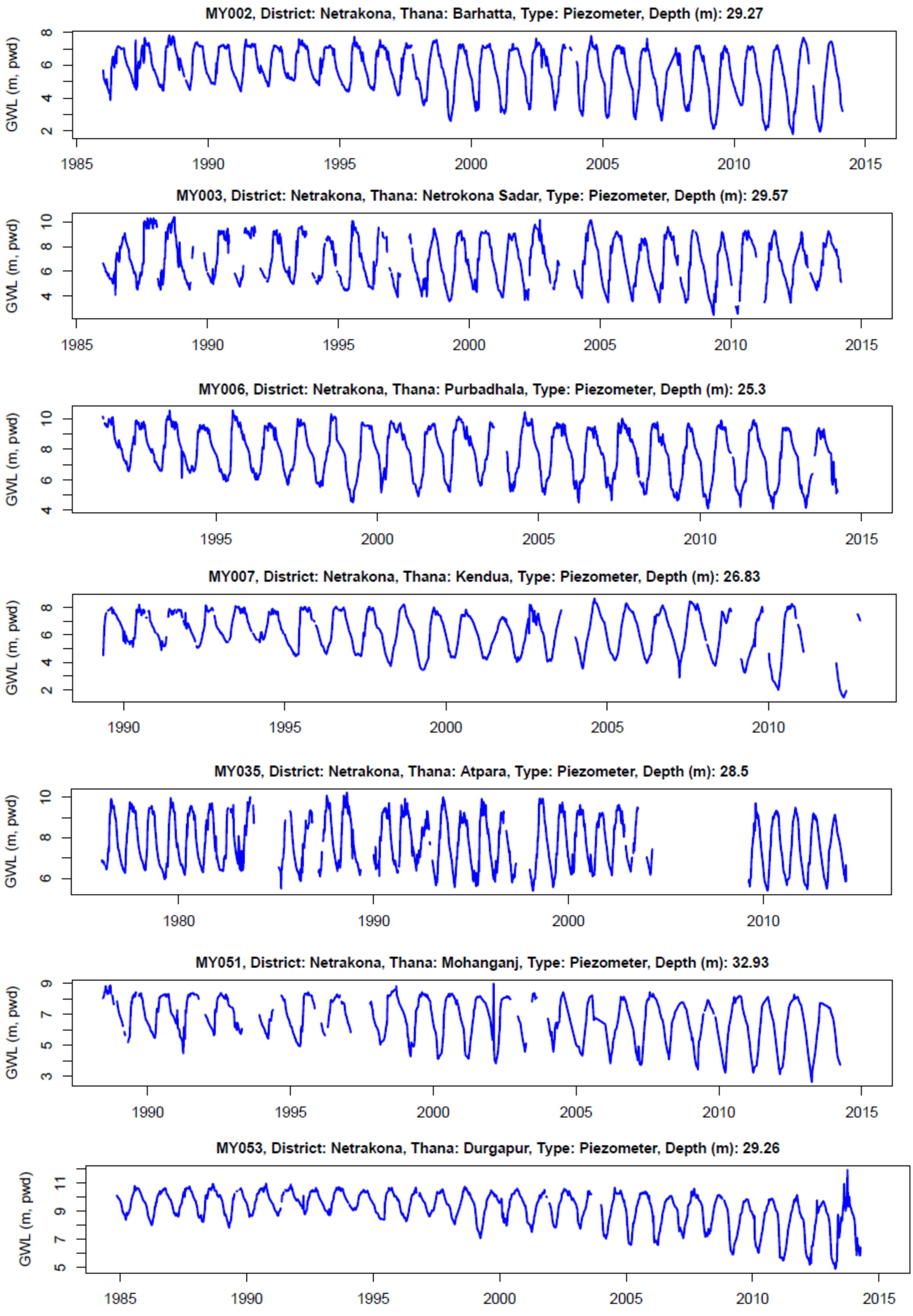


Figure 6-29: Long Duration Hydrographs of Groundwater Level of Different Upazilas under Netrokona District

6.2.3 Trend of Groundwater Table under Sylhet District

Depth to groundwater level/table below ground surface for the project installed observation wells of investigated upazila under Sylhet district reveals that the minimum depth of water level is observed during August and maximum during March or April as shown in Figure 6-30. The minimum and maximum depths to water table is observed as 3.5 m and 5.5 m respectively. The fluctuation of water table is 2.0 m. Groundwater level starts to decline in September and reaches to the maximum depth in March-April and then moves upward again in monsoon to regain the static water level in July-August. However, from both the long duration hydrographs and hydrographs from the project installed wells permanent declination of water level/table by few centimeters is noticed which might be due to increasing abstraction mainly for irrigation use.

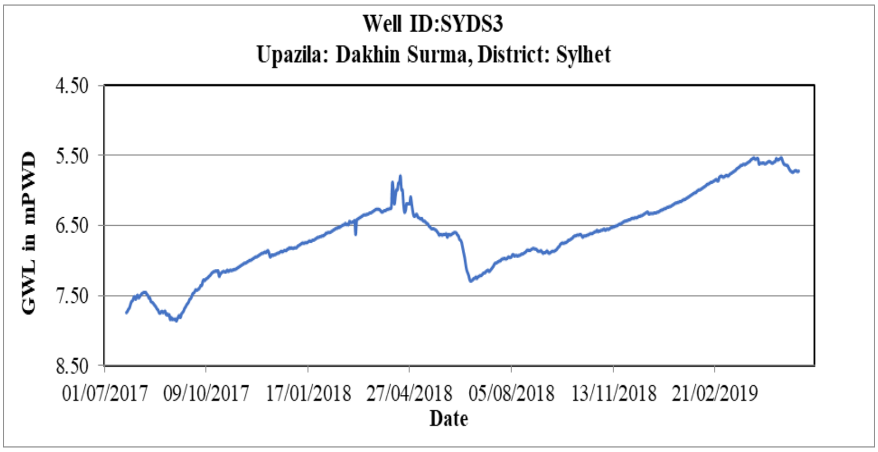


Figure 6-30: Groundwater Table Hydrographs of Different Upazilas under Sylhet District

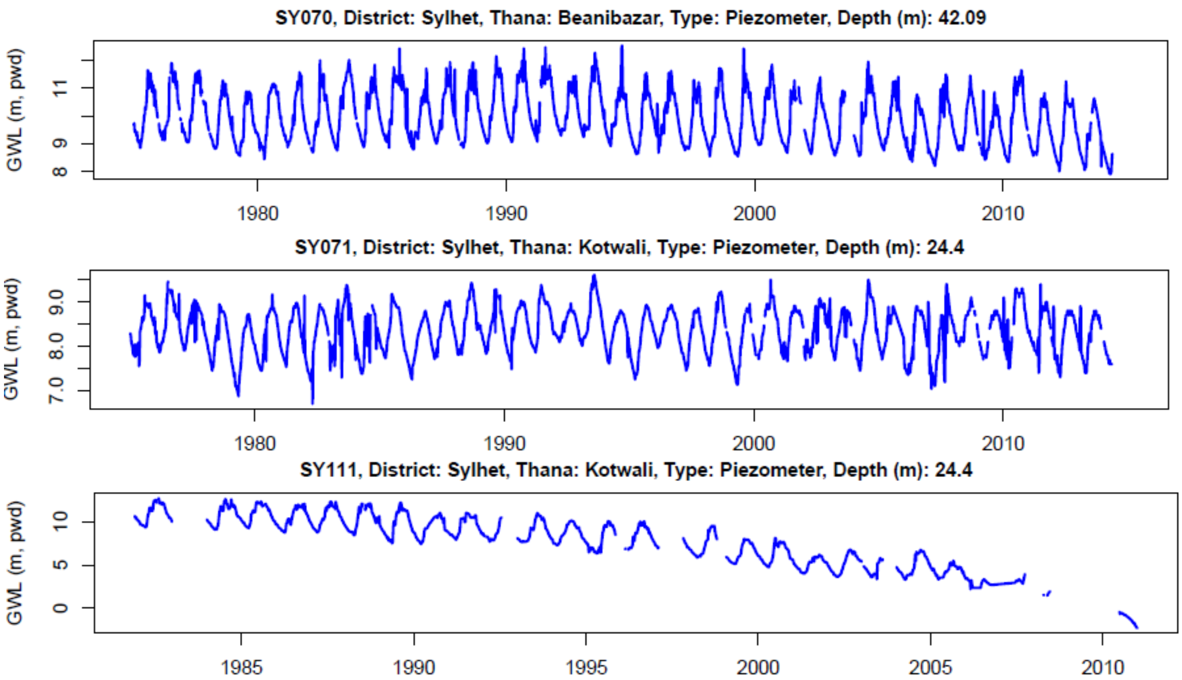


Figure 6-31: Long Duration Hydrographs of Groundwater Level of Different Upazilas under Sylhet District

6.2.4 Trend of Groundwater Table under Maulavibazar District

Depth to groundwater level/table below ground surface for the project installed observation wells of investigated upazilas under Maulavibazar district reveals that the minimum depth of water level is observed during August and maximum during March or April as shown in Figure 6-32. The minimum and maximum depths to water table ranges from 1. to 1.5 m and 2.5 to 3.5 m respectively. The fluctuation of water table ranges between 1.0 and 1.5 m. Groundwater level starts to decline in September and reaches to the maximum depth in March-April and then moves upward again in monsoon to regain the static water level in July-August. However, from both the long duration hydrographs and hydrographs from the project installed wells permanent declination of water level/table by few centimeters is noticed which might be due to increasing abstraction mainly for irrigation use. In Maulavibazar town, the minimum and maximum depths to water table is observed as 7.5 and 8.5 m respectively.

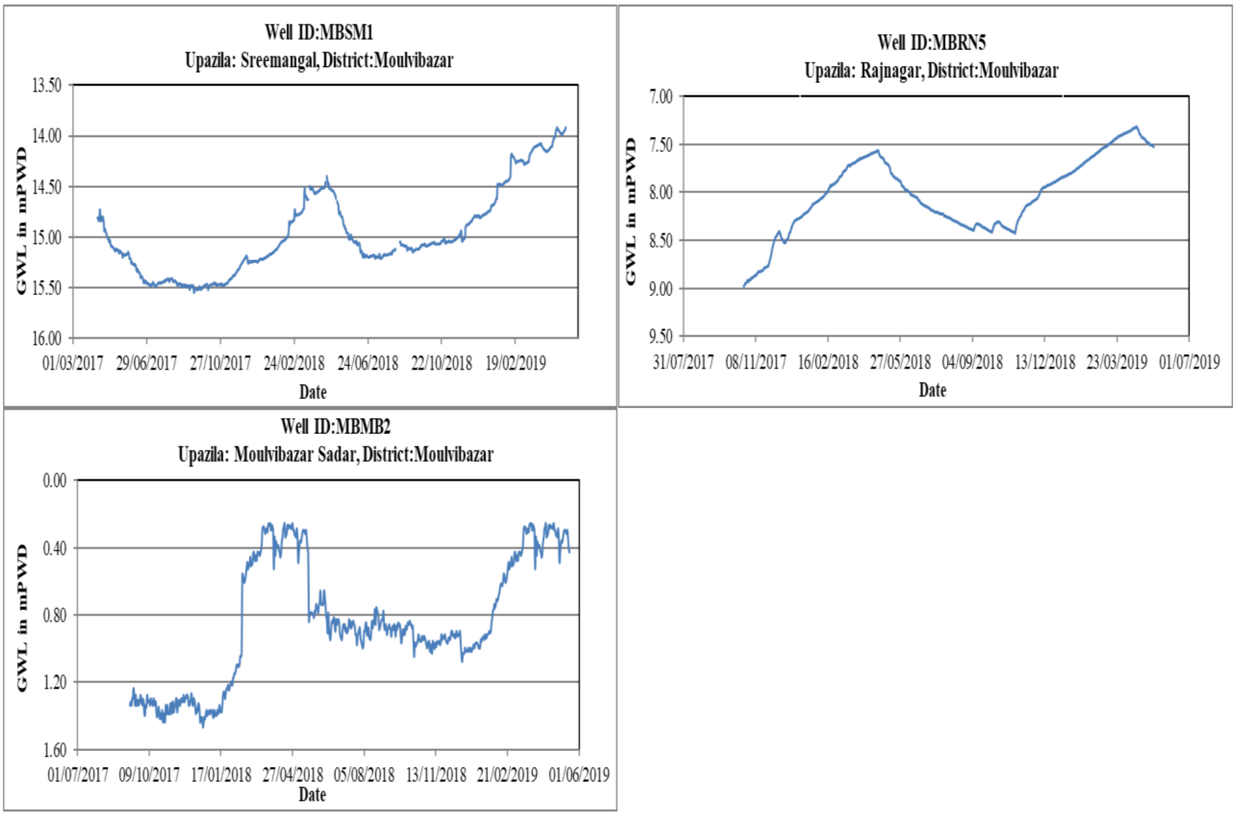


Figure 6-32: Groundwater Table Hydrographs of Different Upazilas under Maulavibazar District

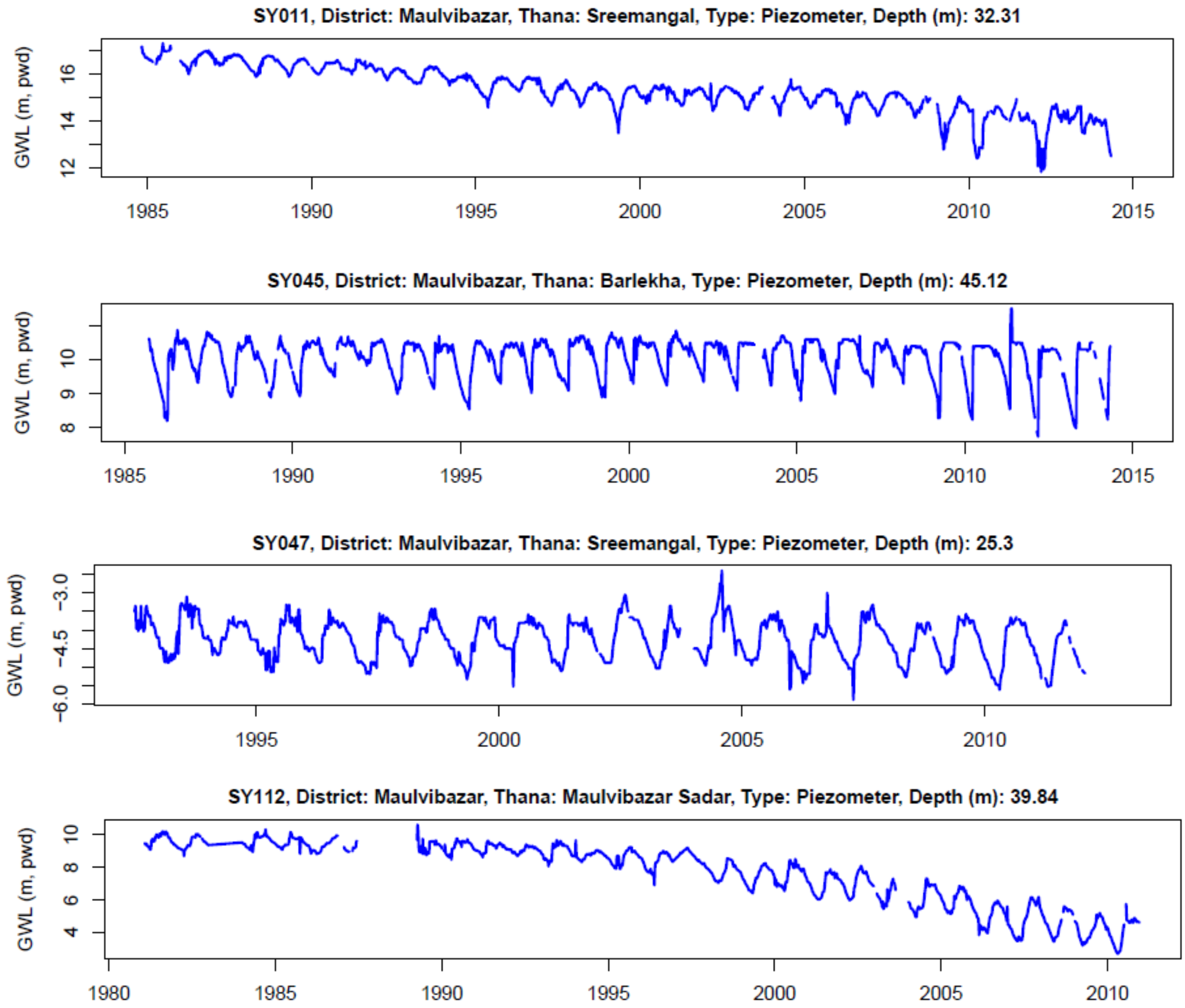


Figure 6-33: Long Duration Hydrographs of Groundwater Level of Different Upazilas under Maulavibazar District

6.2.5 Trend of Groundwater Table under Habiganj District

Depth to groundwater level/table below ground surface for the project installed observation wells of investigated upazilas under Habiganj district reveals that the minimum depth of water level is observed during August and maximum during March or April as shown in Figure 6-34. The minimum and maximum depths to water table ranges from 1.5 to 5.0 m and 6.0 to 10.5 m respectively. The fluctuation of water table ranges between 4.5 and 5.5 m. Groundwater level starts to decline in September and reaches to the maximum depth in March-April and then moves upward again in monsoon to regain the static water level in July-August. However, from both the long duration hydrographs and hydrographs from the project installed wells permanent declination of water level/table by few centimeters is noticed which might be due to increasing abstraction mainly for irrigation use.

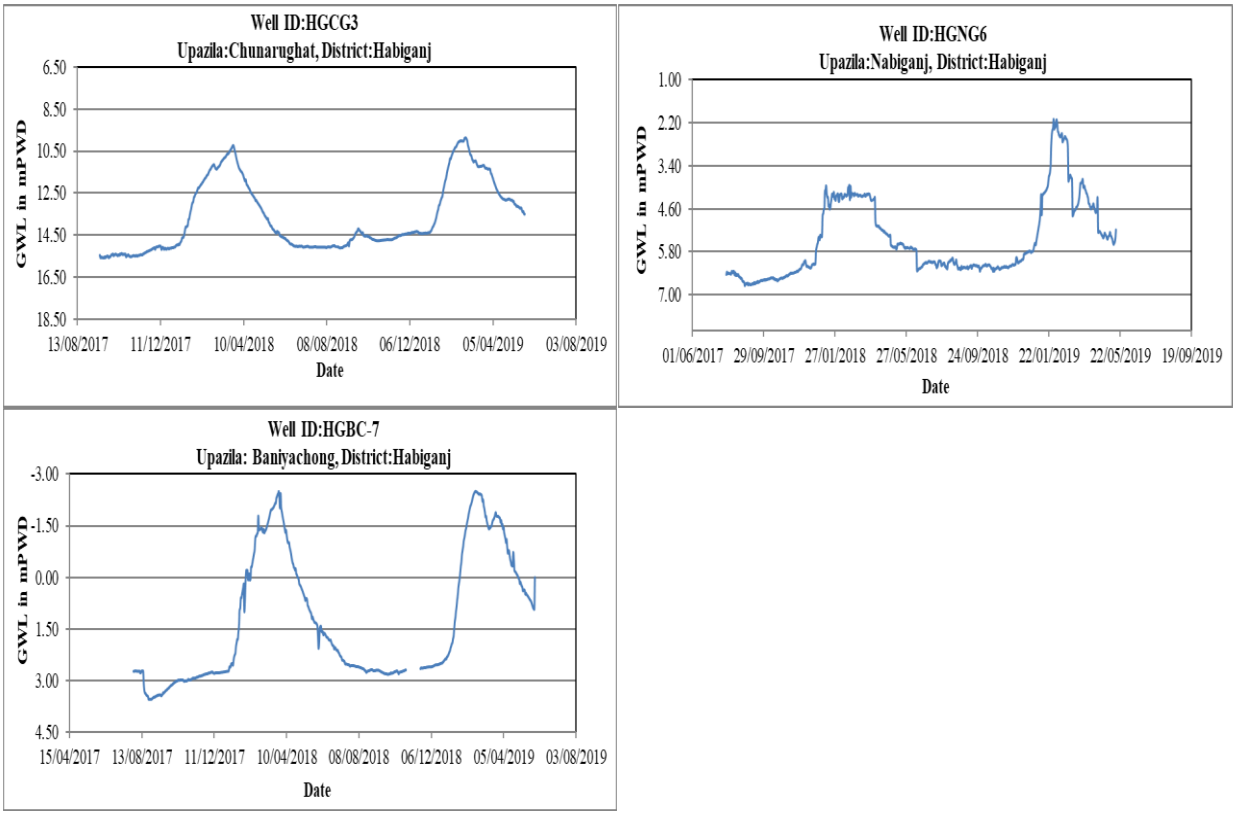


Figure 6-34: Groundwater Table Hydrographs of Different Upazilas under Habiganj District

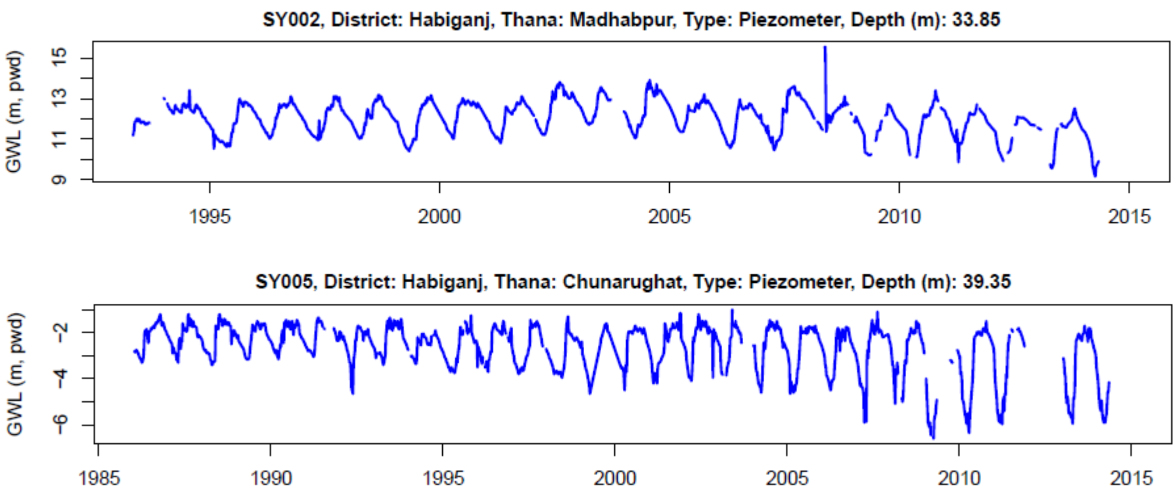


Figure 6-35: Long Duration Hydrographs of Groundwater Level of Different Upazilas under Habiganj District

6.2.6 Trend of Groundwater Table under Sunamganj District

Depth to groundwater level/table below ground surface for the project installed observation wells of investigated upazilas under Sunamganj district reveals that the minimum depth of water level is observed during August and maximum during March or April as shown in Figure 6-36. The minimum and maximum depths to water table ranges from 2.0 to 8.0 m and 6.5 to 9.0 m respectively. The fluctuation of water table ranges between 1.0 and 8.0 m. Groundwater level starts to decline in September and reaches to the maximum depth in March-April and then moves upward again in monsoon to regain the static water level in July-August. However, from both the long duration hydrographs and hydrographs from the project installed wells permanent declination of water level/table by few centimeters is noticed which might be due to increasing abstraction mainly for irrigation use.

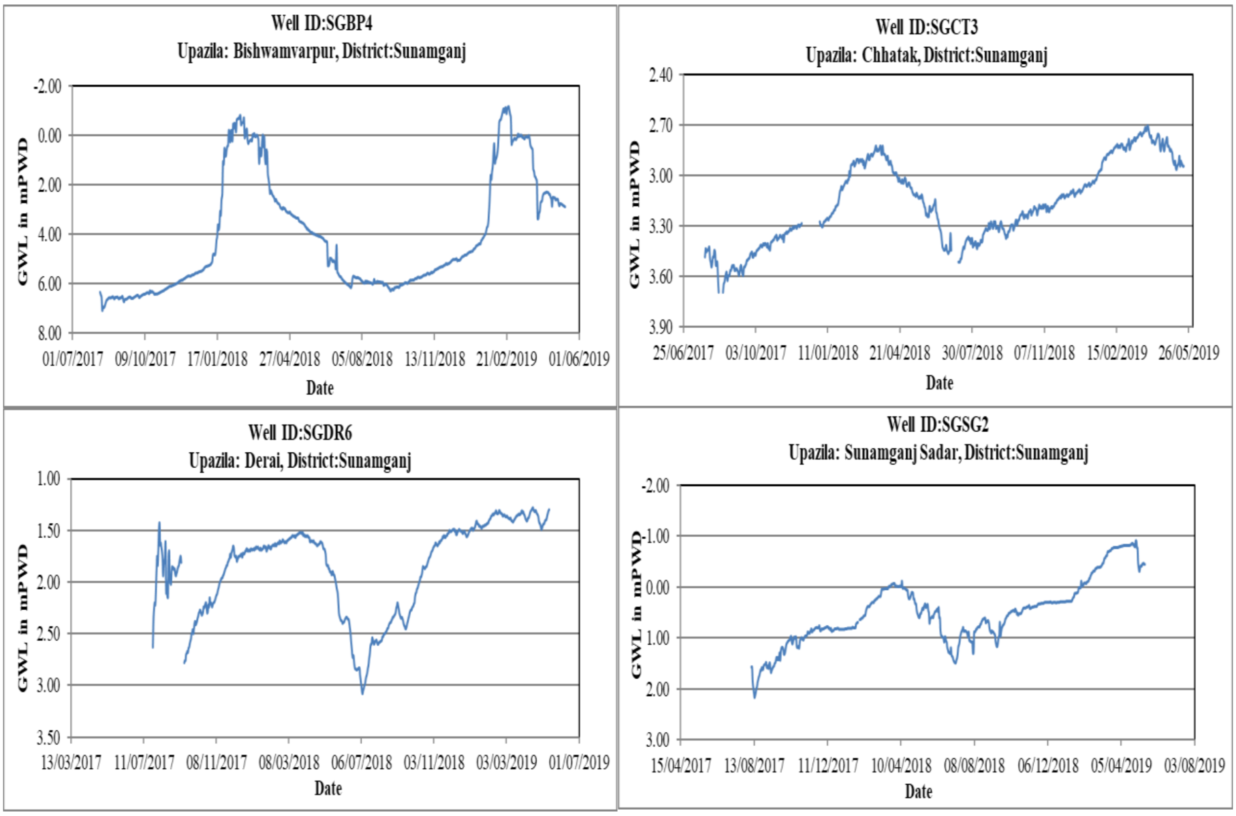


Figure 6-36: Groundwater Table Hydrographs of Different Upazilas under Sunamganj District

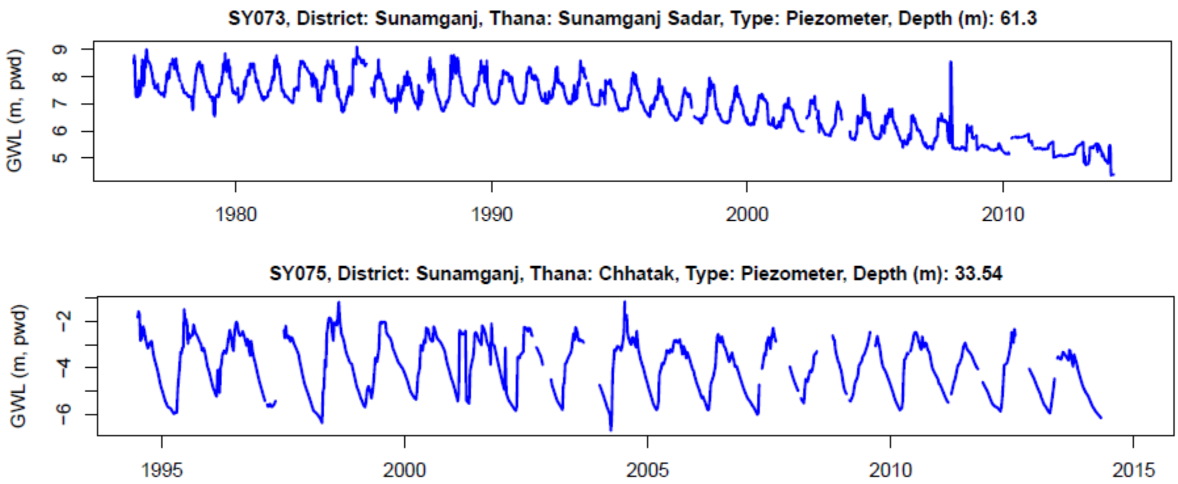


Figure 6-37: Long Duration Hydrographs of Groundwater Level of Different Upazilas under Sunamganj District

7 COMPUTATION OF WATER REQUIREMENT

It is very essential to know the sector wise water requirements for the present and future conditions, and safe available water resources at the planning stage of water development project to establish sector wise future scope for expansion. Water demand of irrigation, domestic and industrial sectors is to be computed for assessing total water requirements in the study area.

7.1 Irrigation Water Requirement

Computation of Irrigation Water Requirement (IWR) is necessary to assess the amount of water that is being presently used for irrigation as well as to measure the future water requirement for agricultural development under different options. Irrigation water requirement mainly depends on crop water requirement, percolation rate, effective rainfall and efficiency of irrigation water distribution system. Other factors associated with irrigation water are land use, cropping pattern, growth stages of crop, soil type and salinity of irrigation water. To calculate crop water requirement for different crops for assessing irrigation water requirement CROPWAT version 5.7 has been used.

Factors Affecting Irrigation Water Requirement

Irrigation water requirement depends on several key factors namely, type of the crop, cropping pattern, reference crop evapotranspiration, rainfall and percolation rate of the soil. Furthermore, water conveyance efficiency also affects the irrigation water requirement of an irrigation scheme.

Selection of Crops

Haor area goes under flooding from late May to October. Almost 80% of this area is covered by Boro rice, while only about 10% area is covered by T. Aman and a little extent is covered by Aus. Basically, rice based agriculture is dominant in Haor basin and other crops like potato, groundnut, sweet potato, mustard and pulses are grown in Rabi season to a small extent. In the study area major irrigation is applied to Boro rice crop.

Reference Crop Evapotranspiration (ETo)

Reference Crop Evapotranspiration of the project area has been calculated using FAO Penman-Montieth method. ETo of an area depends on climatic factors and location of the area. The required climatic factors are mean monthly temperature, relative humidity, wind speed at 2m height and daily sunshine hours.

Crop Co-efficient (Kc)

Crop co-efficient Kc depends on the type of crops, its growing season and development stages. Example of Kc value for Boro Rice crop for different growth stages and growth period are given in Table 7-1.

Table 7-1: Crop Co-efficient of HYV Boro Rice

Growth Stage	Crop Co-efficient	Growth Period (days)
a) Land Preparation	…….	20
b) Nursery	1.20	30
c) Initial Stage (A)	1.10	20
d) Development Stage (B)	1.10	30
e) Mid-Season (C)	1.25	40
f) Late Season (D)	1.00	30

Effective Rainfall

There are several methods of calculating effective monthly rainfall. One of that methods is the fixed percentage of mean monthly areal rainfall (FAO, 1992). Effective monthly rainfall of the study area has been calculated as 80% of mean monthly areal rainfall. Mean monthly aerial rainfall has been determined by Thiessen polygon method using historical rainfall data of available stations located in and around the study area.

Percolation Rate

For determination of Seepage and Percolation (S&P) rate of soil in the study area, daily water losses from irrigated field and the amount of daily irrigation have been collected through field measurement from different locations in the project area. Using the water loss, irrigation, rainfall and ETo data, Seepage and Percolation rate of the soils for the test locations have been estimated.

Field and Scheme Water Requirement

Irrigation water requirement is the most important factor for calculating total amount of water to be abstracted for irrigation. If required quantity of water is supplied to the crop at the right time corresponding to the stages of crop growth, maximum crop production can be achieved. Irrigation Water Requirement (IWR) of a given crop is calculated by subtracting effective rainfall (Reff) from the sum of Potential evapotranspiration (ETo) and percolation rate (P) as shown below:

$$IWR_i = \sum_{t=0}^{T} \left(Kc_i \cdot ET_{0_i} + P - R_{eff} \right)$$

Where, Kc - Crop co-efficient; ET_o - Potential evapotranspiration (mm/day);

P – Percolation (mm/day); R_{eff} – effective rainfall (mm/day).

Scheme Water Requirement (SWR) is the gross irrigation requirement as volume or flow rate (l/s) at source of supply. SWR is calculated from IWR by dividing with the overall irrigation efficiency. For the study area, SWR has been computed considering overall loss of 50%.

Field Water Requirement (FWR) and unit Scheme Water Requirement (SWR) have been computed using CROPWAT, (FAO, 1992) version 5.7 considering following assumptions:

- Rice is cultivated in part of the cultivable land and nursery is done on 5% of the land
- Water requirement for land preparation for rice during dry period is 150 mm for a period of 20 days
- Time staggered plantation of crops has been considered
- Reference Crop Evapotranspiration (ETo) is computed using FAO Penman-Montieth method
- Effective rainfall is taken as the 80% of mean monthly rainfall.

Based on the information, factors and criteria discussed above Field Irrigation Water Requirement (FIWR) and Scheme Irrigation Water Requirement (SIWR) of the major crops that requires appreciable irrigation have been computed. Crop has different planting and harvesting pattern, so is the water requirements. Crop-wise staggering is discussed in the following section.

HYV Boro: Staggered plantation with 15% in 2nd decade of December, 15% in 3rd decade of December, 20% in 1st decade of January and 50% in 2nd decade of January has been considered.

HYV Aus: Staggered plantation with 25% in 3rd decade of March, 40% in 1st decade of April, 25% in 2nd decade of April and 10% in 3rd decade of April has been considered.

Upzila-wise FIWR and SIWR for Boro rice is given in Table 7-2 and for Aus is given in Table-1 of Volume-II, Appendix H.

Table 7-2: FIWR and SIWR for HYV Boro

Sl No	Upazila	Unit	FIWR						SIWR					
			Nov	Dec	Jan	Feb	Mar	Apr	Nov	Dec	Jan	Feb	Mar	Apr
1	Ajmiriganj	mm/d	0.3	2.8	6.3	4	2.4	0	0.6	5.6	12.6	8	4.8	0
		mm/m	8	84	188	120	72	0	16	168	376	240	144	0
		L-s/ha	0.03	0.32	0.73	0.46	0.28	0	0.06	0.64	1.46	0.92	0.56	0
2	Atpara	mm/d	0.3	2.7	6	4.6	4.5	1.4	0.6	5.4	12	9.2	9	2.8
		mm/m	8	81	181	137	134	43	16	162	362	274	268	86
		L-s/ha	0.03	0.31	0.7	0.53	0.52	0.16	0.06	0.62	1.4	1.06	1.04	0.32
3	Austagram	mm/d	0.3	2.8	6.2	5	5.2	2.7	0.6	5.6	12.4	10	10.4	5.4
		mm/m	8	83	187	150	156	81	16	166	374	300	312	162
		L-s/ha	0.03	0.32	0.72	0.58	0.6	0.31	0.06	0.64	1.44	1.16	1.2	0.62
4	Bahubal	mm/d	0.3	2.7	6.3	4.8	5	2	0.6	5.4	12.6	9.6	10	4
		mm/m	8	81	188	145	150	59	16	162	376	290	300	118
		L-s/ha	0.03	0.31	0.73	0.56	0.58	0.23	0.06	0.62	1.46	1.12	1.16	0.46
5	Bhairab	mm/d	0.3	3.4	8.1	6.4	6.8	4	0.6	6.8	16.2	12.8	13.6	8
		mm/m	9	103	243	192	205	119	18	206	486	384	410	238
		L-s/ha	0.04	0.4	0.94	0.74	0.79	0.46	0.08	0.8	1.88	1.48	1.58	0.92

Sl No	Upazila	Unit	FIWR						SIWR					
			Nov	Dec	Jan	Feb	Mar	Apr	Nov	Dec	Jan	Feb	Mar	Apr
6	Bajitpur	mm/d	0.3	3.4	8	6.5	6.7	3.8	0.6	6.8	16	13	13.4	7.6
		mm/m	9	103	241	195	200	114	18	206	482	390	400	228
		L-s/ha	0.04	0.4	0.93	0.75	0.77	0.44	0.08	0.8	1.86	1.5	1.54	0.88
7	Balaganj	mm/d	0.3	2.8	6.2	4.6	4.2	0.4	0.6	5.6	12.4	9.2	8.4	0.8
		mm/m	8	83	186	137	126	11	16	166	372	274	252	22
		L-s/ha	0.03	0.32	0.72	0.53	0.49	0.04	0.06	0.64	1.44	1.06	0.98	0.08
8	Baniachong	mm/d	0.3	2.7	6.3	4.8	5	2	0.6	5.4	12.6	9.6	10	4
		mm/m	8	81	188	145	150	59	16	162	376	290	300	118
		L-s/ha	0.03	0.31	0.73	0.56	0.58	0.23	0.06	0.62	1.46	1.12	1.16	0.46
9	Barhatta	mm/d	0.3	2.8	6.3	4.9	5.4	1.5	0.6	5.6	12.6	9.8	10.8	3
		mm/m	8	84	188	147	162	45	16	168	376	294	324	90
		L-s/ha	0.03	0.32	0.72	0.57	0.63	0.17	0.06	0.64	1.44	1.14	1.26	0.34
10	Barlekha	mm/d	0.3	2.8	6.6	5	3.9	0.3	0.6	5.6	13.2	10	7.8	0.6
		mm/m	8	85	199	150	116	9	16	170	398	300	232	18
		L-s/ha	0.03	0.33	0.77	0.58	0.45	0.04	0.06	0.66	1.54	1.16	0.9	0.08
11	Beanibazar	mm/d	0.3	2.8	6.2	4.4	1.9	0	0.6	5.6	12.4	8.8	3.8	0
		mm/m	8	83	186	131	56	0	16	166	372	262	112	0
		L-s/ha	0.03	0.32	0.72	0.5	0.22	0	0.06	0.64	1.44	1	0.44	0
12	Bishwamvarpur	mm/d	0.3	2.8	6.3	4.8	4.9	2.4	0.6	5.6	12.6	9.6	9.8	4.8
		mm/m	8	84	188	143	148	71	16	168	376	286	296	142
		L-s/ha	0.03	0.32	0.73	0.55	0.57	0.27	0.06	0.64	1.46	1.1	1.14	0.54
13	Bishwanath	mm/d	0.3	2.8	6.2	4.6	4.2	0.4	0.6	5.6	12.4	9.2	8.4	0.8
		mm/m	8	83	186	137	126	11	16	166	372	274	252	22
		L-s/ha	0.03	0.32	0.72	0.53	0.49	0.04	0.06	0.64	1.44	1.06	0.98	0.08
14	Chatak	mm/d	0.3	2.8	6.2	4.7	3.6	0	0.6	5.6	12.4	9.4	7.2	0
		mm/m	8	83	187	142	107	0	16	166	374	284	214	0
		L-s/ha	0.03	0.32	0.72	0.55	0.41	0	0.06	0.64	1.44	1.1	0.82	0
15	Chunarughat	mm/d	0.3	2.7	6.2	4.9	4.9	1.9	0.6	5.4	12.4	9.8	9.8	3.8
		mm/m	8	82	187	147	148	57	16	164	374	294	296	114
		L-s/ha	0.03	0.32	0.72	0.57	0.57	0.22	0.06	0.64	1.44	1.14	1.14	0.44
16	Companiganj	mm/d	0.3	3.9	5.7	4.3	3.6	1.4	0.6	7.8	11.4	8.6	7.2	2.8
		mm/m	10	116	171	130	107	41	20	232	342	260	214	82
		L-s/ha	0.04	0.45	0.66	0.5	0.41	0.16	0.08	0.9	1.32	1	0.82	0.32
17	Dakshin Sunamganj	mm/d	0.2	2.8	6.2	4.7	4.5	0.2	0.4	5.6	12.4	9.4	9	0.4
		mm/m	7	83	187	140	134	5	14	166	374	280	268	10
		L-s/ha	0.03	0.32	0.72	0.54	0.52	0.02	0.06	0.64	1.44	1.08	1.04	0.04
18	Dawarabazar	mm/d	0.3	2.8	6.2	4.5	3.2	0	0.6	5.6	12.4	9	6.4	0
		mm/m	8	84	187	135	95	0	16	168	374	270	190	0
		L-s/ha	0.03	0.32	0.72	0.52	0.37	0	0.06	0.64	1.44	1.04	0.74	0
19	Derai	mm/d	0.3	2.8	6.3	4	2.4	0	0.6	5.6	12.6	8	4.8	0
		mm/m	8	84	188	120	72	0	16	168	376	240	144	0
		L-s/ha	0.03	0.32	0.73	0.46	0.28	0	0.06	0.64	1.46	0.92	0.56	0
20	Dharmopasha	mm/d	0.3	2.8	6.3	4.9	5.4	1.5	0.6	5.6	12.6	9.8	10.8	3
		mm/m	8	84	188	147	162	45	16	168	376	294	324	90

Sl No	Upazila	Unit	FIWR						SIWR					
			Nov	Dec	Jan	Feb	Mar	Apr	Nov	Dec	Jan	Feb	Mar	Apr
		L-s/ha	0.03	0.32	0.72	0.57	0.63	0.17	0.06	0.64	1.44	1.14	1.26	0.34
21	Durgapur	mm/d	0.3	2.8	6.3	5	5.3	1.3	0.6	5.6	12.6	10	10.6	2.6
		mm/m	8	84	188	149	159	39	16	168	376	298	318	78
		L-s/ha	0.03	0.32	0.73	0.57	0.61	0.15	0.06	0.64	1.46	1.14	1.22	0.3
22	Fenchuganj	mm/d	0.3	2.8	6.6	4.9	3.6	0.1	0.6	5.6	13.2	9.8	7.2	0.2
		mm/m	8	85	199	146	107	4	16	170	398	292	214	8
		L-s/ha	0.03	0.33	0.77	0.56	0.41	0.02	0.06	0.66	1.54	1.12	0.82	0.04
23	Golapganj	mm/d	0.3	2.8	6.3	4.3	2.6	0	0.6	5.6	12.6	8.6	5.2	0
		mm/m	8	83	188	130	78	0	16	166	376	260	156	0
		L-s/ha	0.03	0.32	0.72	0.5	0.3	0	0.06	0.64	1.44	1	0.6	0
24	Gowainghat	mm/d	0.3	2.8	6	4.1	1.9	0	0.6	5.6	12	8.2	3.8	0
		mm/m	8	83	180	122	58	0	16	166	360	244	116	0
		L-s/ha	0.03	0.32	0.7	0.47	0.23	0	0.06	0.64	1.4	0.94	0.46	0
25	Habiganj Sadar	mm/d	0.3	2.7	6.3	4.8	5	2	0.6	5.4	12.6	9.6	10	4
		mm/m	8	81	188	145	150	59	16	162	376	290	300	118
		L-s/ha	0.03	0.31	0.73	0.56	0.58	0.23	0.06	0.62	1.46	1.12	1.16	0.46
26	Hossainpur	mm/d	0.3	2.6	5	3.9	4.8	2.9	0.6	5.2	10	7.8	9.6	5.8
		mm/m	8	79	151	116	145	86	16	158	302	232	290	172
		L-s/ha	0.03	0.3	0.58	0.45	0.56	0.33	0.06	0.6	1.16	0.9	1.12	0.66
27	Itna	mm/d	0.3	2.8	6.2	4.9	5.2	2.6	0.6	5.6	12.4	9.8	10.4	5.2
		mm/m	8	83	187	146	155	79	16	166	374	292	310	158
		L-s/ha	0.03	0.32	0.72	0.56	0.6	0.3	0.06	0.64	1.44	1.12	1.2	0.6
28	Jagonnathpur	mm/d	0.3	2.8	6.2	4.6	4.2	0.4	0.6	5.6	12.4	9.2	8.4	0.8
		mm/m	8	83	186	137	126	11	16	166	372	274	252	22
		L-s/ha	0.03	0.32	0.72	0.53	0.49	0.04	0.06	0.64	1.44	1.06	0.98	0.08
29	Jaintapur	mm/d	0.3	2.8	6.1	3.9	0.4	0	0.6	5.6	12.2	7.8	0.8	0
		mm/m	8	83	182	116	13	0	16	166	364	232	26	0
		L-s/ha	0.03	0.32	0.7	0.45	0.05	0	0.06	0.64	1.4	0.9	0.1	0
30	Jamalganj	mm/d	0.2	2.8	6.2	4.7	4.5	0.2	0.4	5.6	12.4	9.4	9	0.4
		mm/m	7	83	187	140	134	5	14	166	374	280	268	10
		L-s/ha	0.03	0.32	0.72	0.54	0.52	0.02	0.06	0.64	1.44	1.08	1.04	0.04
31	Juri	mm/d	0.3	2.7	6.2	4.5	3.4	0.2	0.6	5.4	12.4	9	6.8	0.4
		mm/m	8	82	186	135	101	5	16	164	372	270	202	10
		L-s/ha	0.03	0.31	0.72	0.52	0.39	0.02	0.06	0.62	1.44	1.04	0.78	0.04
32	Kamalganj	mm/d	0.3	2.8	6.2	4.8	4.4	1.2	0.6	5.6	12.4	9.6	8.8	2.4
		mm/m	8	83	186	145	132	37	16	166	372	290	264	74
		L-s/ha	0.03	0.32	0.72	0.56	0.51	0.14	0.06	0.64	1.44	1.12	1.02	0.28
33	Kanaighat	mm/d	0.3	2.8	6.1	3.9	1.3	0	0.6	5.6	12.2	7.8	2.6	0
		mm/m	8	83	184	118	39	0	16	166	368	236	78	0
		L-s/ha	0.03	0.32	0.71	0.46	0.15	0	0.06	0.64	1.42	0.92	0.3	0
34	Karimganj	mm/d	0.3	2.7	5.8	4.3	5.4	3.2	0.6	5.4	11.6	8.6	10.8	6.4
		mm/m	8	80	173	129	161	97	16	160	346	258	322	194
		L-s/ha	0.03	0.31	0.67	0.5	0.62	0.38	0.06	0.62	1.34	1	1.24	0.76
35	Katiadi	mm/d	0.3	2.7	5.8	4.3	5.4	3.2	0.6	5.4	11.6	8.6	10.8	6.4

Sl No	Upazila	Unit	FIWR						SIWR					
			Nov	Dec	Jan	Feb	Mar	Apr	Nov	Dec	Jan	Feb	Mar	Apr
		mm/m	8	80	173	129	161	97	16	160	346	258	322	194
		L-s/ha	0.03	0.31	0.67	0.5	0.62	0.38	0.06	0.62	1.34	1	1.24	0.76
36	Kendua	mm/d	0.3	2.7	6	4.6	4.5	1.4	0.6	5.4	12	9.2	9	2.8
		mm/m	8	81	181	137	134	43	16	162	362	274	268	86
		L-s/ha	0.03	0.31	0.7	0.53	0.52	0.16	0.06	0.62	1.4	1.06	1.04	0.32
37	Kishoreganj Sadar	mm/d	0.3	2.7	5.8	4.3	5.4	3.2	0.6	5.4	11.6	8.6	10.8	6.4
		mm/m	8	80	173	129	161	97	16	160	346	258	322	194
		L-s/ha	0.03	0.31	0.67	0.5	0.62	0.38	0.06	0.62	1.34	1	1.24	0.76
38	Khaliajuri	mm/d	0.3	2.8	6.3	5	5.6	2.6	0.6	5.6	12.6	10	11.2	5.2
		mm/m	8	84	190	149	167	77	16	168	380	298	334	154
		L-s/ha	0.03	0.32	0.73	0.58	0.64	0.3	0.06	0.64	1.46	1.16	1.28	0.6
39	Kolmakanda	mm/d	0.3	2.8	6.3	5	5.3	1.3	0.6	5.6	12.6	10	10.6	2.6
		mm/m	8	84	188	149	159	39	16	168	376	298	318	78
		L-s/ha	0.03	0.32	0.73	0.57	0.61	0.15	0.06	0.64	1.46	1.14	1.22	0.3
40	Kotwali	mm/d	0.3	2.9	6.7	4.8	3.1	0	0.6	5.8	13.4	9.6	6.2	0
		mm/m	8	87	200	145	93	0	16	174	400	290	186	0
		L-s/ha	0.03	0.33	0.77	0.56	0.36	0	0.06	0.66	1.54	1.12	0.72	0
41	Kulaura	mm/d	0.3	2.8	6.6	5.3	4.2	0.9	0.6	5.6	13.2	10.6	8.4	1.8
		mm/m	8	85	197	158	127	26	16	170	394	316	254	52
		L-s/ha	0.03	0.33	0.76	0.61	0.49	0.1	0.06	0.66	1.52	1.22	0.98	0.2
42	Kuliarchor	mm/d	0.3	2.9	6.7	5.5	5.7	3.1	0.6	5.8	13.4	11	11.4	6.2
		mm/m	8	86	200	165	171	92	16	172	400	330	342	184
		L-s/ha	0.03	0.33	0.77	0.64	0.66	0.35	0.06	0.66	1.54	1.28	1.32	0.7
43	Lakhai	mm/d	0.3	2.7	6.3	4.8	5	2	0.6	5.4	12.6	9.6	10	4
		mm/m	8	81	188	145	150	59	16	162	376	290	300	118
		L-s/ha	0.03	0.31	0.73	0.56	0.58	0.23	0.06	0.62	1.46	1.12	1.16	0.46
44	Madan	mm/d	0.3	2.7	6	4.6	4.5	1.4	0.6	5.4	12	9.2	9	2.8
		mm/m	8	81	181	137	134	43	16	162	362	274	268	86
		L-s/ha	0.03	0.31	0.7	0.53	0.52	0.16	0.06	0.62	1.4	1.06	1.04	0.32
45	Madhabpur	mm/d	0.3	2.7	6.3	4.7	4.8	2.3	0.6	5.4	12.6	9.4	9.6	4.6
		mm/m	8	82	189	142	145	70	16	164	378	284	290	140
		L-s/ha	0.03	0.32	0.73	0.55	0.56	0.27	0.06	0.64	1.46	1.1	1.12	0.54
46	Maulvibazar Sadar	mm/d	0.3	2.8	6.3	4.8	4.6	1.4	0.6	5.6	12.6	9.6	9.2	2.8
		mm/m	8	83	188	143	138	42	16	166	376	286	276	84
		L-s/ha	0.03	0.32	0.73	0.55	0.53	0.16	0.06	0.64	1.46	1.1	1.06	0.32
47	Mithamain	mm/d	0.3	2.8	6.3	5	5.3	2.9	0.6	5.6	12.6	10	10.6	5.8
		mm/m	8	83	189	149	160	87	16	166	378	298	320	174
		L-s/ha	0.03	0.32	0.73	0.57	0.62	0.33	0.06	0.64	1.46	1.14	1.24	0.66
48	Mohonganj	mm/d	0.3	2.9	6.7	5.4	5.3	1.8	0.6	5.8	13.4	10.8	10.6	3.6
		mm/m	8	87	200	161	160	55	16	174	400	322	320	110
		L-s/ha	0.03	0.34	0.77	0.62	0.62	0.21	0.06	0.68	1.54	1.24	1.24	0.42
49	Nabiganj	mm/d	0.3	2.8	6.3	4.2	2.7	0	0.6	5.6	12.6	8.4	5.4	0
		mm/m	8	83	188	125	80	0	16	166	376	250	160	0
		L-s/ha	0.03	0.32	0.72	0.48	0.31	0	0.06	0.64	1.44	0.96	0.62	0

Sl No	Upazila	Unit	FIWR						SIWR					
			Nov	Dec	Jan	Feb	Mar	Apr	Nov	Dec	Jan	Feb	Mar	Apr
50	Netrokona Sadar	mm/d	0.3	2.8	6.3	4.9	5.4	1.5	0.6	5.6	12.6	9.8	10.8	3
		mm/m	8	84	188	147	162	45	16	168	376	294	324	90
		L-s/ha	0.03	0.32	0.72	0.57	0.63	0.17	0.06	0.64	1.44	1.14	1.26	0.34
51	Nikli	mm/d	0.3	2.8	6.2	5	5.2	2.7	0.6	5.6	12.4	10	10.4	5.4
		mm/m	8	83	187	150	156	81	16	166	374	300	312	162
		L-s/ha	0.03	0.32	0.72	0.58	0.6	0.31	0.06	0.64	1.44	1.16	1.2	0.62
52	Pakundia	mm/d	0.3	2.8	6.3	5	5.5	3.3	0.6	5.6	12.6	10	11	6.6
		mm/m	8	83	188	149	166	99	16	166	376	298	332	198
		L-s/ha	0.03	0.32	0.72	0.58	0.64	0.38	0.06	0.64	1.44	1.16	1.28	0.76
53	Purbadhala	mm/d	0.3	2.8	6.3	4.9	5.3	2.4	0.6	5.6	12.6	9.8	10.6	4.8
		mm/m	8	84	189	148	159	71	16	168	378	296	318	142
		L-s/ha	0.03	0.32	0.73	0.57	0.61	0.28	0.06	0.64	1.46	1.14	1.22	0.56
54	Rajnagar	mm/d	0.3	2.7	6.2	4.7	3.5	0.1	0.6	5.4	12.4	9.4	7	0.2
		mm/m	8	82	187	140	104	2	16	164	374	280	208	4
		L-s/ha	0.03	0.32	0.72	0.54	0.4	0.01	0.06	0.64	1.44	1.08	0.8	0.02
55	South Surma	mm/d	0.3	2.8	6.3	4.3	2.6	0	0.6	5.6	12.6	8.6	5.2	0
		mm/m	8	83	188	130	78	0	16	166	376	260	156	0
		L-s/ha	0.03	0.32	0.72	0.5	0.3	0	0.06	0.64	1.44	1	0.6	0
56	Sreemongol	mm/d	0.3	2.7	6.2	4.6	4.6	1.5	0.6	5.4	12.4	9.2	9.2	3
		mm/m	8	82	187	138	139	46	16	164	374	276	278	92
		L-s/ha	0.03	0.32	0.72	0.53	0.54	0.18	0.06	0.64	1.44	1.06	1.08	0.36
57	Sullah	mm/d	0.3	2.8	6.3	4	2.4	0	0.6	5.6	12.6	8	4.8	0
		mm/m	8	84	188	120	72	0	16	168	376	240	144	0
		L-s/ha	0.03	0.32	0.73	0.46	0.28	0	0.06	0.64	1.46	0.92	0.56	0
58	Sunamganj Sadar	mm/d	0.2	2.8	6.2	4.7	4.5	0.2	0.4	5.6	12.4	9.4	9	0.4
		mm/m	7	83	187	140	134	5	14	166	374	280	268	10
		L-s/ha	0.03	0.32	0.72	0.54	0.52	0.02	0.06	0.64	1.44	1.08	1.04	0.04
59	Tahirpur	mm/d	0.3	2.8	6.3	4.8	4.9	2.4	0.6	5.6	12.6	9.6	9.8	4.8
		mm/m	8	84	188	143	148	71	16	168	376	286	296	142
		L-s/ha	0.03	0.32	0.73	0.55	0.57	0.27	0.06	0.64	1.46	1.1	1.14	0.54
60	Tarail	mm/d	0.3	2.7	5.8	4.3	5.4	3.2	0.6	5.4	11.6	8.6	10.8	6.4
		mm/m	8	80	173	129	161	97	16	160	346	258	322	194
		L-s/ha	0.03	0.31	0.67	0.5	0.62	0.38	0.06	0.62	1.34	1	1.24	0.76
61	Zakiganj	mm/d	0.3	2.8	6	3.9	0.9	0	0.6	5.6	12	7.8	1.8	0
		mm/m	8	83	181	118	28	0	16	166	362	236	56	0
		L-s/ha	0.03	0.32	0.7	0.46	0.11	0	0.06	0.64	1.4	0.92	0.22	0

NB: The scheme irrigation water requirement SIWR = FIWR/ 0.5, where 0.5 is the conveyance efficiency.

7.2 Domestic and Municipal Water Requirement

Estimation of the present population and projected population is necessary for assessing the present and future domestic and municipal water demand. The Per Capita water demand is the annual average water consumption of one person daily. Thus, average daily demand over a year means the annual average daily demand. The total quantity of water required by the community can be computed using the following equation.

$$Q = P \times q,$$

where,
Q = Present/Projected quantity of water required per day
P = Present/Projected population
q = Rate of water consumption per capita per day.

The projected population is estimated by the following equation:

$$P_p = P_b(1+r)^n$$

where,
P_p = projected population in the year n
P_b = Base population
r = rate of natural increase of population per year
n = number of years being considered

The unit of domestic and municipal water demand is usually expressed as liters per capita per day (lpcd). Several factors influence the per capita water demand such as:

- Size of the town and coverage with piped water supply and sewerage facilities,
- Accessibility of water and quality of services as well as the standard of living of the consumers,
- Climatic conditions of the area,
- Income and affordability of the consumer and habitats of the people
- Quality and quantity of water supplied,
- Development of sewerage system, types of sanitary latrine and flushing system of the latrine,
- Water supply pattern-whether the supply is continuous or intermittent
- Wastage and system losses- leakage in the distribution system

According to the NWMP report, per capita gross water demand for municipal town and rural areas are 166 lpcd and 30 lpcd respectively (NWMP, 2000). The gross water demand of municipal town includes 119 lpcd net domestic water demand, 15% of it as a system loss, 10% as gross commercial demand and 15% as industrial demand. On the other hand, it has 50% returned flow from gross domestic demand and 75% returned flow from commercial & industrial demand, thus the net water demand for municipal town becomes 76 lpcd. The gross water demand for rural areas doesn’t include any loss for commercial and industrial demand.

Thus, net water demand according to NWMP report as 76 lpcd for urban area and 30 lpcd for rural area have been considered for calculation of domestic and municipal water requirement. Rate of natural increase of population per year has been considered as 1.5%. Upazila wise projected population and water demand for rural and urban areas for the year 2017 is given in Table 7-3.

Table 7-3: Present Population and Water Demand for the Year 2017

District	Upazila	Rural Population	Rural Population	Water Demand Rural (m^3/day)	Urban Population	Urban Population	Water Demand Urban (m^3/day)	Total Water Demand Rural & Urban (m^3/day)	Yearly Water Demand Rural & Urban (Mm^3)
		2011	2017	2017	2011	2017	2017	2017	2017
Habiganj	Ajmiriganj	99365	108650	3259	14900	16292	1238	4498	1.64
	Bahubal	193952	212076	6362	4045	4423	336	6698	2.44
	Baniyachong	304024	332433	9973	28506	31170	2369	12342	4.50
	Chunarughat	282459	308853	9266	19651	21487	1633	10899	3.98
	Habiganj Sadar	222392	243173	7295	106701	116671	8867	16162	5.90
	Lakhai	131576	143871	4316	17235	18845	1432	5748	2.10
	Madhabpur	294601	322129	9664	24415	26696	2029	11693	4.27
	Nabiganj	315666	345163	10355	35513	38831	2951	13306	4.86
Kishoreganj	Austagram	143372	156769	4703	9151	10006	760	5464	1.99
	Bajitpur	213832	233813	7014	34898	38159	2900	9914	3.62
	Bhairab	179317	196073	5882	118992	130111	9888	15771	5.76
	Hossainpur	159966	174914	5247	23118	25278	1921	7169	2.62
Kishoreganj	Itna	154280	168696	5061	9847	10767	818	5879	2.15
	Karimganj	260963	285348	8560	26844	29352	2231	10791	3.94
	Katiadi	273804	299389	8982	40725	44530	3384	12366	4.51
	Kishoreganj Sadar	310410	339416	10182	103798	113497	8626	18808	6.87
	Kuliarchar	150455	164514	4935	31781	34751	2641	7576	2.77
	Mithamain	114705	125423	3763	7321	8005	608	4371	1.60
	Nikli	127043	138914	4167	6686	7311	556	4723	1.72
	Pakundia	221454	242147	7264	28606	31279	2377	9642	3.52
	Tarail	150155	164186	4926	9584	10480	796	5722	2.09
Moulvibazar	Barlekha	235373	257367	7721	22247	24326	1849	9570	3.49
	Juri	140411	153531	4606	8547	9346	710	5316	1.94
	Kamalganj	242252	264889	7947	16878	18455	1403	9349	3.41
	Kulaura	334045	365259	10958	26150	28594	2173	13131	4.79
	Moulvibazar Sadar	285931	312649	9379	56537	61820	4698	14078	5.14
	Rajnagar	217611	237945	7138	15055	16462	1251	8389	3.06
	Sreemangal	294994	322559	9677	23031	25183	1914	11591	4.23

District	Upazila	Rural Population	Rural Population	Water Demand Rural (m^3/day)	Urban Population	Urban Population	Water Demand Urban (m^3/day)	Total Water Demand Rural & Urban (m^3/day)	Yearly Water Demand Rural & Urban (Mm^3)
		2011	2017	2017	2011	2017	2017	2017	2017
Netrokona	Atpara	134937	147546	4426	9687	10592	805	5231	1.91
	Barhatta	172599	188727	5662	7850	8584	652	6314	2.30
	Durgapur	198239	216763	6503	26634	29123	2213	8716	3.18
	Khaliajuri	91257	99784	2994	6193	6772	515	3508	1.28
	Kalmakanda	257529	281593	8448	14383	15727	1195	9643	3.52
	Kendua	282366	308751	9263	22363	24453	1858	11121	4.06
	Madan	135667	148344	4450	18812	20570	1563	6014	2.19
	Mohanganj	140314	153425	4603	27193	29734	2260	6863	2.50
	Netrokona Sadar	280849	307092	9213	91936	100527	7640	16853	6.15
	Purbadhala	288702	315679	9470	22132	24200	1839	11310	4.13
Sunamganj	Bishwamvarpur	153225	167543	5026	3156	3451	262	5289	1.93
	Chhatak	346964	379385	11382	50678	55414	4211	15593	5.69
	Dakshin Sunamganj	178700	195398	5862	5181	5665	431	6292	2.30
	Derai	207507	226897	6807	36183	39564	3007	9814	3.58
	Dharamapasha	211399	231153	6935	11803	12906	981	7915	2.89
	Dowarabazar	213666	233632	7009	14794	16176	1229	8238	3.01
	Jagannathpur	218791	239236	7177	40699	44502	3382	10559	3.85
	Jamalganj	157127	171809	5154	10133	11080	842	5996	2.19
Sunamganj	Sullah	109829	120092	3603	3914	4280	325	3928	1.43
	Sunamganj Sadar	208893	228413	6852	70126	76679	5828	12680	4.63
	Tahirpur	205750	224976	6749	9450	10333	785	7535	2.75
Sylhet	Balaganj	312416	341609	10248	7811	8541	649	10897	3.98
	Beanibazar	211586	231357	6941	42030	45957	3493	10433	3.81
	Bishwanath	211514	231279	6938	21059	23027	1750	8688	3.17
	Companigonj	155994	170571	5117	18035	19720	1499	6616	2.41
	Fenchuganj	82900	90646	2719	21841	23882	1815	4534	1.66
	Golapganj	278692	304734	9142	37457	40957	3113	12255	4.47
	Gowainghat	281443	307742	9232	6069	6636	504	9737	3.55
	Jaintiapur	153857	168234	5047	7887	8624	655	5702	2.08
	Kanaighat	236891	259027	7771	27078	29608	2250	10021	3.66
	Sylhet Sadar	302691	330975	9929	526412	575602	43746	53675	19.59
	Zakiganj	216331	236546	7096	20806	22750	1729	8825	3.22
	South Surma	236324	258407	7752	17064	18659	1418	9170	3.35

8 DEVELOPMENT OF MATHEMATICAL MODEL

8.1 Study Approach

The models developed under the present study are based on MIKE-11 for surface water model and MIKE SHE for groundwater model. Both the models have been coupled and run dynamically.

8.2 Surface Water Model

Mathematical model is being developed with concurrent hydrometric and topographic data with the purpose to investigate the probable hydrological and hydraulic aspects. Another purpose of developing one-dimensional (1-D) hydrodynamic model is to assess surface water resources in the study area. 1-D models have been calibrated and verified with the measured data. The calibrated/verified models have been used to predict the available surface water resources.

National Water Management Plan (NWMP), considering the surface water hydrology and hydraulics, divided the territory of Bangladesh into six hydrological regions. North East Region Model (NERM) is one of the six regional models covering east of the Old Brahmaputra River, and north of the Upper Meghna river and Titas basin. The NERM comprises a hydrological (rainfall-runoff) model and a hydrodynamic (river/channel/floodplain hydraulics) model. Both the rainfall runoff model (NAM) and hydrodynamic (HD) model are calibrated and validated against observed data. MIKE 11 of MIKE Zero platform developed by the DHI Water & Environment, Denmark has been applied in developing these models. MIKE 11 model computes discharge and water level in the river/floodplain system of the study area. Computation of MIKE 11 modelling system has two major hydrological processes as follows:

- MIKE 11 NAM to process runoff from rainfall
- MIKE 11 HD to process flow, velocity and water levels in river channels

8.2.1 Development of Hydrological Model

Model Set Up

The NAM hydrological model simulates the rainfall-runoff processes occurring at the catchment scale. NAM forms part of the rainfall-runoff (RR) module of the MIKE 11 River modelling system. A mathematical hydrological model like NAM is a set of linked mathematical statements describing, in a simplified quantitative form, the behavior of the land phase of the hydrological cycle. The process of model setup involves delineation of sub-catchment, assessing the weightage factor of rainfall station contributing to the sub-catchment, assigning the hydrological parameters and computing the mean areal rainfall.

NERM-NAM (hydrology) model was developed for the catchments of the north east region (NER) area. Delineation of catchments have been carried out on the basis of the National Water

Management Plan (NWMP) study. In the NAM model, the meteorological inputs and parameters covering an individual catchment are considered as lumped or homogeneously. It is therefore a common practice to delineate the whole area into a number of sub-catchments or catchments and develop the model for each catchment in a single model setup. The basic inputs for this model are rainfall, evaporation and parameters associated with catchment land cover and soil characteristics addressing surface and groundwater process, irrigation practice, etc. Thiessen Polygons have been drawn using GIS Software to calculate the weightage factors for different rainfall stations to each sub-catchment and the values thus found are used in the model set-up. This rainfall-runoff (MIKE 11 NAM) model was integrated to the 1-D River (MIKE 11 HD) model to establish the surface runoff inflow to the river hydrodynamics.

Catchment

The NERM has an area of about 24,265 sq. km. It receives external inflows coming from India of an area about 20311 sq. km. There are a total of 57 sub-catchments of which 39 internal located inside Bangladesh and 18 are cross border catchments located within Indian territory. The Hydrology Department of BWDB maintains 44 rainfalls, 4 evaporations and 21 groundwater recording stations in the region, inside Bangladesh. The mean areal rainfall and evaporation for a particular catchment were calculated using the Thiessen polygon method. The data from these stations are daily in most cases. The availability of data ranges from 1980s to 2016. The Figure 8-1 shows the inland and transboundary catchments with relevant rivers as well as locations of hydro-meteorological stations in the model extent and Table 8-1 shows the list of catchments. Internal rainfall stations have been used for transboundary catchment distribution. In this case each external catchment contribution has been found out using the rainfall stations closer to respective catchments. Three catchments namely NEX-1, NEX-1A and NEX-2 are dominating compared to other catchments due to excessive rainfall where weighted average factor has taken more than 1.

Parameters

NAM simulates the rainfall-runoff process by continuously accounting for the water content in three different and mutually interrelated storages that represent different physical elements of the catchment; these storages are: Surface storage, Lower or root zone storage, Groundwater storage. For each sub-catchment parameters are selected based on the topography, soil type, moisture content, hydrograph type, vegetation etc.

It is difficult to determine values of the NAM parameters on the basis of soil physical measurements because most of the parameters are of lumped semi-empirical nature, and calibration is required. Calibration commences with a comparison of simulated groundwater levels and runoff hydrographs against measured discharges, after a first successful model run. It involves consistency and quality checking of input data, and a series of model runs with changed parameter values, until reasonable agreement between the modelled and observed hydrographs is achieved.

8.2.2 Development of Hydrodynamic Model

Model Setup

Hydrodynamic Model routes the channel and floodplain flow and includes storage computation in flood cells. The primary inputs in the model are bathymetry of routing channels, topography of floodplains and flood cells, information of infrastructures, local catchments runoff (Output of Rainfall-Runoff Model) and peripheral water mass that enters into or leave the system.

NERM-HD (1-D River) model for the north east region was developed during early 1991 and since then it has been updated to serve various project activities time to time. In the latest validation model setup of 2005-06 hydrological year the total river length is appx. 3500 km having around 1200 cross sections. Since 2006 more rivers of the NERM are being updated considering both length and new cross sections. The cross sections were surveyed in connection with various projects for the major rivers and its tributaries as part of representing physical setup of the north east regional river system. There are 55 water level and 38 discharge stations in the region. Contribution of catchments' runoff to the entire river system of the study area was taken into account as point inflow and laterally distributed runoff. NERM river systems and hydrometric stations are shown in Figure 8-1.

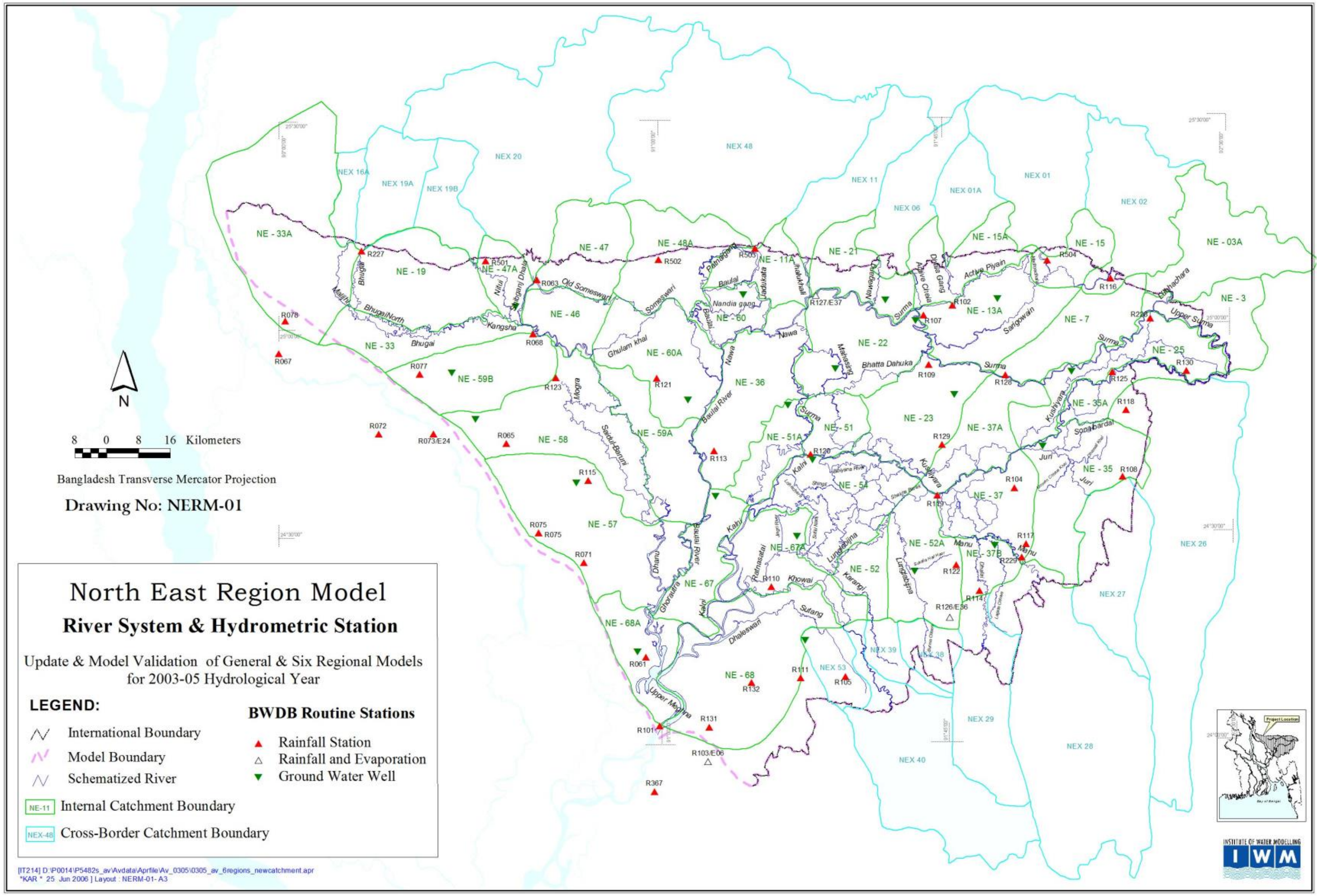


Figure 8-1: Inland and Trans Boundary Catchments with Hydrometric Stations in the NERM

Table 8-1: List of Catchments used in the Hydrological Model of NERM

Sl No	Catchment ID	Area in sqkm	Remarks
1	NE - 33A	1598	Internal
2	NE - 47	501	Internal
3	NE - 48A	644	Internal
4	NE - 15A	447	Internal
5	NE - 15	261	Internal
6	NE - 21	406	Internal
7	NE - 11A	343	Internal
8	NE - 19	749	Internal
9	NE - 47A	225	Internal
10	NE - 13A	696	Internal
11	NE - 07	505	Internal
12	NE - 03	420	Internal
13	NE - 60	242	Internal
14	NE - 46	295	Internal
15	NE - 22	720	Internal
16	NE - 60A	733	Internal
17	NE - 36	789	Internal
18	NE - 33	444	Internal
19	NE - 25	574	Internal
20	NE - 59B	617	Internal
21	NE - 23	651	Internal
22	NE - 35A	236	Internal
23	NE - 37A	471	Internal
24	NE - 51	244	Internal
25	NE - 51A	298	Internal
26	NE - 35	775	Internal
27	NE - 37	492	Internal
28	NE - 54	760	Internal
29	NE - 57	1181	Internal
30	NE - 52A	595	Internal
31	NE - 67	399	Internal
32	NE - 67A	566	Internal
33	NE - 52	232	Internal
34	NE - 37B	203	Internal
35	NE - 68	1276	Internal
36	NE - 68A	425	Internal
37	NE - 59A	538	Internal
38	NE - 58	1007	Internal
39	NE - 03A	750	Internal
1	NEX 20	2324	Transboundary
2	NEX 48	2442	Transboundary
3	NEX 11	610	Transboundary

Sl No	Catchment ID	Area in sqkm	Remarks
4	NEX 01	1028	Transboundary
5	NEX 06	538	Transboundary
6	NEX 02	879	Transboundary
7	NEX 01A	351	Transboundary
8	NEX 28	2356	Transboundary
9	NEX 29	747	Transboundary
10	NEX 19A	457	Transboundary
11	NEX 16A	162	Transboundary
12	NEX 19B	348	Transboundary
13	NEX 26	2256	Transboundary
14	NEX 27	746	Transboundary
15	NEX 53	247	Transboundary
16	NEX 38	226	Transboundary
17	NEX 39	185	Transboundary
18	NEX 40	1325	Transboundary

Schematization of the Hydrodynamic Model (HD)

Alignments of rivers are digitized according to IWM survey and using various sources of images such as Google Earth, Indian Remote Sensing Satellite (IRS) Images etc. available at IWM. Floodplains incorporated in the model are around 1400 km whose bathymetry has been taken from existing Digital Elevation Model (DEM) available in IWM. Several haor projects are incorporated in the model as routing channels taking into account submersible embankments, control structures, bridges and culverts during ongoing other projects in the NERM. Link channels are incorporated for allowing spillage through breaches as well as over topping of banks of rivers/khals, and flow over submersible embankments. Several weirs are also inserted in the floodplains to allow functions of existing bridges and culverts located on highways and railways on a lumped basis.

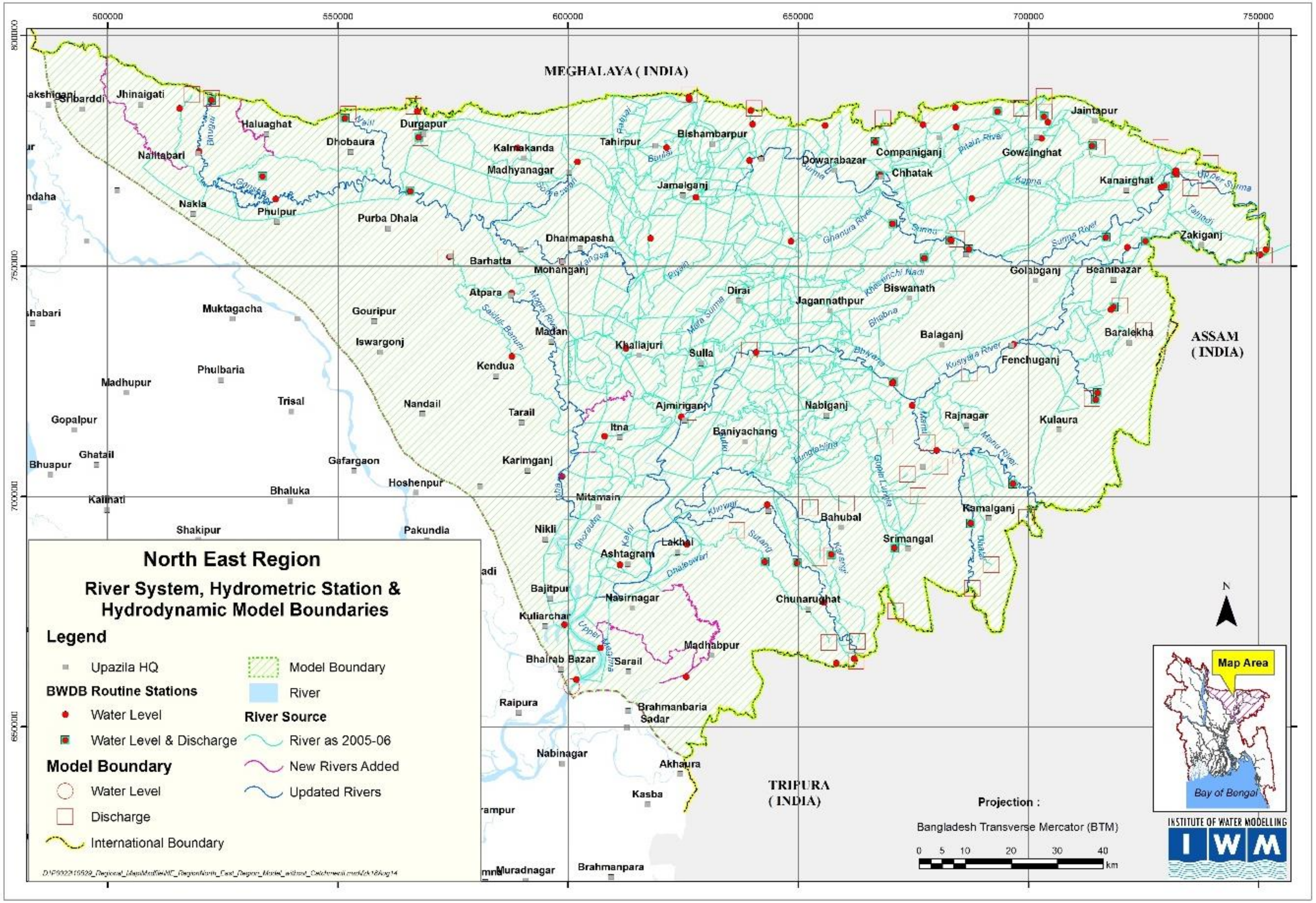


Figure 8-2: River Systems and Hydrometric Stations in the NERM

Boundary Conditions

There are 22 inflows as upstream boundaries out of which only one carries flow generated from local rainfall within the country, and the rest of them carry flows generated within Indian Territory. Bhairab Bazar water level has been used as downstream boundary condition. Point discharge and distributed surface runoff thus act as upstream boundary condition as well as intermediate runoff contribution to the river system. Boundary characteristics whether flows, NAM flows or combination of the both are shown in Figure 8-3.

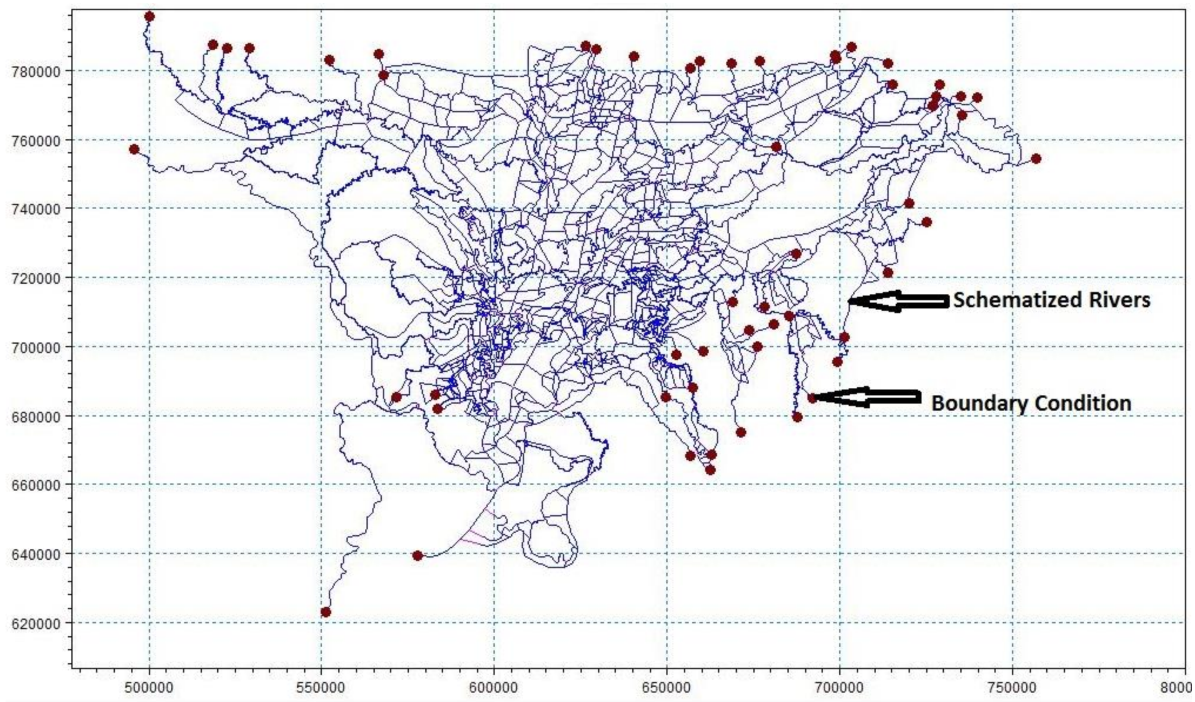


Figure 8-3: Schematized Rivers and Boundary Conditions in the NERM

In the present study, the major river system with its tributaries has been given emphasis and importance. For updating process, substantial upgrading has been under taken using information of different ongoing projects and routine measurement of BWDB. Cross-sections of number of rivers have been updated using survey data under taken from several projects of BWDB. The consideration for catchments has been kept same as that of the latest updated NERM model. The time series data such as rainfall, evaporation, abstraction, water level, discharge etc. have been up to date time series up to 2016. The run-off generated by the rainfall calculated by NAM model has been included in the river set-up through catchment area of each river inside the project area. The river model requires time series of discharge at the upstream and water level at the downstream to compute water level, discharge and flow velocity at the internal points. The boundaries have been kept same as those of the latest NERM model. The hydrodynamic model layout is show in Figure 8-2. The Table 8-2 shows the list of status of updated rivers.

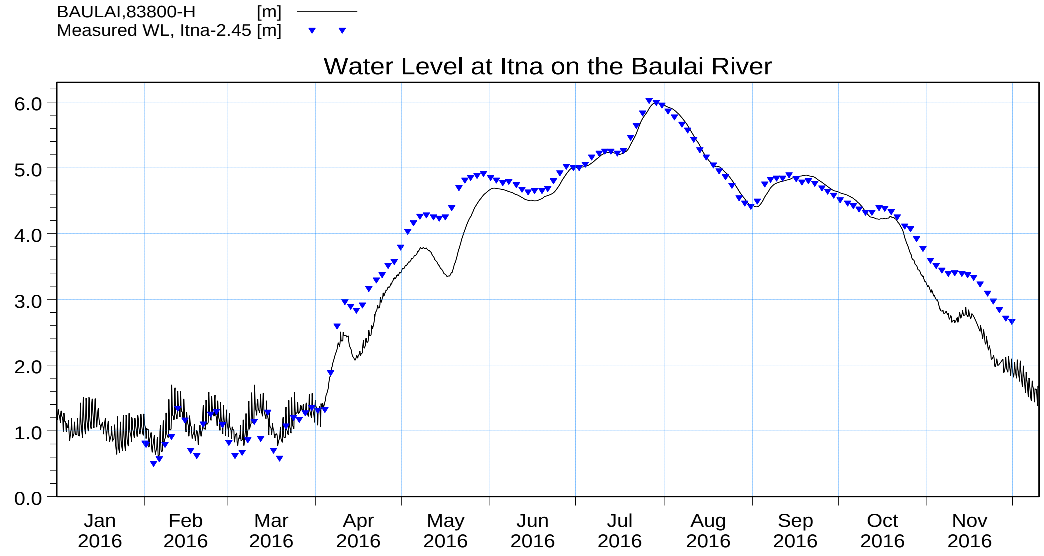
Table 8-2: List of Updated Rivers

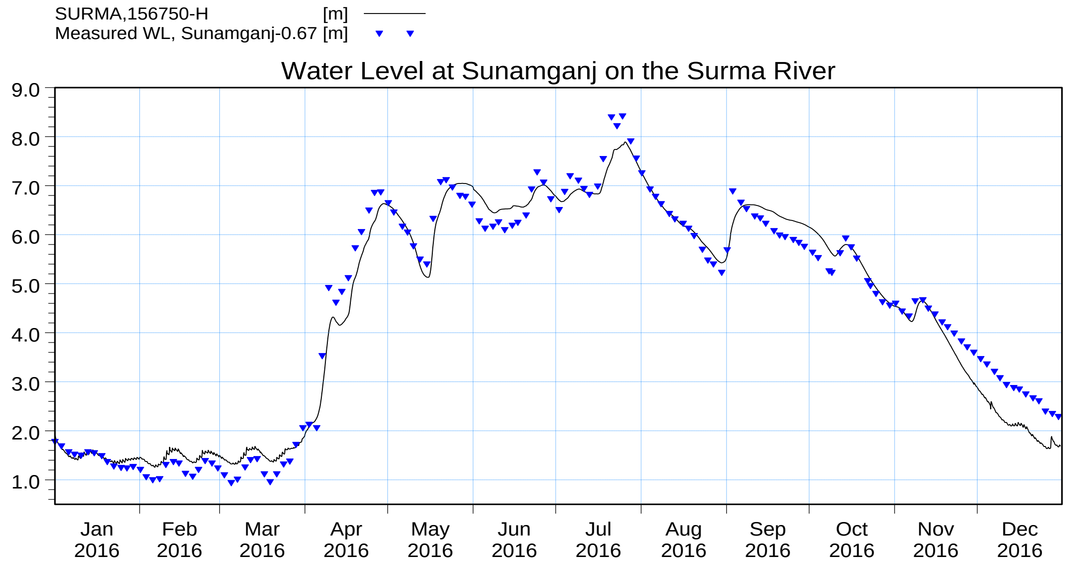
River Name	Survey Year	Length (Km)	Cross-section (nos.)
Bandsa	IWM-2015	42.25	21
Bhugai	IWM-2013	56.2	41
Dhalai_Khal	IWM-2016	21.1	23
Dema Nadi	IWM-2016	11.1	10
Dhalai	IWM-2013	27	20
Dhalai Up	IWM-2013	25.81	20
Dhanu	IWM-2013	93.5	56
Dhonaikhal	IWM-2016	25.5	14
Ghulamkhal	IWM-2016	29	30
Jadukata	IWM-2012	33	13
Jingri	IWM-2016	14	7
Juri	IWM-2013	32.4	18
Kachamati_River	IWM-2015	36.45	16
Kangsha	IWM-2013	98.5	76
Karangi	IWM2010	31	12
Kharia	IWM-2015	35.5	19
Khowai	IWM2010	50.2	19
Kushiyara	IWM-2013	135.5	32
Lakhya	IWM-2013	1.025	2
Lokchora	IWM-2016	4.5	4
Lower-Chamti	IWM-2016	36	15
LowerKangsha	IWM-2013	65	52
Manu	IWM-2013	55	42
Manu Up	IWM-2013	20.02	11
Moghabathail	IWM-2015	51.88	27
Mogra	IWM-2016	30	15
Mogra Up	IWM-2015	50.15	27
Narsunda	IWM-2015	56.3	42
Old-Brahmaputra	IWM-2014	204.21	101
Old-Brahmaputra-Br	IWM-2016	24.8	9
Oldkushiyara	IWM-2016	18.5	12
Phingli	IWM-2016	36.5	13
Ratnasat	IWM-2010	43.5	30
River-10	IWM-2015	27.25	14
Saidulbaruni	IWM-2016	67.6	35
Shakha-Barak	IWM-2016	17.35	10
Soai	IWM-2015	79.65	41
Someswari	IWM-2016	56	30
Sukti	IWM-2016	19.375	12
Surma	IWM-2013	172	40
Titas-A	IWM-2013	60.05	27
Titas_Upper	IWM-2013	53.935	20
Khowai Up	IWM-2010	39	15
Upper-Kush	IWM-2013	44.5	14

River Name	Survey Year	Length (Km)	Cross-section (nos.)
Upper-Surma	IWM-2013	48.5	17
Dhanu-Baulai Link	IWM-2013	3.5	2
Issapur Loopcut	IWM-2017	2.8	3
Kalni	IWM-2017	58.87	32
Dhaleswar-NE	IWM-2017	44.1	25
Cherapur Khal	IWM-2017	16.8	9

8.2.3 Calibration and Valiadation of the HD Model

The NERM model has been calibrated for the year 2016 and validated against 2017 year. Sample calibration plots of simulated and measured data for the year 2016 and validation plot for 2017 of water levels for selected hydrometric stations have been shown in Figure 8-4 to Figure 8-5 where as the rest are given in Volume-II, Appendix J.





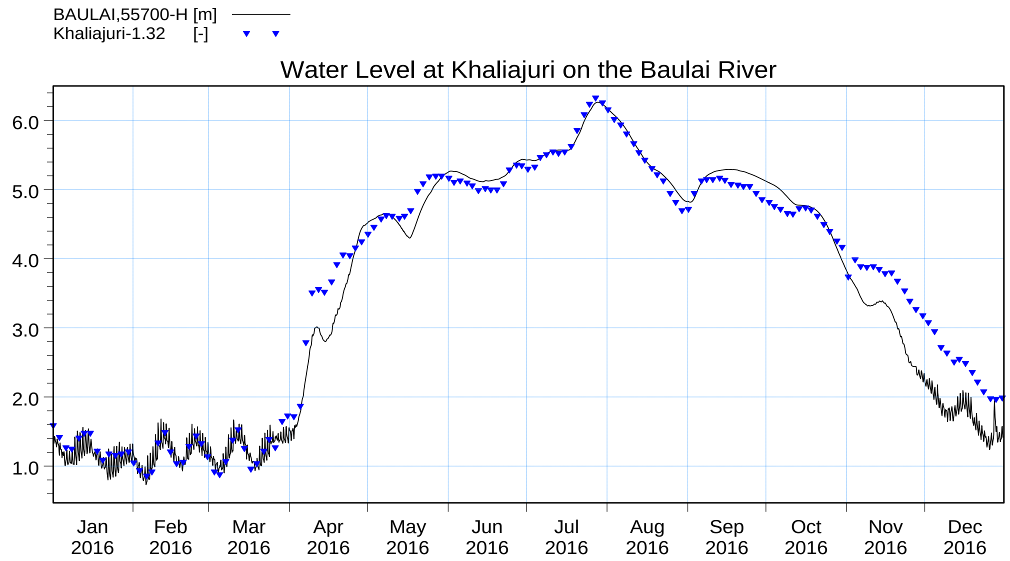


Figure 8-4: Calibration Plot of Surface Water Level

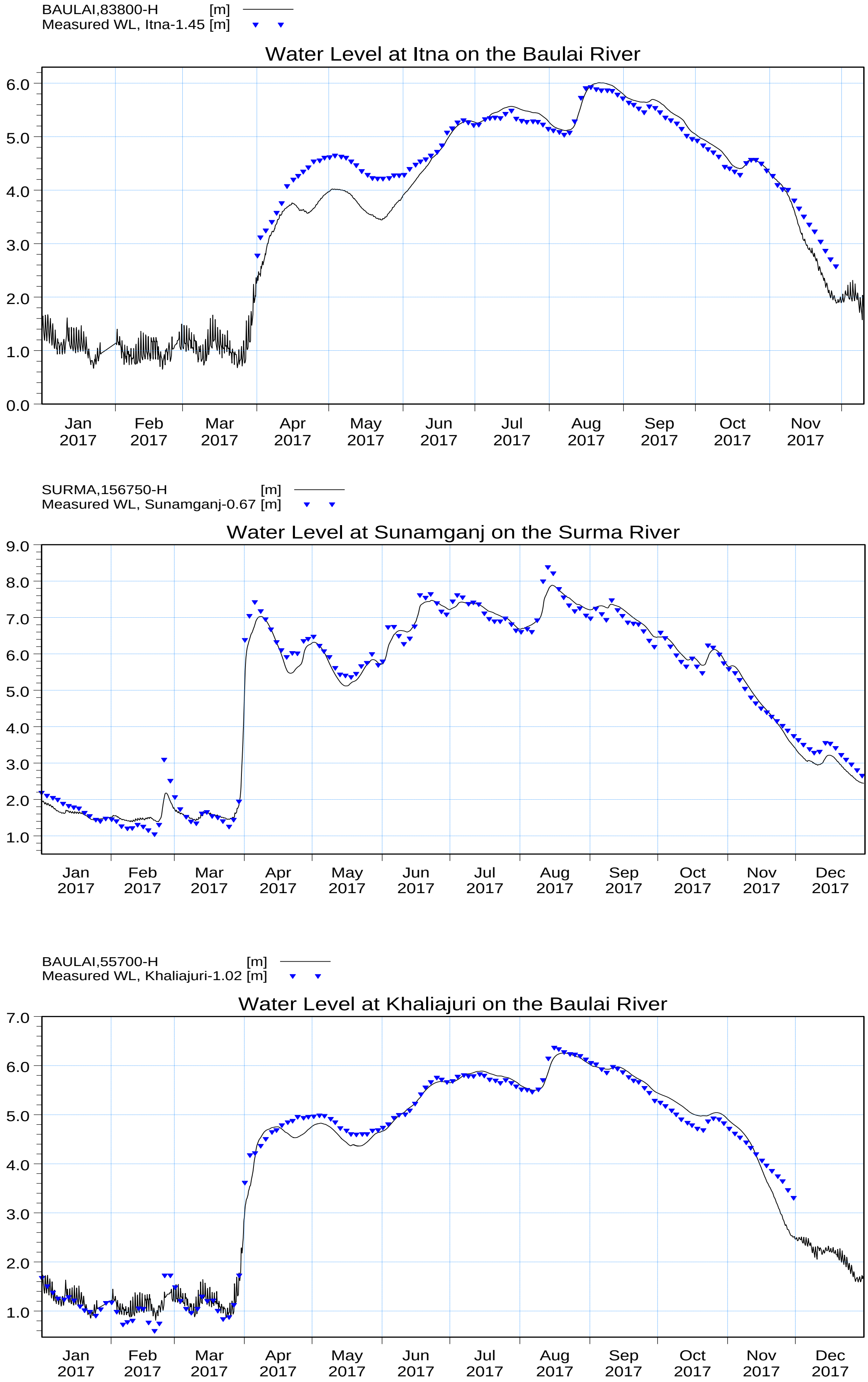


Figure 8-5: Validation Plot of Surface Water Level

8.3 Groundwater Model

The major activities in connection with groundwater modelling includes: selection of model domain, development groundwater model, fixation of boundary conditions and necessary data preparation, calibration and validation of models, coupling of surface water and groundwater model, selection of design year, option formulation and simulations, analysis and interpretation of results etc. Necessary data have been collected and checked for consistency and processed for model input. The description of the model set up has been presented in the following section.

8.3.1 Model Area

The model area is located in the North-East region of Bangladesh. The north and east side of the model area is bounded by Indian boarder, Brahmanbaria and Narsingdi districts in the south side of the model area whereas the west side is bounded by Mymensingh district as shown in Figure 8-6. The gross area of the model is about 19066km^2. Model domain has been selected based on the presence of groundwater observation well to define model boundary. Model domain has been selected as greater than the study area to reduce the boundary effect.

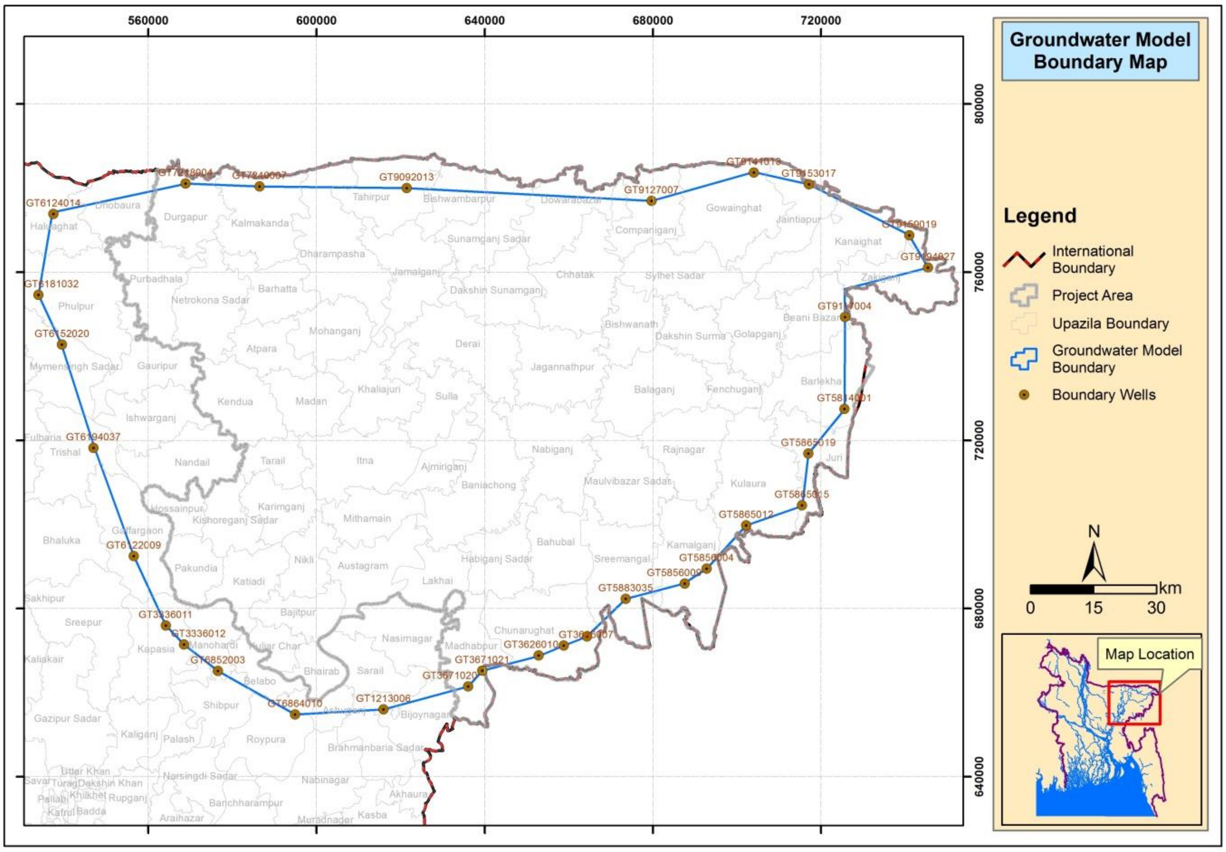


Figure 8-6: Map Showing the Model Area

8.3.2 Model Setup

Model setup includes identification of the area of model domain (area to be modeled), river system that would be included in the model, delineation of catchment area, identification of hydraulic structures, identification of geological layers and their hydraulic properties, identification of boundary stations and conditions, land use and preparation of various hydro-meteorological input data. A brief description of the model setup activities is presented in the following sections.

Simulation Specification

The time step control and computational control parameters for overland flow (OL), unsaturated zone (UZ) and Saturated Zone (SZ) have been used for entire simulation period. However, simulation periods of the calibration, validation and prediction models were different and user specified.

Model Domain and Grid Size

The model area has been discretized into 1000m square grids in the horizontal plan as shown in Figure 8-7. The model has 19,605 number cells, of which 534 are boundary cells and the rest are calculation cells. The grid cells are the basic units to provide all the spatial and temporal data as input and to obtain corresponding data as output.

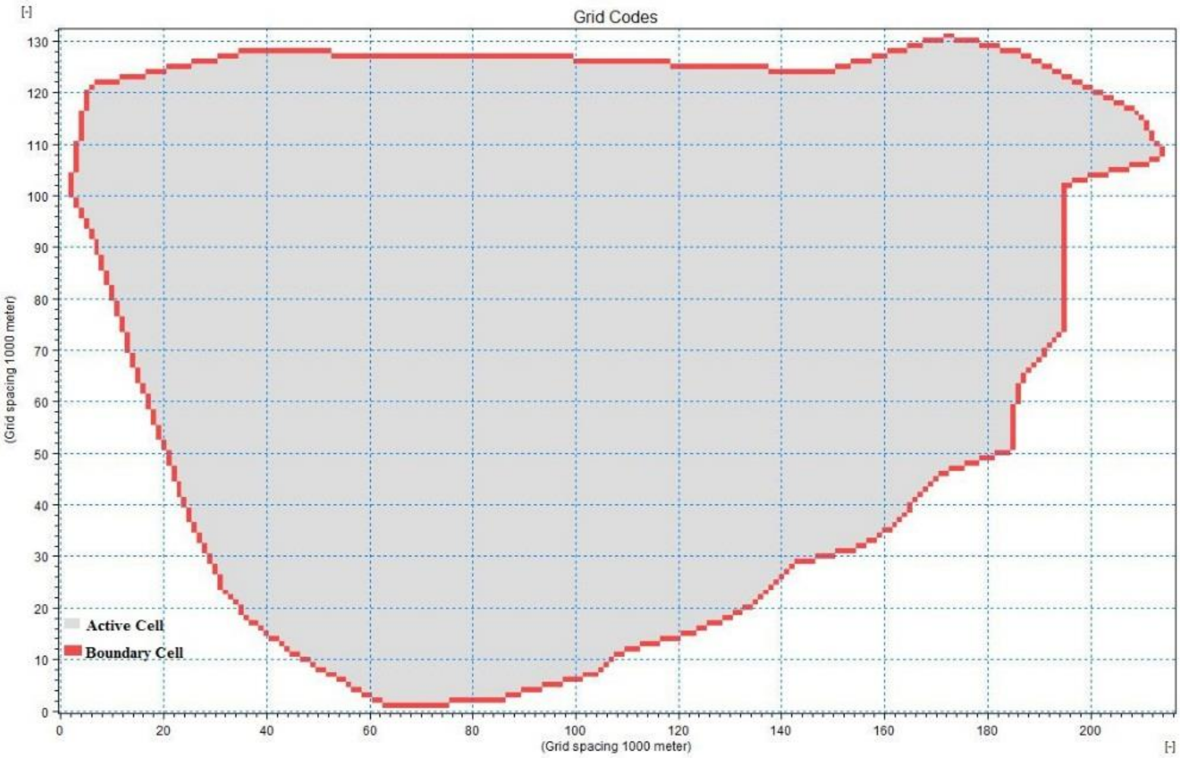


Figure 8-7: Model Domain of the Study Area

Topography

A well-prepared DEM is essential for visualizing the floodplain topography and for accurate modeling. Elevation of the area varies from 0mPWD to 88.0mPWD. The Digital Elevation Model (DEM) for the model domain has been presented in Figure 8-8.

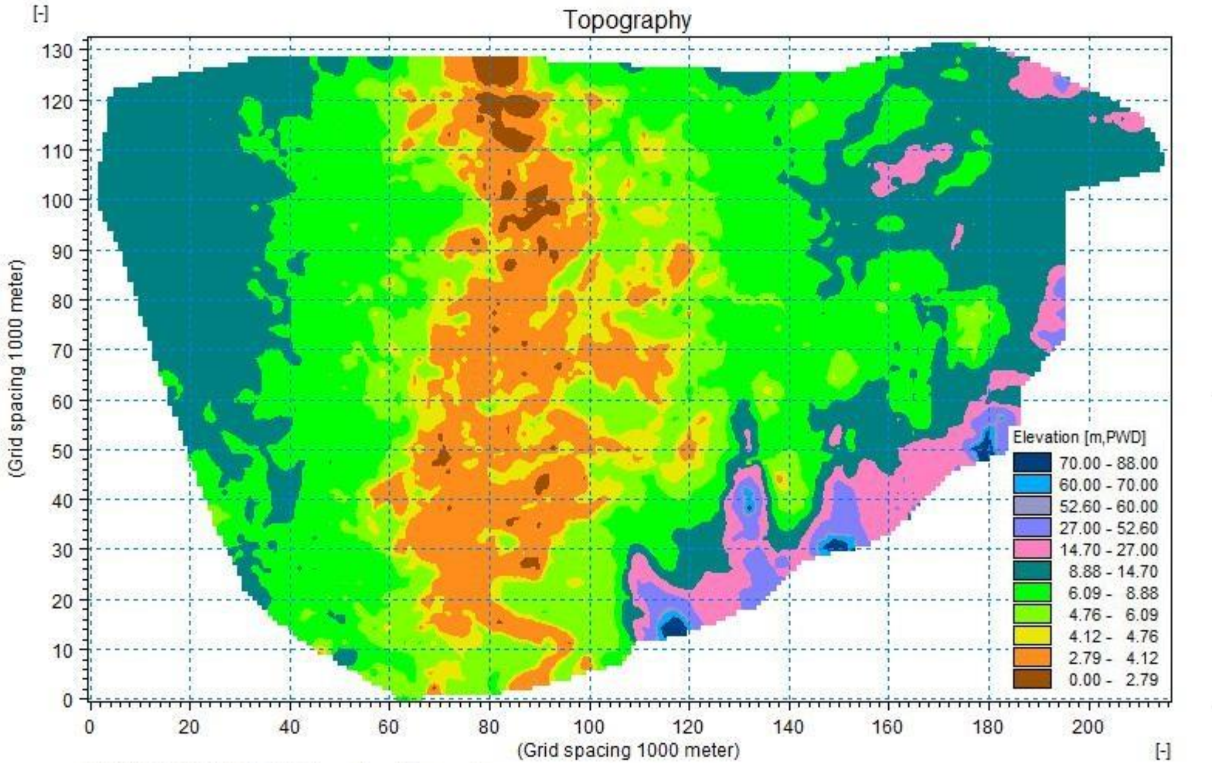


Figure 8-8: Digital Elevation Model for Model Area

Precipitation

Rainfall data are needed as input for the model. Forty-two rainfall stations are available in and around the model areas. To account for the spatial variation in rainfall, the time series data for each station has been associated with an area. This area has been estimated by Theissen polygon method. Theissen polygons for each rainfall stations have been shown in the Figure 8-9.

Evapo-transpiration

The actual evapotranspiration estimates in the model on the basis of potential evapotranspiration rates, the root depths and leaf area indices of different crops over the seasons. Model uses Kristensen and Jensen formula for calculation of actual evapotranspiration. Time series of the potential evapotranspiration are given as input to the model. Six evaporation stations are found in and around the model area.

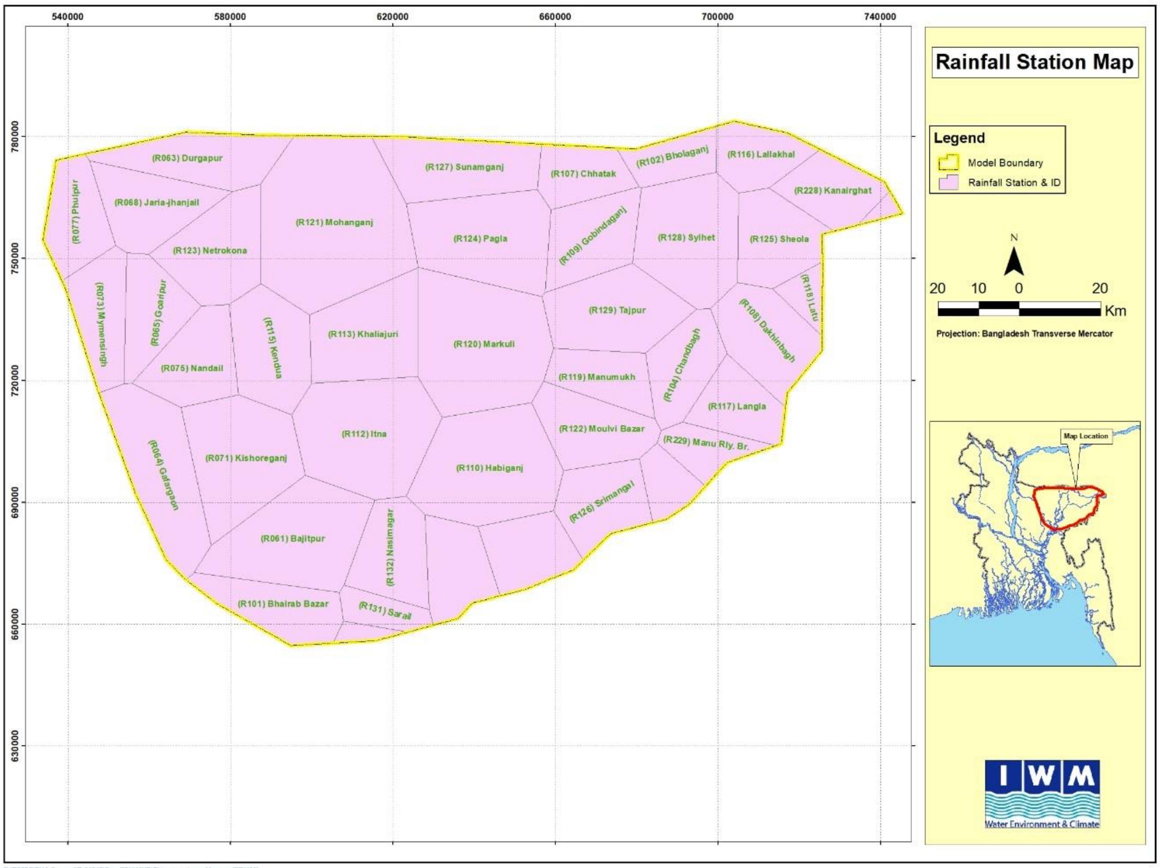


Figure 8-9: Theissen Polygons for Rainfall Stations

Land Use

Land use and vegetation are used in the model to calculate actual evapo-transpiration depending on the actual crops grown in the project area. The major part of the study area is agricultural land. It has homestead, pond, river and forest also. A crop database for each crop, which defines leaf area index, root depth and other properties of each crop are developed based on FAO publications (FAO, 1979) and used in the model. Land use of the study area shown in Figure 8-10.

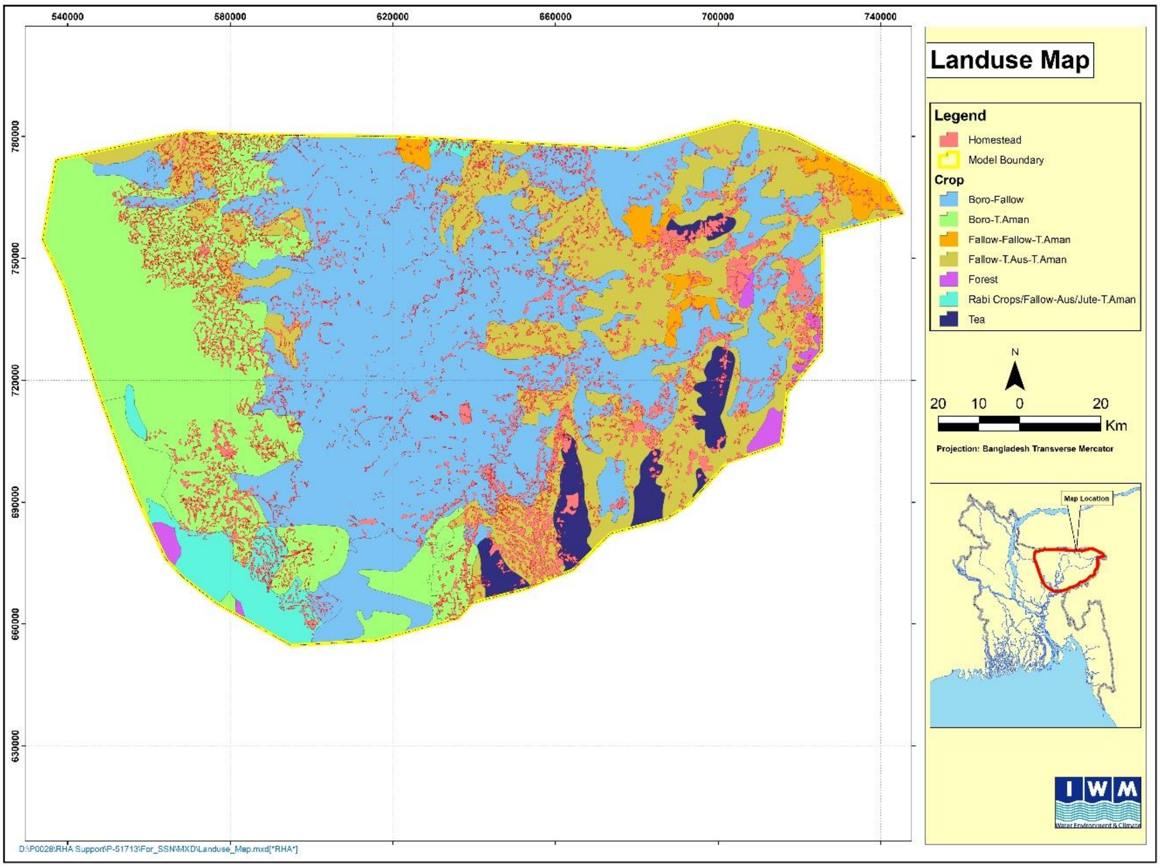


Figure 8-10: Land Use of the Study Area

Soil Map

The General Soil Map of Bangladesh developed by Soil Resource Development Institute (SRDI) shows that twelve soil series cover the model study area as shown in Figure 8-11. Properties of soils similar to study area have also been taken from similar past studies.

Overland Flow

The study area is dominated by agricultural land and the main crops are different varieties of paddy. The usual practice of paddy field band height is in the range of 10cm to 20cm. In the project area, there is also lot of water body/channel. Considering the fact, detention storage is taken 50mm for the initiation of the runoff flows.

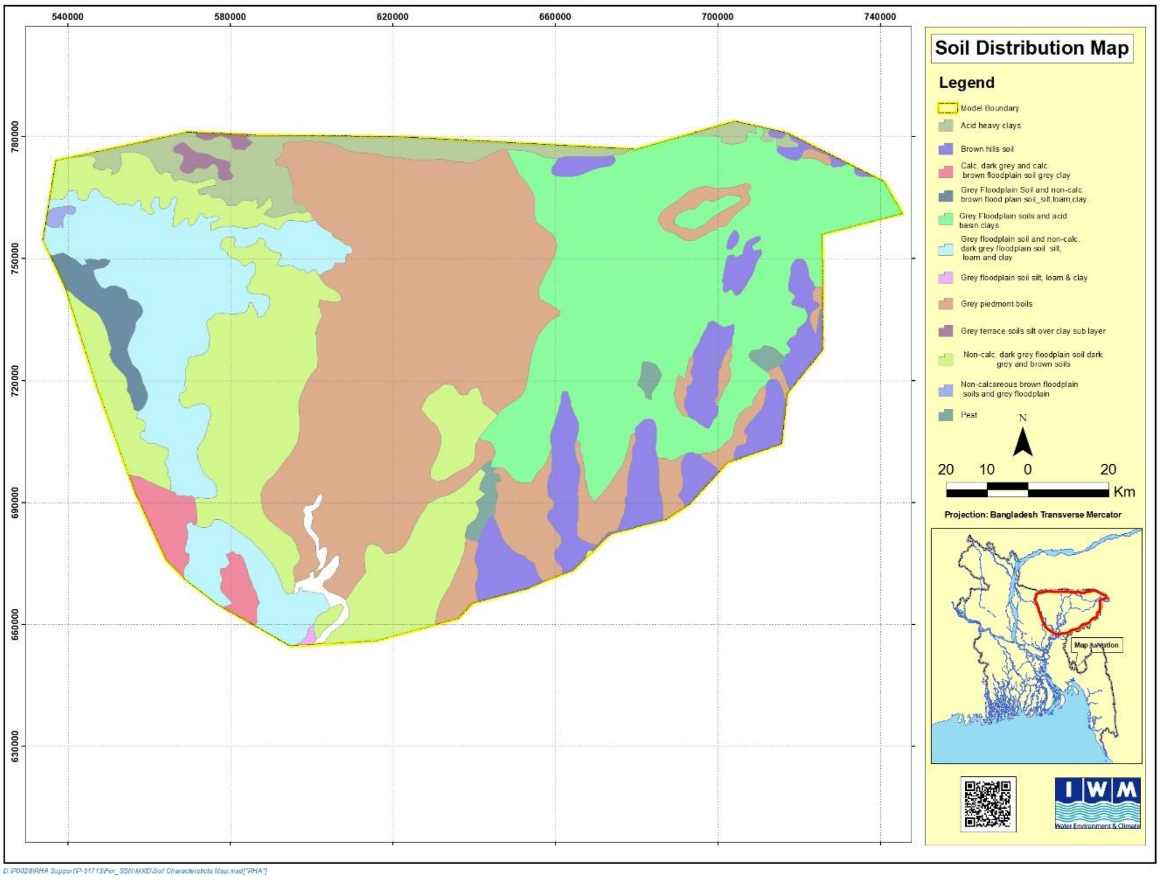


Figure 8-11: Soil Map of the Study Area

Saturated Zone

The saturated zone component of MIKE SHE Water Movement Module is the platform for exchanging water with the other components and estimates the saturated subsurface flow in the catchment. MIKE SHE allows a full three-dimensional flow in a heterogeneous aquifer with switching conditions between unconfined and confined situations. The spatial and temporal variations of the potential heads are described mathematically by the non-linear Boussinesq equation and solved numerically by an iterative implicit finite difference technique. Setting up the saturated zone component includes defining the computational layers from geological layers, hydrogeological characteristics, initial and boundary conditions, drainage and pumping wells, etc.

Geology and Hydrogeology: In the present study, sub-surface geology of the study area has been defined by five hydro-stratigraphic layers. Elevations of base of these layers are used in the model to define the geological formations. Under the study 556 nos. of borelog has been collected and used in the model to define the sub-surface geology of the model area. Using this bore log data 5 numbers of geological layer have been identified namely 1) Top Soil, 2) 1st Aquifer, 3) 1st Aquitard, 4) 2nd Aquifer and 5) 2nd Aquitard.

Boundary and Initial Conditions: Time varying groundwater level boundaries are defined at all the boundary cells of all 5 computational layers. The specification of the initial conditions is required for transient simulations, but not necessary for steady state simulations. Based on observation well data in and around the model area, potential head map has been prepared by interpolation for January 2012. Figure 8-12 shows the potential head map at the start of simulation.

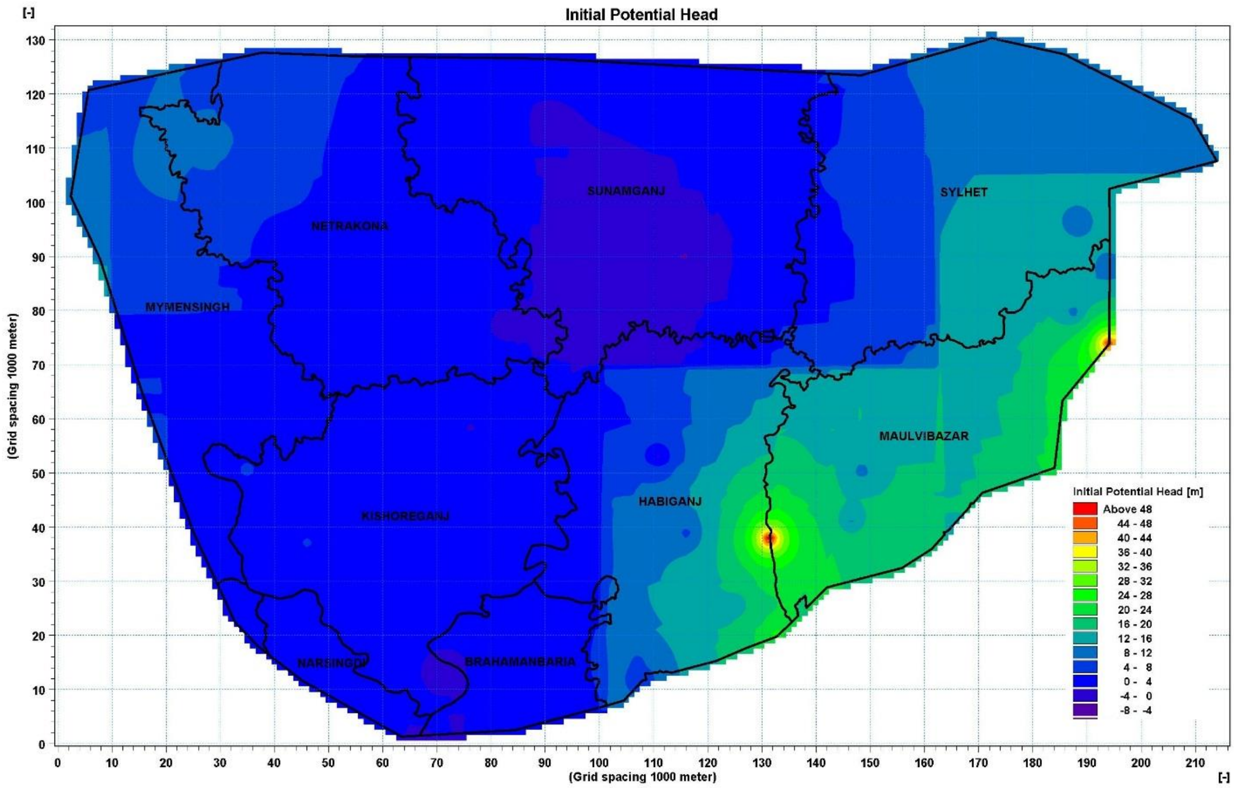


Figure 8-12: Initial Potential Head of the Study Area

Spatial and Vertical Discretization: The study area is discretized into 19605 cells having 1000m grid squares in its horizontal plan. The five computational layers define the vertical discretization of the 3-D groundwater model. Special consideration is given to the unsaturated zone, where the vertical resolution is as fine as 0.05 m, 0.1 m and 0.5 m towards the increasing depths.

Coupling of Surface Water and Groundwater Model: GW-SW interaction mainly deals with the interaction between river and aquifer at the river-aquifer interface. It has been incorporated through coupling of river model with groundwater model and has been duly calibrated and validated. The coupling of surface water with groundwater model involves a number of specifications. The river reaches where the coupling will take place have been defined in river model. In the present study, all the major rivers, khals and haors within the study area have been coupled with groundwater. Type of river-aquifer exchange and the flooding condition have also been defined. The exchange of flow between the saturated zone component and the river component is mainly dependent on head difference between river and aquifer and properties of riverbed material such as leakage coefficient. For this study, the leakage coefficient is taken as $1e^{-6}$/s. For river-aquifer exchange, leakage coefficients along with the hydraulic conductivity of the saturated zone are also taken into account for most of the river reaches.

8.3.3 Model Calibration

The purpose of calibration is to achieve an acceptable agreement between model results with measured data by adjusting input parameters within acceptable range. The initial input parameters have been obtained from field measurements and other secondary sources. The model has been calibrated for the period 2012 to 2016.

Model calibration has been done against groundwater levels. Initial calibration has been started with the groundwater parameters. While there are some minor parameters to influence the groundwater calibration, however, it appears that the hydraulic conductivity is the main parameter for groundwater model calibration. The evapotranspiration and unsaturated zone parameters, and drainage levels have also been adjusted. Finally, the controlling parameter for river-aquifer interaction has been adjusted to match the simulated and observed groundwater heads. The locations of the monitoring wells used in calibration process are shown in Figure 8-13. Overall calibration results show good match between simulated and observed values of groundwater levels. Sample calibration plots are given in Figure 8-14 where as the details are given in Volume-II, Appendix J.

8.3.4 Model Validation

It is customary that the calibrated model should be verified outside the calibration period. As such verification has been done for a period of 2017 to 2018. Model validation has been carried out against groundwater level. Examples of validation results against groundwater levels for the period of 2017 to 2018 are shown in Figure 8-15 where as details are given in Volume-II, Appendix J. Overall, validation results show similar trend of groundwater fluctuation and good matching of groundwater levels between observed and simulated values for the validation periods. From the results of the model validation, it could be concluded that the parameters used in the calibrated model are acceptable, thus the model can be used for prediction purposes.

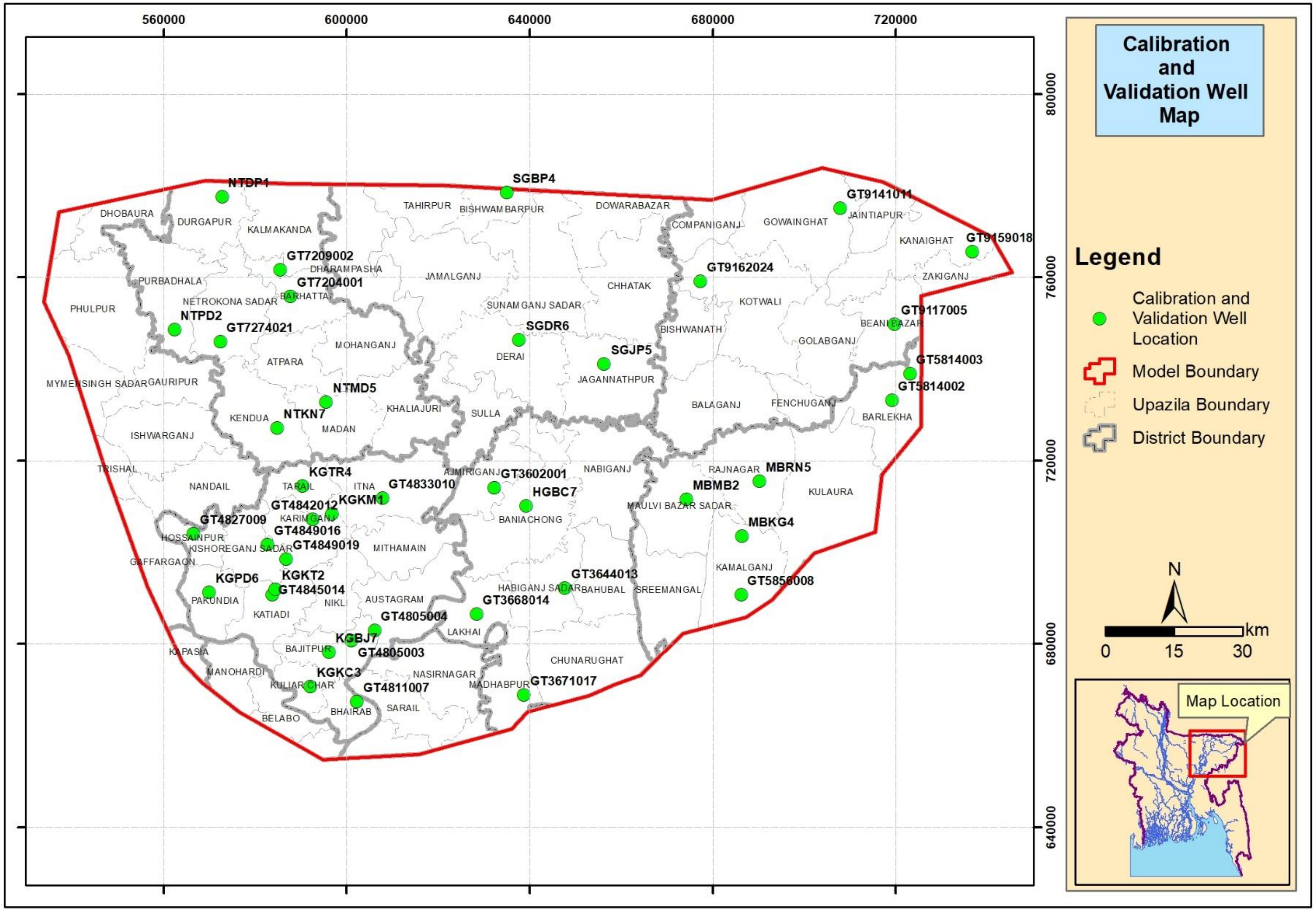
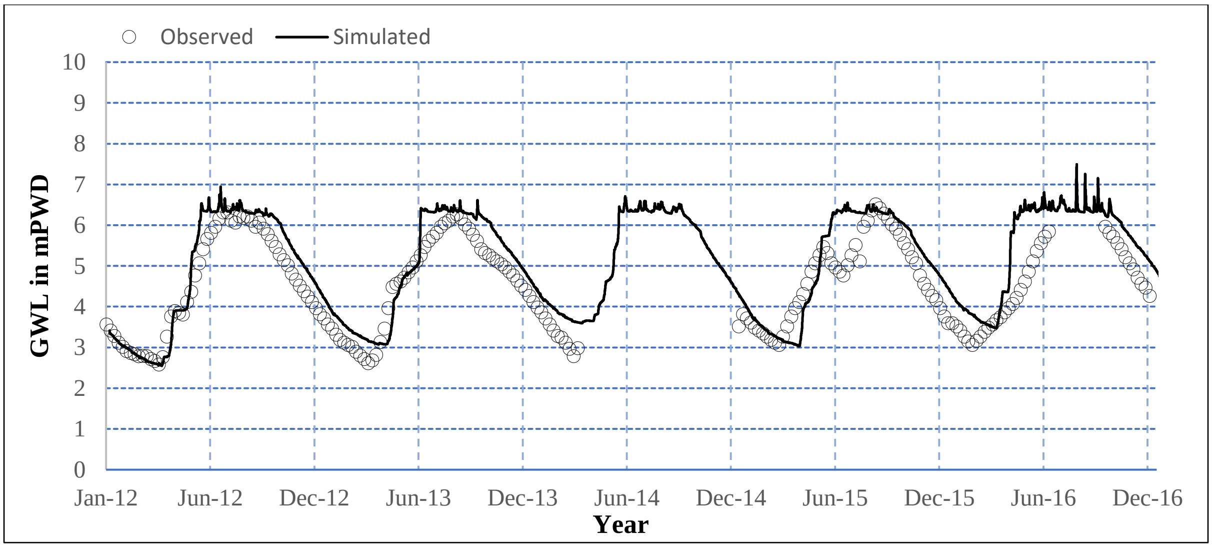


Figure 8-13: Location of Calibration and Valiadition Well



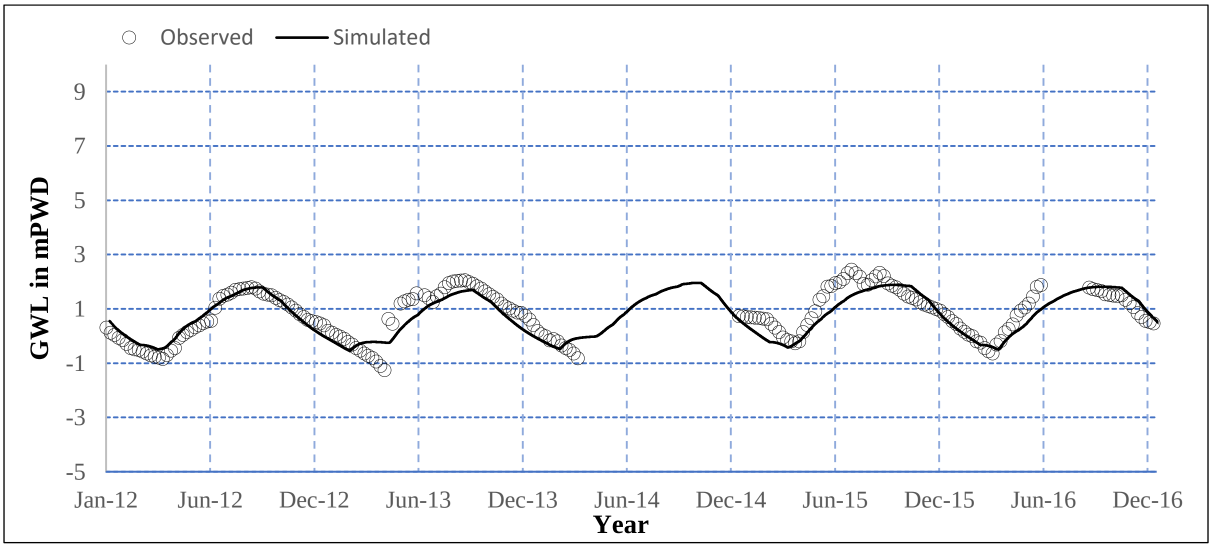
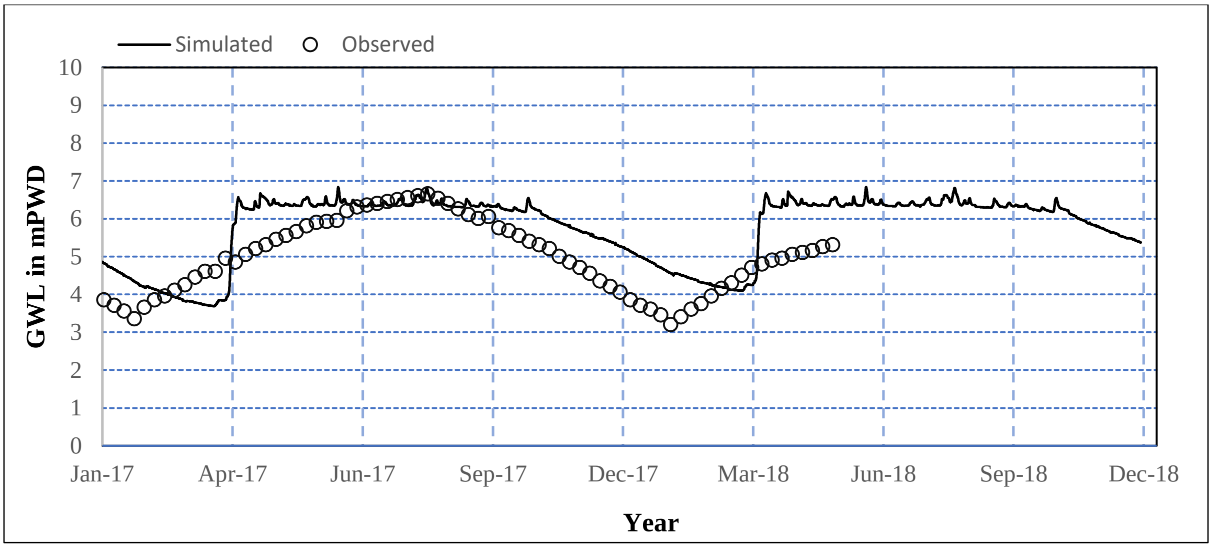


Figure 8-14: Sample Calibration Plot



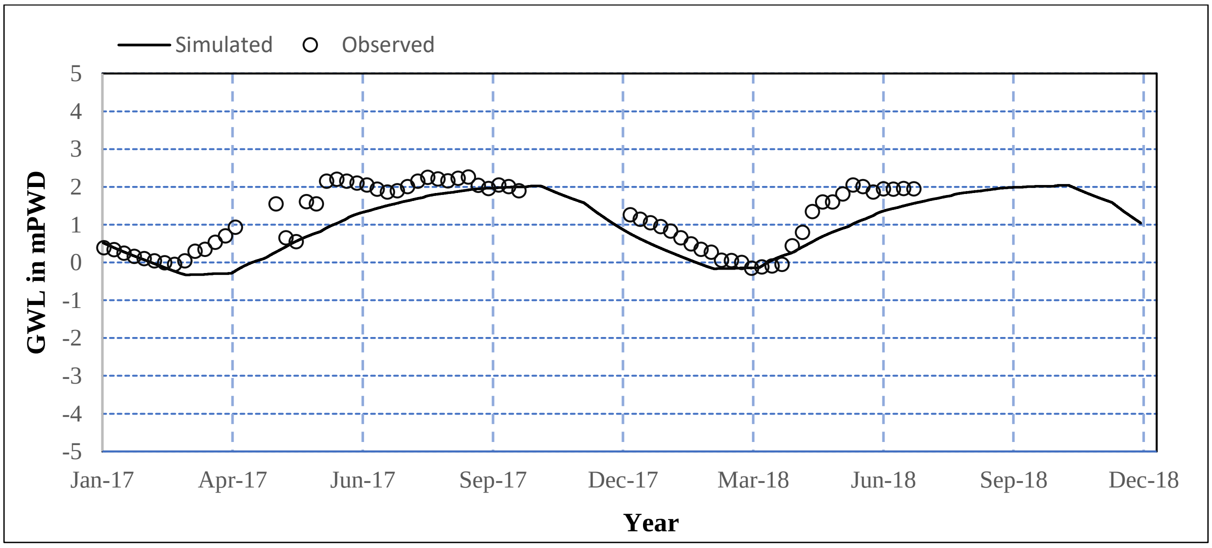


Figure 8-15: Sample Validation Plot

8.3.5 Sensitivity Analysis

Sensitivity analysis is a procedure for quantifying the impact on an aquifer's simulated response due to an incremental variation in a model parameter or a model stress. The purpose of sensitivity analysis is to identify those parameters which are most important in determining the aquifer behavior. First parameters have been ranked in order of importance, and then priorities have been set for focusing field investigations on key parameters to reduce model uncertainty. Sensitivity analysis has been carried out for the horizontal hydraulic conductivity, detention storage, boundary condition and subsurface drainage. The hydraulic conductivities have been multiplied by 2 and 0.5 times to its base condition where as detention storage has been considered as 50mm instead of 100mm as in base condition. The biasness due to the boundary has been checked by considering no flow boundary condition in all the layers. The sensitivity of the above mentioned parameters have been presented in Figure 8-16 to Figure 8-19 whereas the details are given in Volume-II, Appendix K.

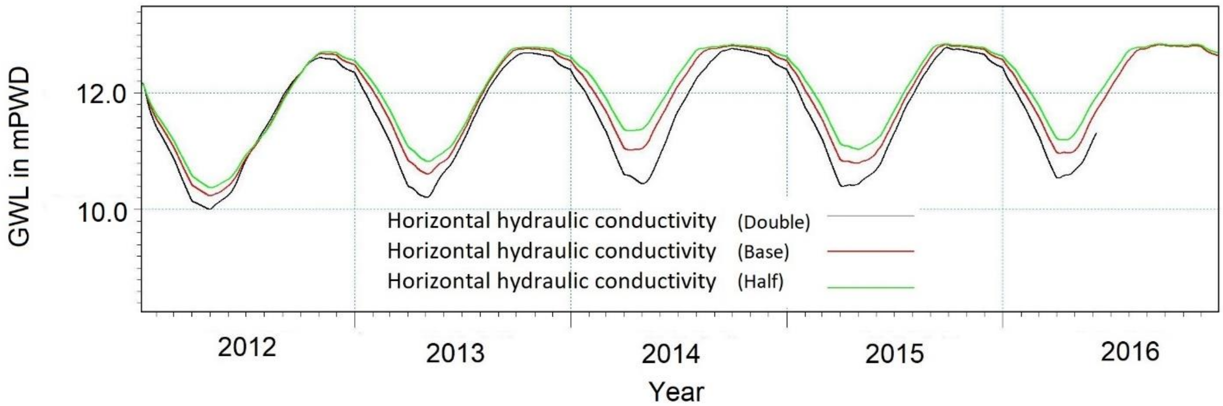


Figure 8-16: Sensitivity Analysis for Horizontal Conductivity (Double, Half and Base) of GT5814003

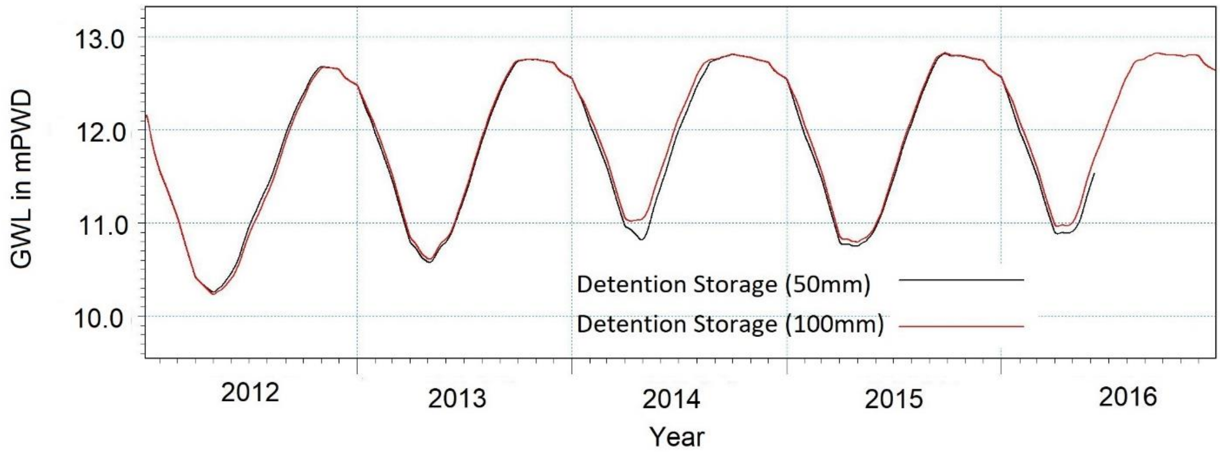


Figure 8-17: Sensitivity Analysis for Detention Storage (50mm and 100mm) of GT5814003

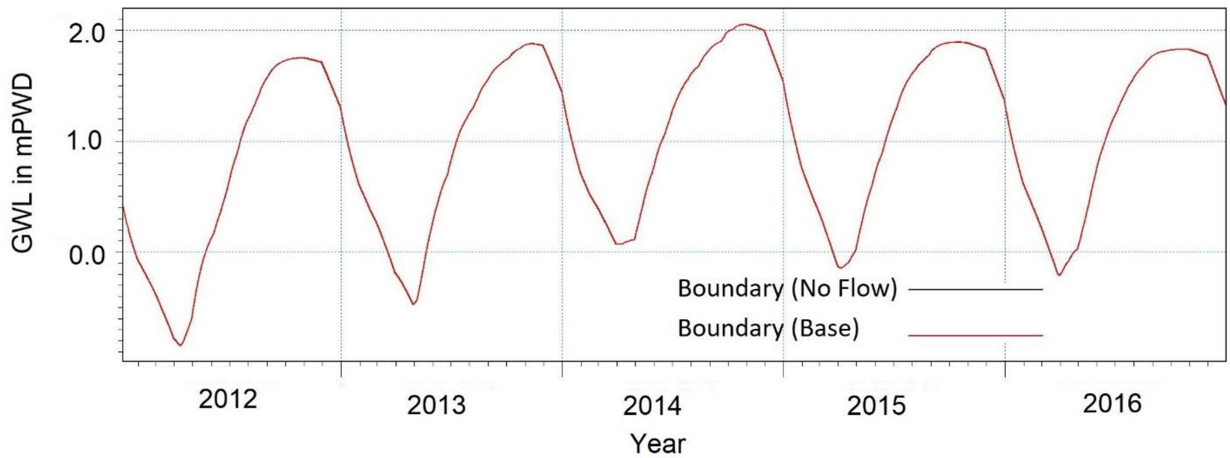


Figure 8-18: Sensitivity Analysis for Boundary Condition (No Flow and Base) of GT4805004

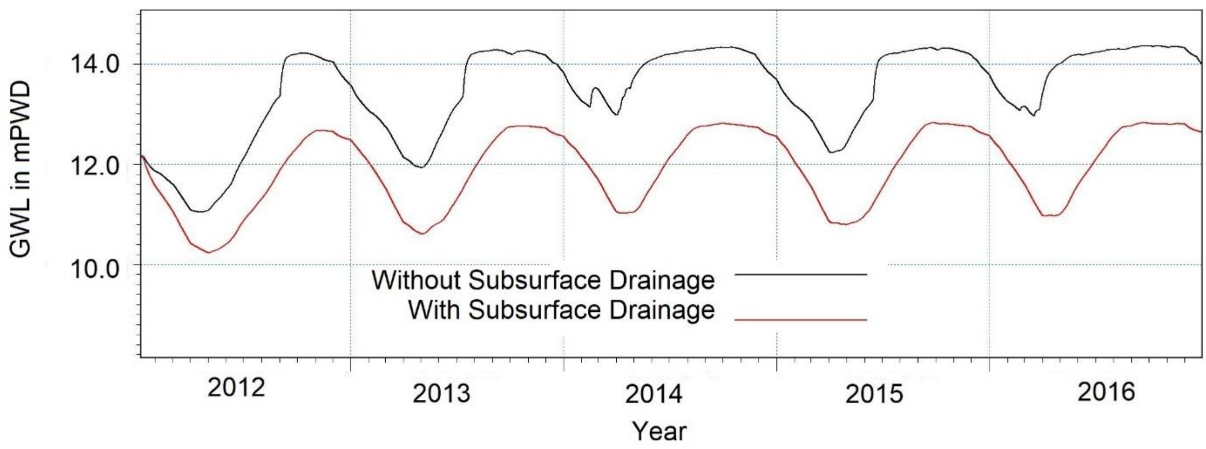


Figure 8-19: Sensitivity Analysis for Subsurface Drainage (with and without) of GT5814003

The sensitivity analysis shows that subsurface drainage has a great influence followed by horizontal hydraulic conductivity in the model calibration. The sensitivity plot also indicates that the detention storage and boundary does not have significant influence on model calibration. As the boundary condition does not have any influence on model simulation so it can be concluded the model is unbiased with respect to boundary condition.

8.3.6 Water Balance

In order to assess the recharge characteristics, water resources and component wise contribution, total water balance of the study area for the year 2012, 2013, 2014, 2015, 2016, 2017 and 2018 have been made considering all the physical processes in saturated and unsaturated zones and rivers systems in an integrated way. In general, water balance includes the hydrological components which come as inflow to or outflow from the system. The difference between inflow and outflow is the net storage change within the system. Water balance of the calibrated model is used to understand the overall recharge characteristics of the study area. Recharge means the replenishment of groundwater storage that has been depleted by the withdrawal of groundwater with the irrigation wells, and by the natural processes. The losses are due to outflow to rivers, canals, ditches, ponds, beels (depression areas) and other water bodies. The loss of water through evaporation from the water tables and transpiration by plants also attributes to depletion of groundwater storage. Recharge to groundwater depends on different physical, climatic and hydraulic properties related to soil and aquifers.

Year 2012

Water balance of the study area describing inflow and outflow for the period of January 01, 2012 to December 31, 2012 is graphically shown in Figure 8-20 while the same in tabular form is given in Table 8-3. It appears from the Table 8-3 that in unsaturated zone (UZ) a total of 2796 mm of water enters into the system mainly from rainfall and irrigation applied to the field from both groundwater and surface water sources while a total of 2791 mm of water goes out of the system mainly as evapotranspiration (ET), deep percolation from UZ to SZ and overland flow to river. The percentage of ET is about 28% of applied water (rainfall and irrigation application). The net flow from the UZ amounting to a total of 1965 mm enters into the SZ. In the saturated zone, a total of 1969 mm of water enters into the system mainly from UZ and 1948 mm goes out mainly as groundwater abstraction and drain flow to boundary, resulting to a positive change of storage of 21 mm. It appears from the water balance of river/aquifer interaction system that river receives a total of 17 mm of water mainly from overland flow to river and base flow, while it has a little contribution to aquifer. Thus, throughout the year, river system gains a significant amount of water. The net or actual recharge for the simulation period is 329 mm, calculated from the net recharge /discharge figures given in the Table 8-3.

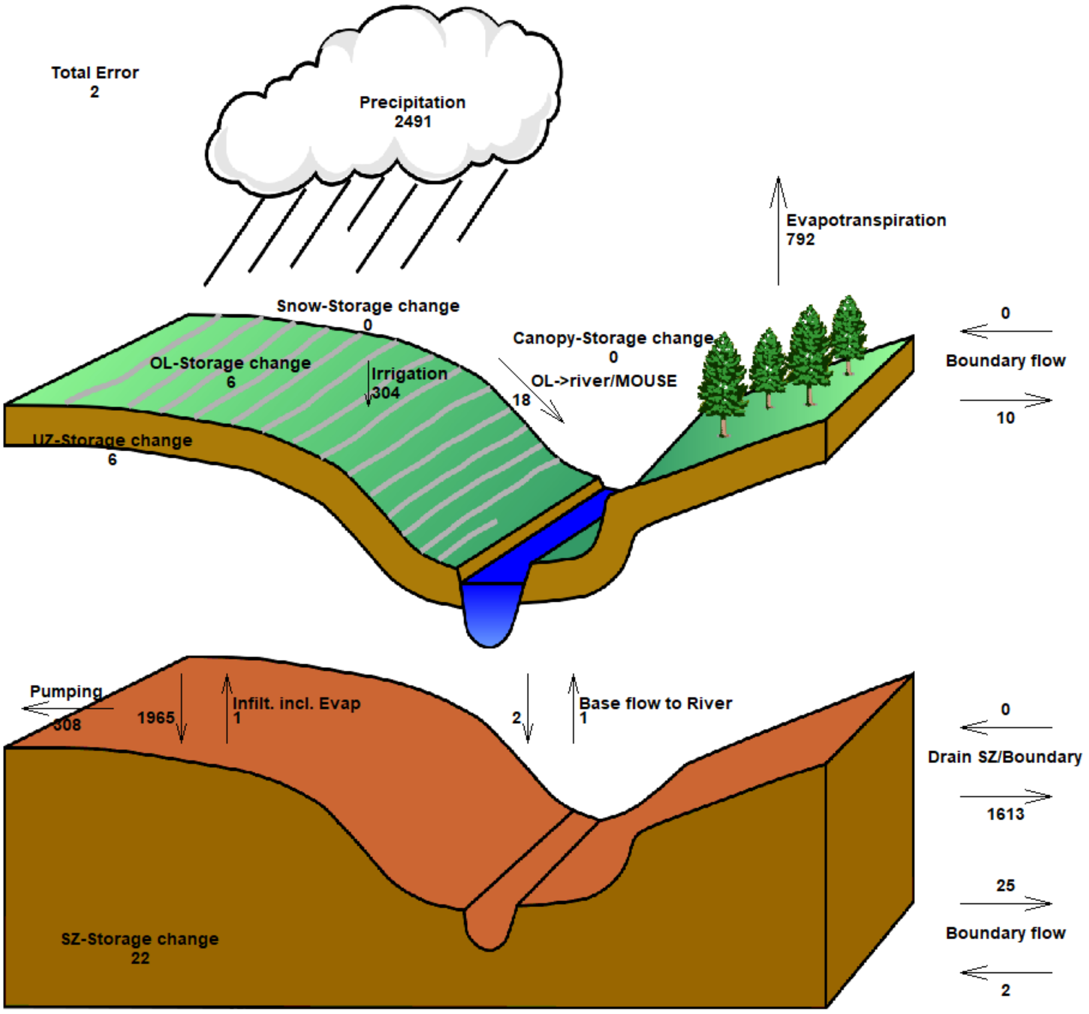


Figure 8-20: Water Balance (in mm) for the Period of 01st January 2012 to 31st December 2012

Table 8-3: Water Balance for the Period 01st January 2012 to 31st December 2012

Sl. No.	Components	Unsaturated Zone(UZ)		Saturated Zone (SZ)		River System		GW Recharge/Discharge	
		Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Recharge	Discharge
		(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
1	Rainfall	2491	—	—	—	—	—	—	—
2	Evapotranspiration(ET)	—	792	—	—	—	—	—	—
3	Abstraction	—	—	—	308	—	—	—	—
4	Irrigation	304	—	—	—	—	—	—	—
5	Capilary rise & ET from SZ to UZ	1	—	—	1	—	—	—	—
6	Deep Percolation from UZ to SZ	—	1965	1965	—	—	—	1964	0
7	Boundary Flow	0	10	2	25	—	—	0	23
8	Base Flow	—	—	2	1	1	2	1	0
9	Overland flow to river	—	18	—	—	18	—	—	—
10	Drain flow to river	—	—	0	0	0	0	0	0
11	OL storage Change	0	6	—	—	—	—	—	—
12	Drain SZ/Boundary	—	—	0	1613	—	—	0	1613
Total		**2796**	**2791**	**1969**	**1948**	**19**	**2**	**1965**	**1636**
Net Balance=Inflow-Outflow		**5**		**21**		**17**		**329**	
Explanation		**Inflow/Outflow of SZ**		**Change in Storage**		**River/Aquifer Interaction**		**Net Recharge /Discharge**	

Year 2013

Water balance of the study area describing inflow and outflow for the period of January 01, 2013 to December 31, 2013 is graphically shown in Figure 8-21 while the same in tabular form is given in Table 8-4. It appears from the Table 8-4 that in unsaturated zone (UZ) a total of 2704 mm of water enters into the system mainly from rainfall and irrigation applied to the field from both groundwater and surface water sources while a total of 2697 mm of water goes out of the system mainly as evapotranspiration (ET), deep percolation from UZ to SZ and overland flow to river. The percentage of ET is about 31% of applied water (rainfall and irrigation application). The net flow from the UZ amounting to a total of 1795 mm enters into the SZ. In the saturated zone, a total of 1797 mm of water enters into the system mainly from UZ and 1798 mm goes out mainly as groundwater abstraction and drain flow to boundary, resulting to a negative change of storage of 1 mm. It appears from the water balance of river/aquifer interaction system that river receives a total of 27 mm of water mainly from overland flow to river and base flow, while it has a little contribution to aquifer. Thus, throughout the year, river system gains a significant amount of water. The net or actual recharge for the simulation period is 330 mm, calculated from the net recharge /discharge figures given in the Table 8-4.

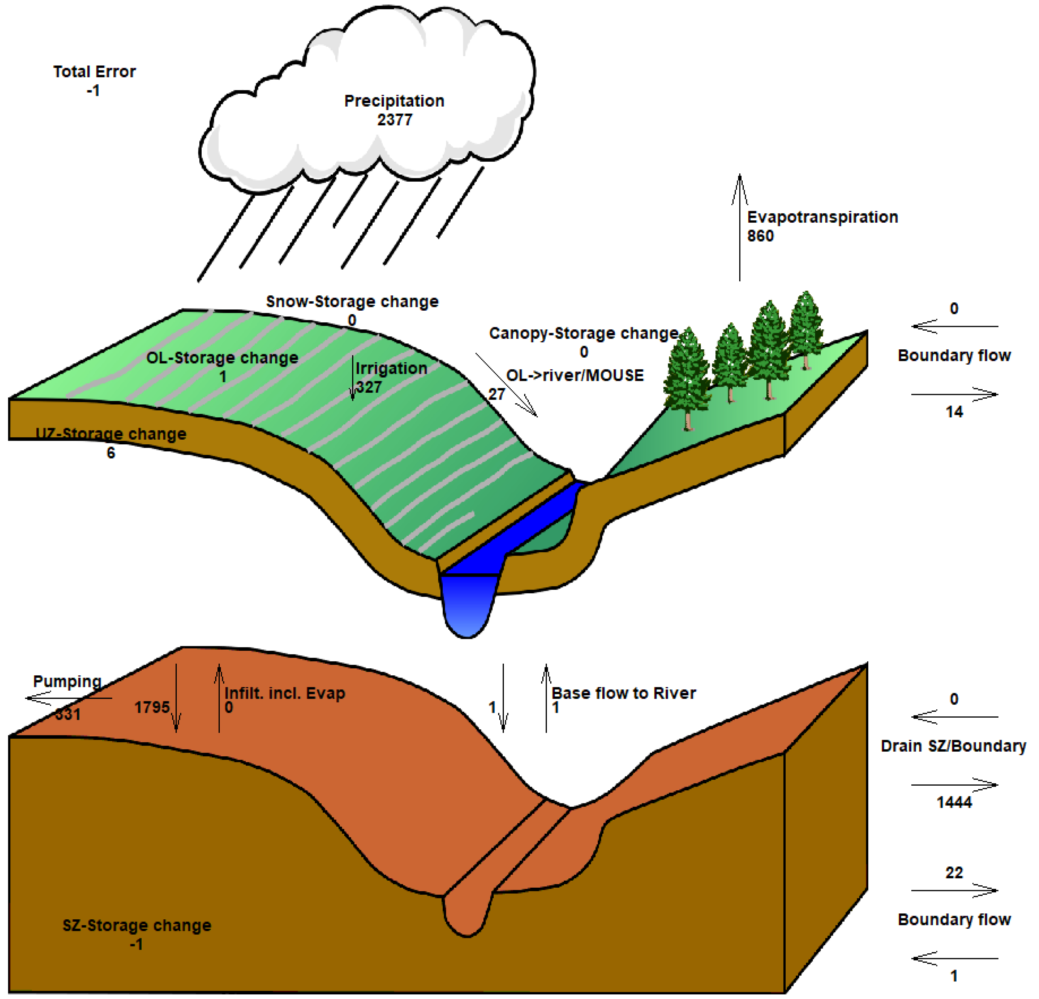


Figure 8-21: Water Balance (in mm) for the Period of 01st January 2013 to 31st December 2013

Table 8-4: Water Balance for the Period 01st January 2013 to 31st December 2013

Sl. No.	Components	Unsaturated Zone(UZ)		Saturated Zone (SZ)		River System		GW Recharge/Discharge	
		Inflow (mm)	Outflow (mm)	Inflow (mm)	Outflow (mm)	Inflow (mm)	Outflow (mm)	Recharge (mm)	Discharge (mm)
1	Rainfall	2377	—	—	—	—	—	—	—
2	Evapotranspiration(ET)	—	860	—	—	—	—	—	—
3	Abstraction	—	—	—	331	—	—	—	—
4	Irrigation	327	—	—	—	—	—	—	—
5	Capilary rise & ET from SZ to UZ	0	—	—	0	—	—	—	—
6	Deep Percolation from UZ to SZ	—	1795	1795	—	—	—	1795	0
7	Boundary Flow	0	14	1	22	—	—	0	21
8	Base Flow	—	—	1	1	1	1	0	0
9	Overland flow to river	—	27	—	—	27	—	—	—
10	Drain flow to river	—	—	0	0	0	0	0	0
11	OL storage Change	0	1	—	—	—	—	—	—
12	Drain SZ/Boundary	—	—	0	1444	—	—	0	1444
Total		**2704**	**2697**	**1797**	**1798**	**28**	**1**	**1795**	**1465**
Net Balance=Inflow-Outflow		**7**		**-1**		**27**		**330**	
Explanation		**Inflow/Outflow of SZ**		**Change in Storage**		**River/Aquifer Interaction**		**Net Recharge /Discharge**	

Year 2014

Water balance of the study area describing inflow and outflow for the period of January 01, 2014 to December 31, 2014 is graphically shown in Figure 8-22 while the same in tabular form is given in Table 8-5. It appears from the Table 8-5 that in unsaturated zone (UZ) a total of 2777 mm of water enters into the system mainly from rainfall and irrigation applied to the field from both groundwater and surface water sources while a total of 2774 mm of water goes out of the system mainly as evapotranspiration (ET), deep percolation from UZ to SZ and overland flow to river. The percentage of ET is about 21% of applied water (rainfall and irrigation application). The net flow from the UZ amounting to a total of 2151 mm enters into the SZ. In the saturated zone, a total of 2153 mm of water enters into the system mainly from UZ and 2149 mm goes out mainly as groundwater abstraction and drain flow to boundary, resulting to a positive change of storage of 4 mm. It appears from the water balance of river/aquifer interaction system that river receives a total of 27 mm of water mainly from overland flow to river and base flow, while it has a little contribution to aquifer. Thus, throughout the year, river system gains a significant amount of water. The net or actual recharge for the simulation period is 345 mm, calculated from the net recharge /discharge figures given in the Table 8-5.

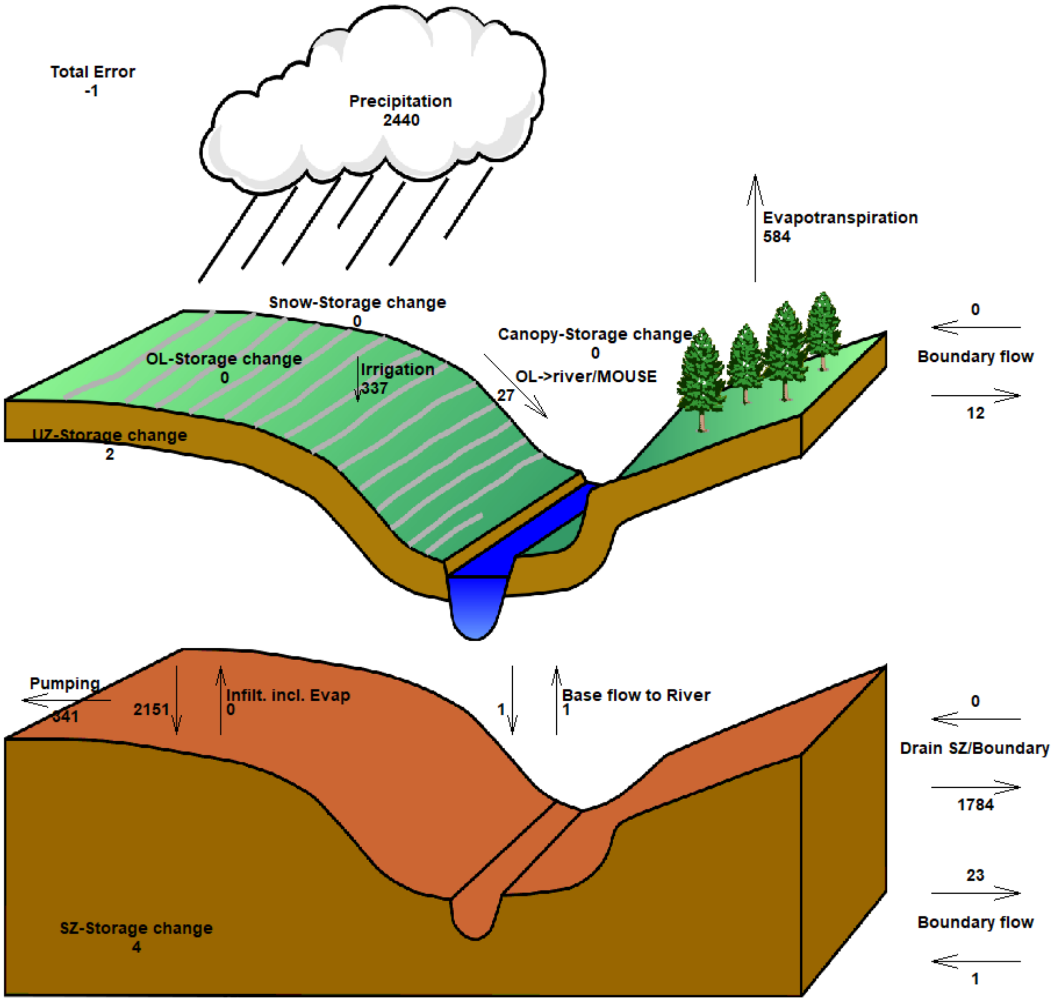


Figure 8-22: Water Balance (in mm) for the Period of 01st January 2014 to 31st December 2014

Table 8-5: Water Balance for the Period 01st January 2014 to 31st December 2014

Sl. No.	Components	Unsaturated Zone(UZ)		Saturated Zone (SZ)		River System		GW Recharge/Discharge	
		Inflow (mm)	Outflow (mm)	Inflow (mm)	Outflow (mm)	Inflow (mm)	Outflow (mm)	Recharge (mm)	Discharge (mm)
1	Rainfall	2440	—	—	—	—	—	—	—
2	Evapotranspiration(ET)	—	584	—	—	—	—	—	—
3	Abstraction	—	—	—	341	—	—	—	—
4	Irrigation	337	—	—	—	—	—	—	—
5	Capilary rise & ET from SZ to UZ	0	—	—	0	—	—	—	—
6	Deep Percolation from UZ to SZ	—	2151	2151	—	—	—	2151	0
7	Boundary Flow	0	12	1	23	—	—	0	22
8	Base Flow	—	—	1	1	1	1	0	0
9	Overland flow to river	—	27	—	—	27	—	—	—
10	Drain flow to river	—	—	0	0	0	0	0	0
11	OL storage Change	0	0	—	—	—	—	—	—
12	Drain SZ/Boundary	—	—	0	1784	—	—	0	1784
Total		**2777**	**2774**	**2153**	**2149**	**28**	**1**	**2151**	**1806**
Net Balance=Inflow-Outflow		**3**		**4**		**27**		**345**	
Explanation		**Inflow/Outflow of SZ**		**Change in Storage**		**River/Aquifer Interaction**		**Net Recharge /Discharge**	

Year 2015

Water balance of the study area describing inflow and outflow for the period of January 01, 2015 to December 31, 2015 is graphically shown in Figure 8-23 while the same in tabular form is given in Table 8-6. It appears from the Table 8-6 that in unsaturated zone (UZ) a total of 2888 mm of water enters into the system mainly from rainfall and irrigation applied to the field from both groundwater and surface water sources while a total of 2892 mm of water goes out of the system mainly as evapotranspiration (ET), deep percolation from UZ to SZ and overland flow to river. The percentage of ET is about 29% of applied water (rainfall and irrigation application). The net flow from the UZ amounting to a total of 2021 mm enters into the SZ. In the saturated zone, a total of 2023 mm of water enters into the system mainly from UZ and 2023 mm goes out mainly as groundwater abstraction and drain flow to boundary, resulting to no change of storage. It appears from the water balance of river/aquifer interaction system that river receives a total of 19 mm of water mainly from overland flow to river and base flow, while it has a little contribution to aquifer. Thus, throughout the year, river system gains a significant amount of water. The net or actual recharge for the simulation period is 349 mm, calculated from the net recharge /discharge figures given in the Table 8-6

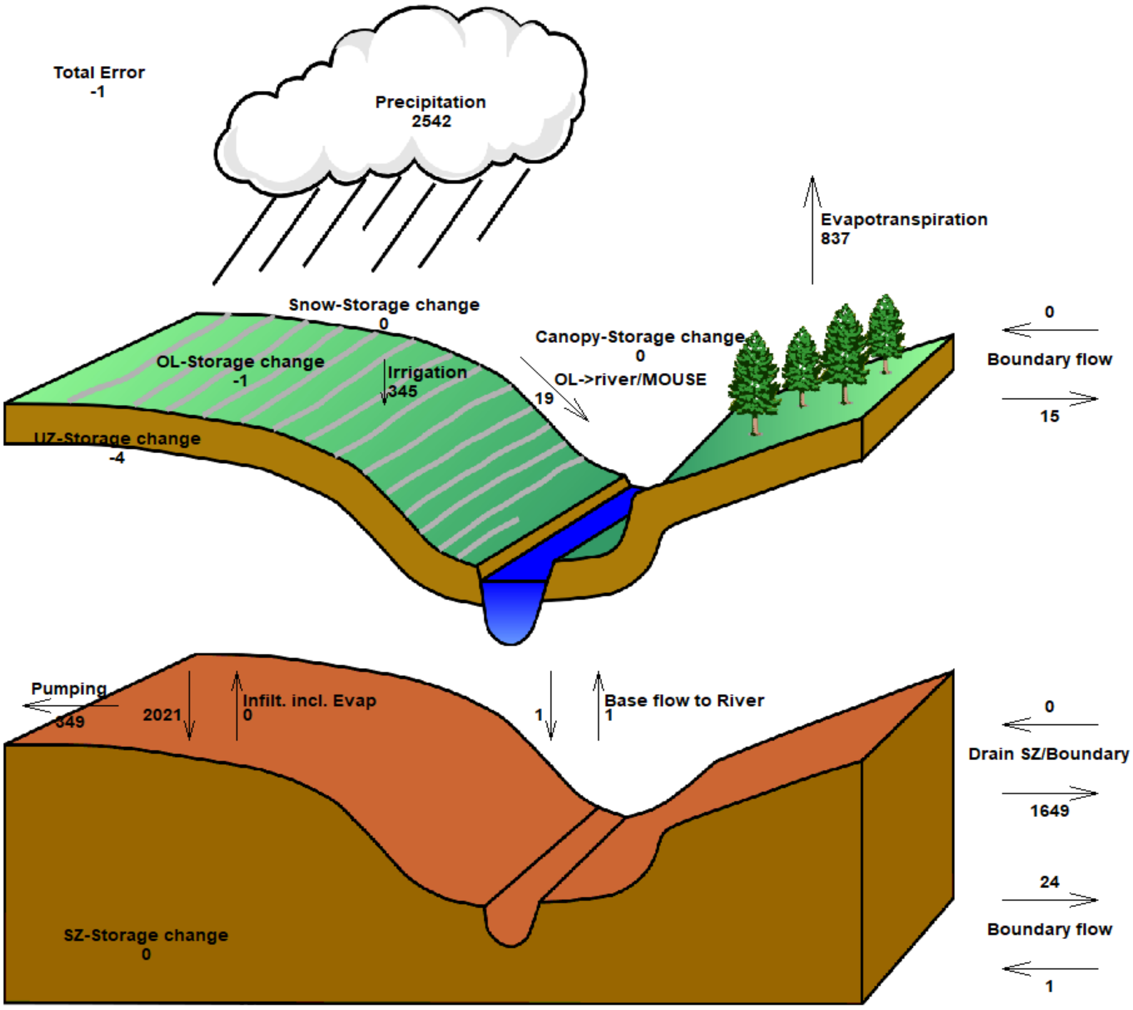


Figure 8-23: Water Balance (in mm) for the Period of 01st January 2015 to 31st December 2015

Table 8-6: Water Balance for the Period 01st January 2015 to 31st December 2015

Sl. No.	Components	Unsaturated Zone(UZ)		Saturated Zone (SZ)		River System		GW Recharge/Discharge	
		Inflow (mm)	Outflow (mm)	Inflow (mm)	Outflow (mm)	Inflow (mm)	Outflow (mm)	Recharge (mm)	Discharge (mm)
1	Rainfall	2542	—	—	—	—	—	—	—
2	Evapotranspiration(ET)	—	837	—	—	—	—	—	—
3	Abstraction	—	—	—	349	—	—	—	—
4	Irrigation	345	—	—	—	—	—	—	—
5	Capilary rise & ET from SZ to UZ	0	—	—	0	—	—	—	—
6	Deep Percolation from UZ to SZ	—	2021	2021	—	—	—	2021	0
7	Boundary Flow	0	15	1	24	—	—	0	23
8	Base Flow	—	—	1	1	1	1	0	0
9	Overland flow to river	—	19	—	—	19	—	—	—
10	Drain flow to river	—	—	0	0	0	0	0	0
11	OL storage Change	1	0	—	—	—	—	—	—
12	Drain SZ/Boundary	—	—	0	1649	—	—	0	1649
Total		**2888**	**2892**	**2023**	**2023**	**20**	**1**	**2021**	**1672**
Net Balance=Inflow-Outflow		**-4**		**0**		**19**		**349**	
Explanation		**Inflow/Outflow of SZ**		**Change in Storage**		**River/Aquifer Interaction**		**Net Recharge /Discharge**	

Year 2016

Water balance of the study area describing inflow and outflow for the period of January 01, 2016 to December 31, 2016 is graphically shown in Figure 8-24 while the same in tabular form is given in Table 8-7. It appears from the Table 8-7 that in unsaturated zone (UZ) a total of 3004 mm of water enters into the system mainly from rainfall and irrigation applied to the field from both groundwater and surface water sources while a total of 2994 mm of water goes out of the system mainly as evapotranspiration (ET), deep percolation from UZ to SZ and overland flow to river. The percentage of ET is about 28% of applied water (rainfall and irrigation application). The net flow from the UZ amounting to a total of 2109 mm enters into the SZ. In the saturated zone, a total of 2111 mm of water enters into the system mainly from UZ and 2104 mm goes out mainly as groundwater abstraction and drain flow to boundary, resulting to a positive change of storage of 7 mm. It appears from the water balance of river/aquifer interaction system that river receives a total of 22 mm of water mainly from overland flow to river and base flow, while it has a little contribution to aquifer. Thus, throughout the year, river system gains a significant amount of water. The net or actual recharge for the simulation period is 358 mm, calculated from the net recharge /discharge figures given in the Table 8-7.

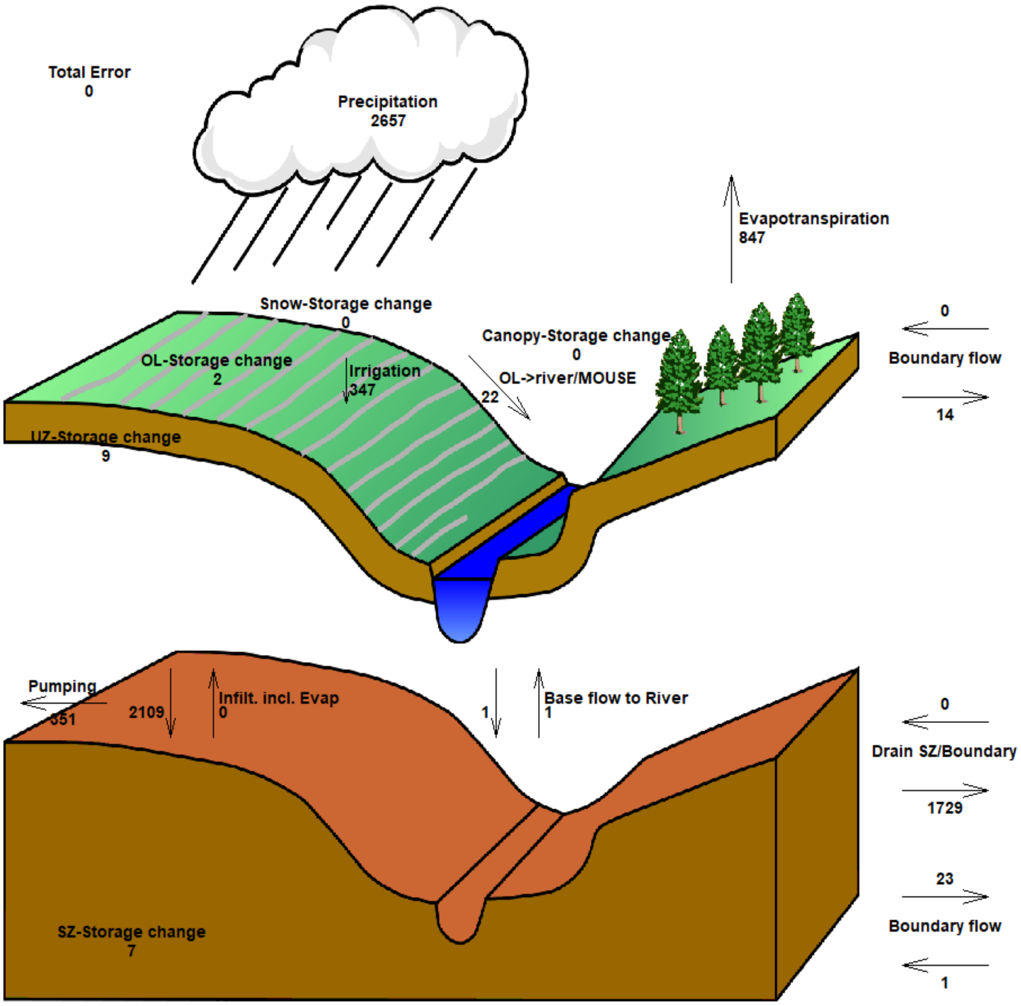


Figure 8-24: Water Balance (in mm) for the Period of 01st January 2016 to 31st December 2016

Table 8-7: Water Balance for the Period 01st January 2016 to 31st December 2016

Sl. No.	Components	Unsaturated Zone(UZ)		Saturated Zone (SZ)		River System		GW Recharge/Discharge	
		Inflow (mm)	Outflow (mm)	Inflow (mm)	Outflow (mm)	Inflow (mm)	Outflow (mm)	Recharge (mm)	Discharge (mm)
1	Rainfall	2657	—	—	—	—	—	—	—
2	Evapotranspiration(ET)	—	847	—	—	—	—	—	—
3	Abstraction	—	—	—	351	—	—	—	—
4	Irrigation	347	—	—	—	—	—	—	—
5	Capilary rise & ET from SZ to UZ	0	—	—	0	—	—	—	—
6	Deep Percolation from UZ to SZ	—	2109	2109	—	—	—	2109	0
7	Boundary Flow	0	14	1	23	—	—	0	22
8	Base Flow	—	—	1	1	1	1	0	0
9	Overland flow to river	—	22	—	—	22	—	—	—
10	Drain flow to river	—	—	0	0	0	0	0	0
11	OL storage Change	0	2	—	—	—	—	—	—
12	Drain SZ/Boundary	—	—	0	1729	—	—	0	1729
Total		**3004**	**2994**	**2111**	**2104**	**23**	**1**	**2109**	**1751**
Net Balance=Inflow-Outflow		**10**		**7**		**22**		**358**	
Explanation		**Inflow/Outflow of SZ**		**Change in Storage**		**River/Aquifer Interaction**		**Net Recharge /Discharge**	

Year 2017

Water balance of the study area describing inflow and outflow for the period of January 01, 2017 to December 31, 2017 is graphically shown in Figure 8-25 while the same in tabular form is given in Table 8-8. It appears from the Table 8-8 that in unsaturated zone (UZ) a total of 4325 mm of water enters into the system mainly from rainfall and irrigation applied to the field from both groundwater and surface water sources while a total of 4304 mm of water goes out of the system mainly as evapotranspiration (ET), deep percolation from UZ to SZ and overland flow to river. The percentage of ET is about 20% of applied water (rainfall and irrigation application). The net flow from the UZ amounting to a total of 3333 mm enters into the SZ. In the saturated zone, a total of 3336 mm of water enters into the system mainly from UZ and 3304 mm goes out mainly as groundwater abstraction and drain flow to boundary, resulting to a positive change of storage of 32 mm. It appears from the water balance of river/aquifer interaction system that river receives a total of 55 mm of water mainly from overland flow to river and base flow, while it has a little contribution to aquifer. Thus, throughout the year, river system gains a significant amount of water. The net or actual recharge for the simulation period is 360 mm, calculated from the net recharge /discharge figures given in the Table 8-8.

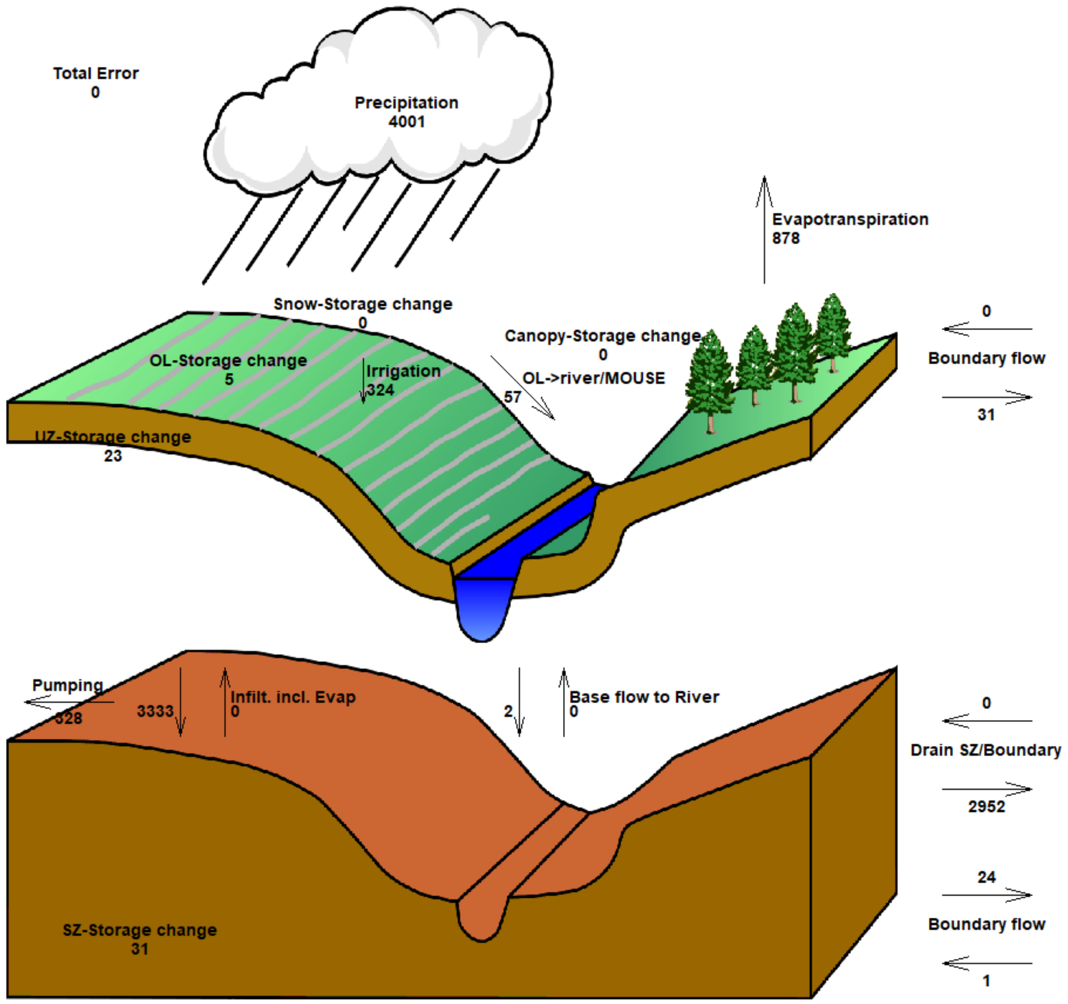


Figure 8-25: Water Balance (in mm) for the Period of 01st January 2017 to 31st December 2017

Table 8-8: Water Balance for the Period 01st January 2017 to 31st December 2017

Sl. No.	Components	Unsaturated Zone(UZ)		Saturated Zone (SZ)		River System		GW Recharge/Discharge	
		Inflow (mm)	Outflow (mm)	Inflow (mm)	Outflow (mm)	Inflow (mm)	Outflow (mm)	Recharge (mm)	Discharge (mm)
1	Rainfall	4001	—	—	—	—	—	—	—
2	Evapotranspiration(ET)	—	878	—	—	—	—	—	—
3	Abstraction	—	—	—	328	—	—	—	—
4	Irrigation	324	—	—	—	—	—	—	—
5	Capilary rise & ET from SZ to UZ	0	—	—	0	—	—	—	—
6	Deep Percolation from UZ to SZ	—	3333	3333	—	—	—	3333	0
7	Boundary Flow	0	31	1	24	—	—	0	23
8	Base Flow	—	—	2	0	0	2	2	0
9	Overland flow to river	—	57	—	—	57	—	—	—
10	Drain flow to river	—	—	0	0	0	0	0	0
11	OL storage Change	0	5	—	—	—	—	—	—
12	Drain SZ/Boundary	—	—	0	2952	—	—	0	2952
Total		**4325**	**4304**	**3336**	**3304**	**57**	**2**	**3335**	**2975**
Net Balance=Inflow-Outflow		**21**		**32**		**55**		**360**	
Explanation		**Inflow/Outflow of SZ**		**Change in Storage**		**River/Aquifer Interaction**		**Net Recharge /Discharge**	

Year 2018

Water balance of the study area describing inflow and outflow for the period of January 01, 2018 to December 31, 2018 is graphically shown in Figure 8-26 while the same in tabular form is given in Table 8-9. It appears from the Table 8-9 that in unsaturated zone (UZ) a total of 4324 mm of water enters into the system mainly from rainfall and irrigation applied to the field from both groundwater and surface water sources while a total of 4318 mm of water goes out of the system mainly as evapotranspiration (ET), deep percolation from UZ to SZ and overland flow to river. The percentage of ET is about 20% of applied water (rainfall and irrigation application). The net flow from the UZ amounting to a total of 3341 mm enters into the SZ. In the saturated zone, a total of 3343 mm of water enters into the system mainly from UZ and 3327 mm goes out mainly as groundwater abstraction and drain flow to boundary, resulting to a positive change of storage of 16 mm. It appears from the water balance of river/aquifer interaction system that river receives a total of 60 mm of water mainly from overland flow to river and base flow, while it has a little contribution to aquifer. Thus, throughout the year, river system gains a significant amount of water. The net or actual recharge for the simulation period is 343 mm, calculated from the net recharge /discharge figures given in the Table 8-9.

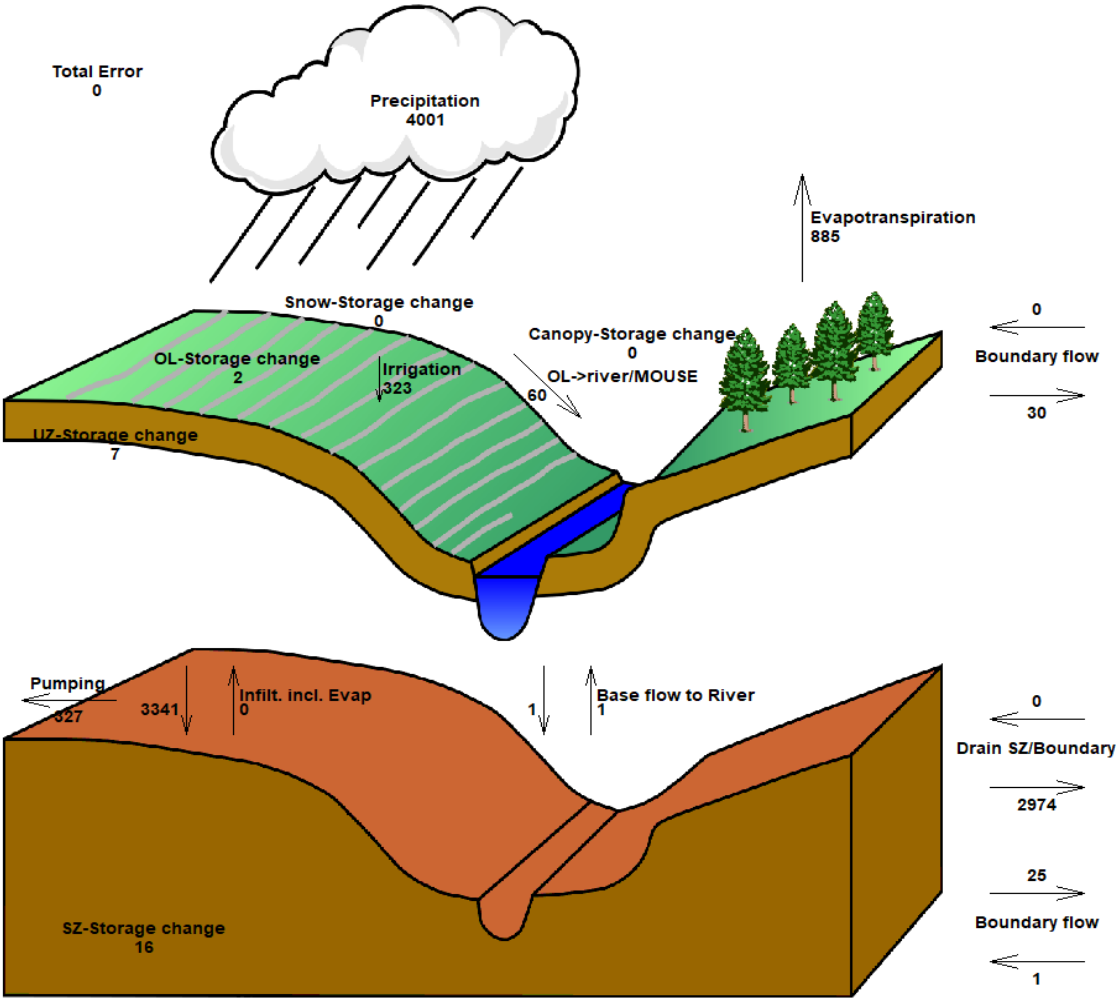


Figure 8-26: Water Balance (in mm) for the Period of 01st January 2018 to 31st December 2018

Table 8-9: Water Balance for the Period 01st January 2018 to 31st December 2018

Sl. No.	Components	Unsaturated Zone(UZ)		Saturated Zone (SZ)		River System		GW Recharge/Discharge	
		Inflow (mm)	Outflow (mm)	Inflow (mm)	Outflow (mm)	Inflow (mm)	Outflow (mm)	Recharge (mm)	Discharge (mm)
1	Rainfall	4001	—	—	—	—	—	—	—
2	Evapotranspiration(ET)	—	885	—	—	—	—	—	—
3	Abstraction	—	—	—	327	—	—	—	—
4	Irrigation	323	—	—	—	—	—	—	—
5	Capilary rise & ET from SZ to UZ	0	—	—	0	—	—	—	—
6	Deep Percolation from UZ to SZ	—	3341	3341	—	—	—	3341	0
7	Boundary Flow	0	30	1	25	—	—	0	24
8	Base Flow	—	—	1	1	1	1	0	0
9	Overland flow to river	—	60	—	—	60	—	—	—
10	Drain flow to river	—	—	0	0	0	0	0	0
11	OL storage Change	0	2	—	—	—	—	—	—
12	Drain SZ/Boundary	—	—	0	2974	—	—	0	2974
Total		**4324**	**4318**	**3343**	**3327**	**61**	**1**	**3341**	**2998**
Net Balance=Inflow-Outflow		**6**		**16**		**60**		**343**	
Explanation		**Inflow/Outflow of SZ**		**Change in Storage**		**River/Aquifer Interaction**		**Net Recharge /Discharge**	

9 PROSPECT OF FUTURE SURFACE WATER DEVELOPMENT

9.1 General

There is a possibility of development of surface water irrigation by utilizing available river water in the study area in two ways: (a) by constructing rubber dam / water control structure to raise and retain perennial water supply and lifting by LLPs and (b) by reviving / rehabilitating of defunct LLP projects.

9.2 Assessment of Surface Water Resources

The calibrated and verified model has been applied for assessment of the surface water resources. Model simulation has been carried out for the design year to assess the dry period water availability in different rivers of the study area as the historical data are not available at desired sites.

9.2.1 Selection of Design Year

The statistical analysis shows that 37-years average annual volume of flow at Bhairabbazar is computed around 155.27 billion m^3 as shown in Table 9-1. The same is computed around 157.91 billion m^3 for hydrological event of Average-Year return period as shown in Table 9-2. It is observed that annual flow volume at Bhairabbazar in year 2000 is computed around 165.5 billion m^3, which is very close to that computed for Average-Year return period. Thus, hydrological event of year 2000 has been taken as the Average Hydrological Event for the region.

Table 9-1: Average Annual Flow Volume (billion m^^{3}) at Bhairab Bazar

Year	Average Annual Flow Volume (billion m$^{\wedge 3}$)	Year	Average Annual Flow Volume (billion m$^{\wedge 3}$)
1980	153.50	2000	165.51
1981	155.64	2001	131.09
1982	152.80	2002	153.17
1983	191.98	2003	139.72
1984	178.78	2004	181.72
1985	154.94	2005	145.63
1986	129.64	2006	120.20
1987	165.15	2007	176.30
1988	211.88	2008	142.19
1989	182.94	2009	117.27
1990	177.25	2010	189.46
1991	193.48	2011	153.35
1992	119.18	2012	173.31
1993	187.15	2013	144.30
1994	113.41	2014	140.14
1995	144.76	2015	166.63
1996	126.83	2016	129.46

Year	Average Annual Flow Volume (billion m^{3})	Year	Average Annual Flow Volume (billion m^{3})
1997	130.51	2017	171.70
1998	145.08		
1999	144.08		

Table 9-2: Annual Flow Volume at Bhairab Bazar for Hydrological event of Different Return Periods.

Return Period	3 Parameter Log Normal Distribution	Pearson Distribution	2 Parameter Log Normal Distribution	Gumbel's Distribution
2	153.57	154.27	153.47	151.36
2.33	157.91	158.60	157.73	155.80
5	175.11	175.30	174.64	175.06
10	187.56	186.93	186.86	190.75
25	201.87	199.85	200.85	210.58
50	211.77	208.48	210.45	225.28
100	221.15	216.45	219.47	239.88

9.2.2 Available Surface Water Resources

Model simulation has been carried out for the year 2000 to assess the dry period water availability in different rivers of the study area. Table 9-3 shows the dry period volume of water to be irrigated from different Khals of the study area. Sufficient resources are available in Dhanu, Baulai, Ghorautra rivers for round the year irrigation while limited resources are available in Saidulbaruni, Mogra, Kangsha rivers in dry period but sufficient water is available in October for supplemental irrigation. Though water is available in major rivers, conservation of resources inside the haor areas by controlling major internal khals is essential for dry season irrigation. Available surface water resources in the selected khals after controlling by water control structure is given Table 9-3.

Table 9-3: Surface Water Resources in (m^{3}) for Dry Season Irrigation.

District	Haor Name	Khal Name	Length of Khal (Km)	Volume (m^{3}) of Water to be used for Irrigated
Kishoreganj	Boro Haor	Digha Nadi	6	504500
		Baniajan Gang	7	122000
		Singua Khal	12	178000
	Noapara Haor	Pania Khal	3	341000
	Naogaon Haor	Khaiyar Khal	7	351000
		Markhali Khal	5	900000
		Nandir Khal	6	299000
	Dakhshiner Haor	Shankir Khal	6	242500
	Sunair Haor	Suti Khal	16	1590000
	Chatal Haor	Noaparakhali	1.8	324000
Netrokona	Khaliajuri-4	Putia khal	5	165000
	Khaliajuri-2	Naiyari Khal	8	889000
Sunamganj	Jaliar Haor	Rauli Khal	6	71500

District	Haor Name	Khal Name	Length of Khal (Km)	Volume ($m^{\wedge 3}$) of Water to be used for Irrigated
		Dora Nadi	8	42500
	Dhakua Haor	Muktakhai Khal	12	670000
	Dharmapasha Haor	Manai Khal	16	680000
		Dahar gang	7	132500
		Agunia Khal	8	221500
Moulvibazar	Hail Haor	Lunglabijna	24	2145000
	Kawardighi Haor	Lash Gang	12	525000
		Sampad Khal	9	630000
		Udna Gang	12	531000
Habiganj	Mokhar Haor	Medhabeel Khal	5	304500
		Old kushiyara-2	18	948000
		Rajendrapur Khal	5	118500
	Gangajuri	Teli Khal	6	214000
		Shashya Nadi	10	118000

9.3 Proposed Sites and Mode of Irrigation Development

To increase the extent of surface water irrigation in the study area, rubber dam/water control structure option was formulated primarily; potential sites have been identified at this stage. The main goal of this option was to store surface water for irrigation in major internal khals of haors lying Kishoreganj, Netrokona, Sunamganj, Moulvibazar, Habiganj districts. Operation of control structure of khals in post monsoon (October-March) without creating any drainage problem in monsoon. The locations of rubber dams/ water control structure (WCS) are given in Table 9-4 and Figure 9-1.

Table 9-4: Locations of Rubber Dams / Water Control Structures in Different Rivers

SL	Khal Name	Location	Chainage (Km)	Type of Structure	Remarks
1	Digha Nadi	Nikli	2.4	Water Control Structure	Proposed
2	Baniajan Gang	Karpasha, Nikli	0.1	Water Control Structure	Proposed
3	Pania Khal	Dampara, Nikli	0.1	Water Control Structure	Proposed
4	Khaiyar Khal	Mithamain	0.2	Water Control Structure	Proposed
5	Markhali Khal	Singpur, Nikli	0.15	Water Control Structure	Proposed
6	Shankir Khal	Charigram, Itna	0.1	Water Control Structure	Proposed
7	Suti Khal	Sailahati, Trail	2.5	Water Control Structure	Proposed
8	Noaparakhali	Raituti, Itna	0.1	Water Control Structure	Proposed
9	Putia Khal	Gazipur, Khaliajuri	0.1	Water Control Structure	Existing
10	Naiyari Khal	Khaliajuri	0.1	Water Control Structure	Existing
11	Rauli Khal	Jawa, Chatak	0.1	Water Control Structure	Proposed
12	Dora Nadi	Dolar Bazar	0.1	Water Control Structure	Proposed
13	Muktakhai Khal	Akhtarpara	0.1	Water Control Structure	Proposed
14	Manai Khal	Sawarsshstipur	0.1	Water Control Structure	Proposed
15	Agunia Khal	Bharatpur	0.1	Water Control Structure	Proposed
16	Lunglabijna	Shomeswarganj Bazar	58	Water Control Structure	Proposed

SL	Khal Name	Location	Chainage (Km)	Type of Structure	Remarks
17	Lash Gang	Manumukh Bazar	0.1	Water Control Structure	Proposed
18	Medhabeel Khal	Mashakali	0.1	Water Control Structure	Proposed
19	Old Kushiyara-2	Milon Bazar	3	Water Control Structure	Proposed
20	Teli Khal	Panchparia	0.1	Water Control Structure	Existing
21	Shashya Nadi	Gurua	0.1	Water Control Structure	Existing

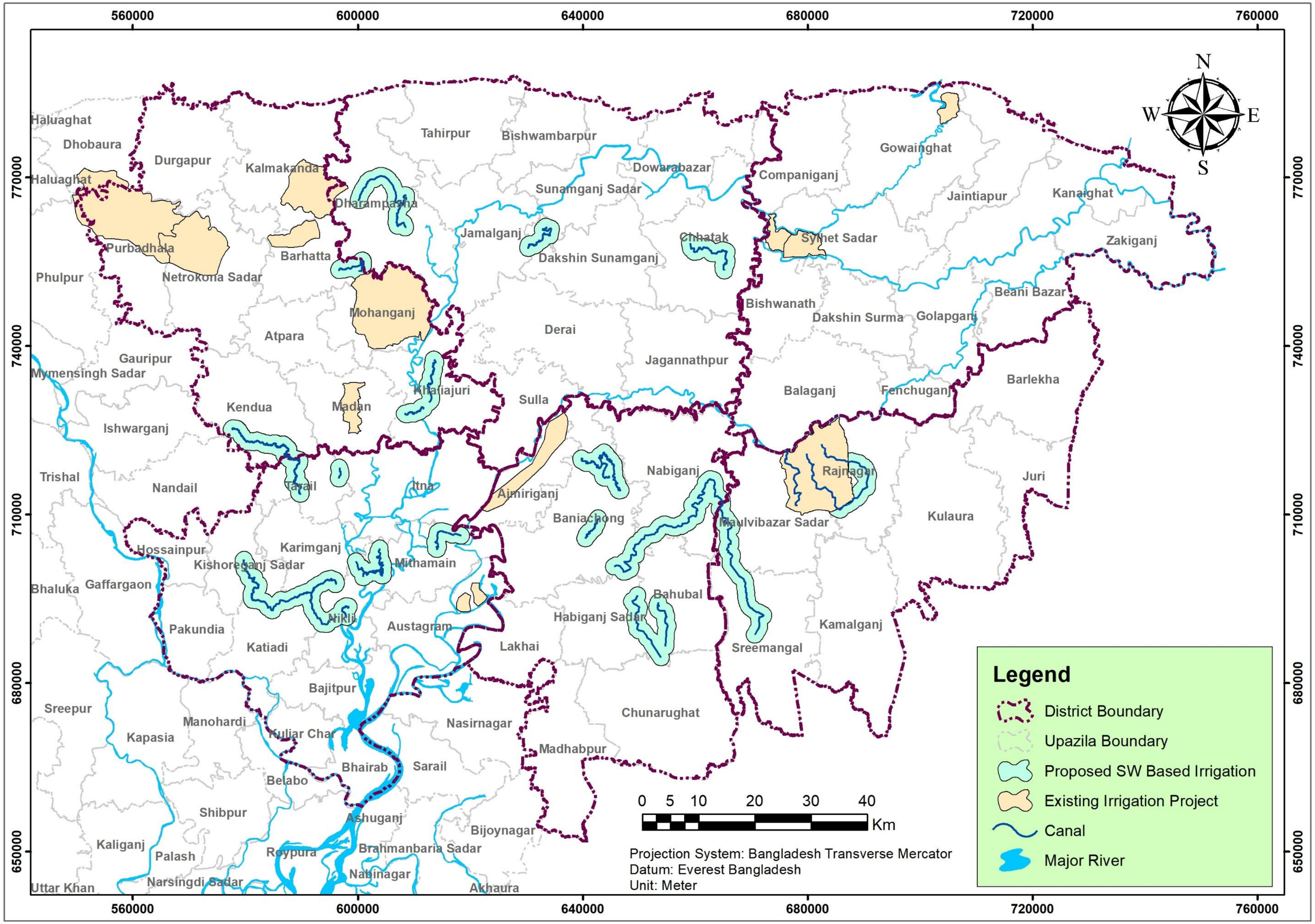


Figure 9-1: Zoning Map for Future Surface Water Irrigation Expasion

Model simulation has been carried out incorporating a water control structures for the year 2000 in NERM. Long Profile from model result for Shankir Khal of Dakhshiner Haor has been shown in Figure 9-2 where comparison of water level due to water control structure in riverside and project side has been shown in Figure 9-3. From the study it revealed that water can be stored at the upstream of control structure with no adverse effect at the downstream. In this option water level is increased from existing situation up to 6.00 km from u/s of Water Control Structure location for Shankir Khal.

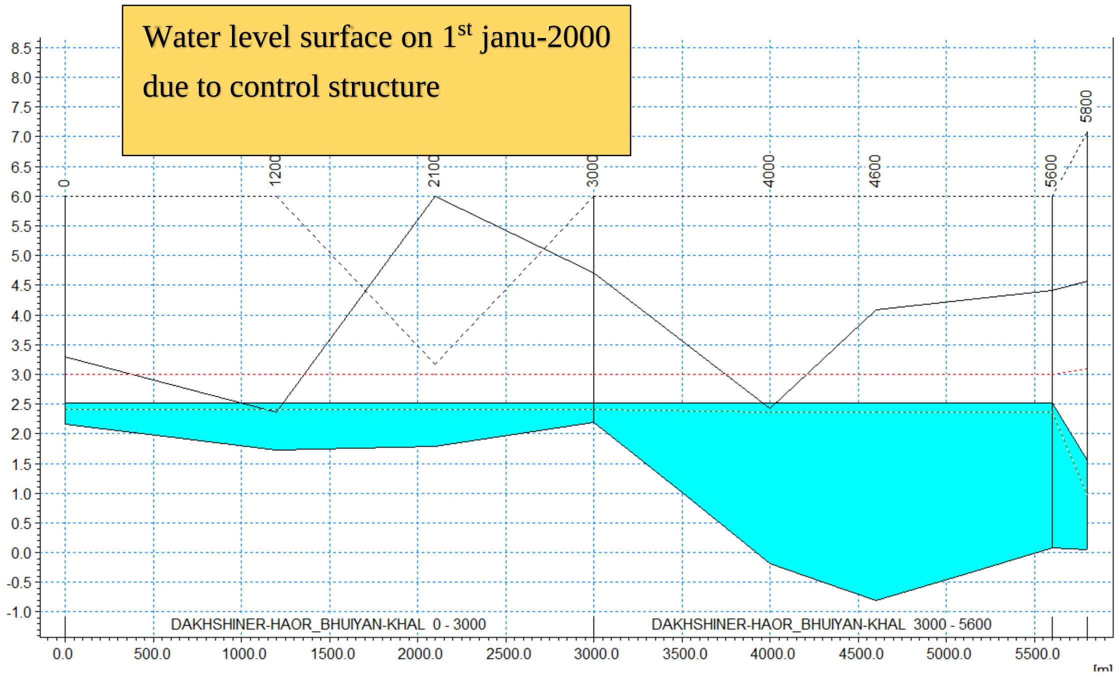


Figure 9-2: Long Profile of Water Level along Shankir Khal for Water Control Structure Option

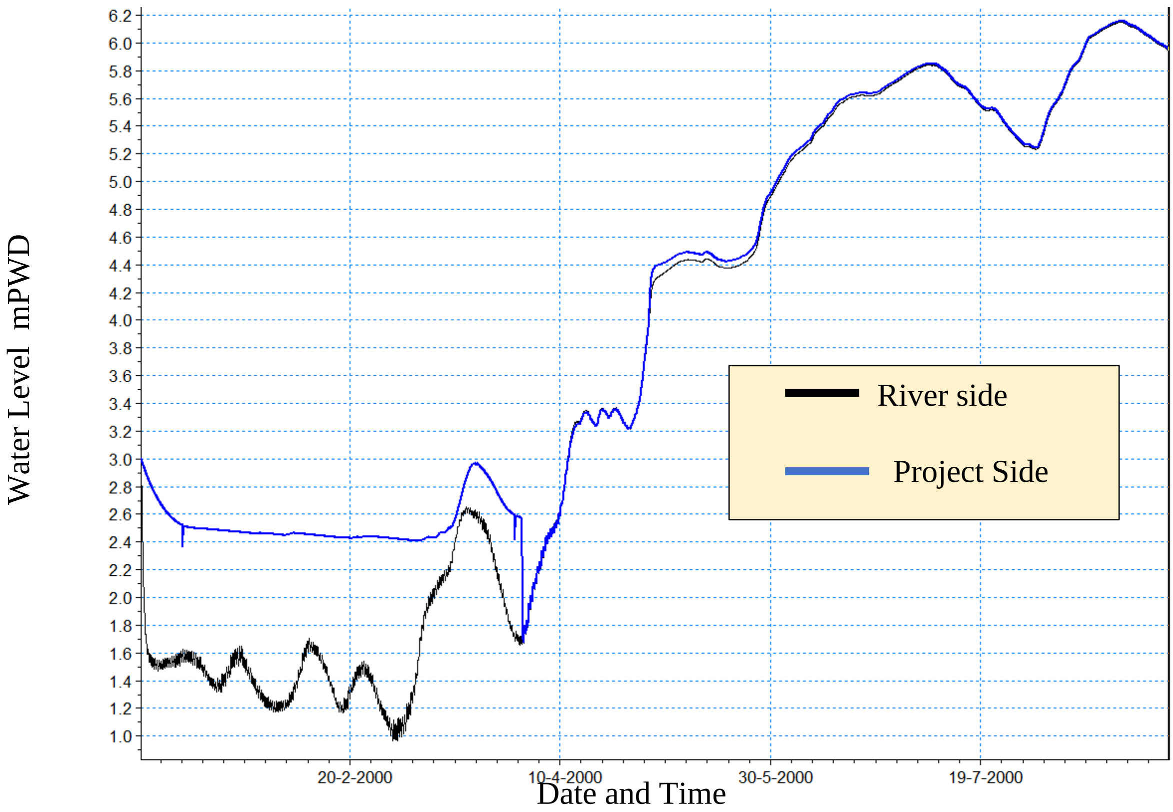


Figure 9-3: Water Level Comparison between Riverside and Projectside for Structure Condition.

9.4 Area under Surface Water Development

Available surface water resources in different rivers/khals in haor areas have been furnished in Table 9-3. For sustainability of a river, it is not feasible to utilize all available resources. As such usable resource has been considered as 70% of the available resources and 30% of the available resources have been taken into account as "in stream flow" in the river. It is observed from Table 9-3 that surface water based irrigation development is possible by using the rubber dam and control structure. The prospect for surface water irrigation development during dry season has been investigated considering the following criteria:

- Low lift pumps (LLP) are the major mode of technology for surface water irrigation. The capacity of LLP is variable and may range from less than 1.0 cusec to 4.0 cusec although the actual discharges are often less than these values.
- The maximum gross area that can be irrigated is determined considering 1.5 km strip of lands along each bank of river up to which the ponded water extends.

On the basis of above criteria, the proposed additional surface water irrigation area during dry season is about 87492 ha, the project-wise details of which, is shown in Table 9-5.

Table 9-5: Proposed Surface Water Irrigation Area during Dry Period

District	Haor Name	Khal Name	Length of Khal (Km)	Upazilla	Propose Area (ha) for Irrigation
Kishoreganj	Boro Haor	Digha Nadi	6	Nikli	15.3
				Katiadi	10.1
		Baniajan Gang	7	Nikli	8.9
				Karimganj	11.7
		Singua Khal	28	Kishoreganj Sadar	47.5
				Karimganj	8.15
				Katiadi	12.8
	Noapara Haor	Pania Khal	3	Nikli	14
	Naogaon Haor	Khaiyar Khal	7	Mithamain	20.3
		Markhali Khal	5	Nikli	12.6
		Nandir Khal	6	Nikli	9.1
	Dakhshiner Haor	Shankir Khal	9	Itna	2.9
				Ajmeriganj	1.1
				Mithamain	24.9
	Sunair Haor	Suti Khal	30	Tarail	31
				Kendua	46.75
	Chatal Haor	Noaparakhali	1.8	Itna	7.2
				Tarail	6.15
Netrokona	Khaliajuri-4	Putia Khal	5	Khaliajuri	17.8
				Madan	1.2
	Khaliajuri-2	Naiyari Khal	8	Khaliajuri	3170
Sunamganj	Jaliar Haor	Rauli Khal	6	Chatak	1860
		Dora Nadi	8	Chatak	2830
	Dhakua Haor	Muktakhai Khal	12	Sunamganj Sadar	1075
				Jamalganj	330
				Dakshin Sunamganj	1460
	Dharmapasha Haor	Manai Khal	16	Dharamapasha	5200
		Dahar Gang	7	Dharamapasha	1630
		Agunia Khal	8	Barhatta	1920
				Dharamapasha	610
				Mohanganj	35
Moulvibazar	Hail Haor	Lunglabijna	24	Bahubal	440
				Baniachong	1160
				Habiganj Sadar	1750
				Nabiganj	7670
				Moulvibazar Sadar	260
				Sreemangal	6000
	Kawardighi Haor	Udna Gang	12	Rajnagar	3850

District	Haor Name	Khal Name	Length of Khal (Km)	Upazilla	Propose Area (ha) for Irrigation
Habiganj	Mokhar Haor	Medhabeel Khal	5	Baniachong	2077
		Old Kushiyara-2	18	Baniachong	4410
		Rajendrapur Khal	5	Baniachong	750
	Gangajuri	Teli Khal	6	Habiganj Sadar	2510
				Bahubal	2350
		Shashya Nadi	10	Bahubal	3200

10 GROUNDWATER RESOURSES ASSESMENT AND ZONING

10.1 Assessment of Groundwater Resources

Groundwater resource of the study area has been assessed based on recharge characteristics, potential recharge and safe yield criteria.

10.1.1 Recharge Characteristics

Recharge means the replenishment of groundwater storage that is depleted by withdrawal of groundwater with tube wells and by natural processes. The sources of groundwater replenishment of the study area are deep percolation of rainwater and irrigated water from the crop fields, seepage from the rivers, khals, ponds and other water bodies, and horizontal flow of groundwater from the surrounding areas. Recharge to groundwater depends on different physical and climatic conditions as well as hydraulic properties related to soil, aquifer and water. Recharge to groundwater begins with the rainfall from late May and continues up to October while recharge from irrigated crop field occurs from December to the end of March.

The aquifer becomes full in the months of August/September but excess rains are available to recharge till October if there is room for recharge. By creating additional storing space the magnitude of annual replenishment of groundwater may be increased but it depends on the availability of water and the percolation rate of soil. Direct percolation occurs during the rains from naturally submerged fields and un-submerged lands. Excess rainwater is also stored within the bund that surrounds the paddy field and in the depression areas. This water is also available for recharging the groundwater after meeting the demand of evapotranspiration. The long term average of annual replenishment of groundwater may be considered as safe yield. Groundwater storage reduces due to withdrawal for irrigation and domestic uses and outflow to rivers, canals, ditches, ponds and other water bodies. The loss of groundwater due to evaporation from water table and transpiration by plants also attributes to depletion of groundwater storage.

10.1.2 Potential and Useable Recharge

Potential recharge is the actual recharge plus rejected recharge. In the study area, generally recharge to groundwater starts from the June and continues till the end of October. During October there is still some rainfall, which goes straightway as runoff because aquifer is full. Excess rainfall for the month of October could have been recharged to groundwater if there were room for recharge. Sometimes the water table attains this highest elevation before September. After that there is no room to recharge to groundwater but excess rainfall is available, which is mainly lost by surface runoff. This water is termed as rejected recharge.

To evaluate the potential recharge, a model simulation has been carried out. The average year without irrigation has been considered. The intention was to simulate a situation with a storage that maintains a representative situation for estimation of potential recharge. This has been done by starting the simulation with an artificially low groundwater table to ascertain that all the available recharge from rainfall will enter the saturated zone, where soil properties are the only controlling factor against recharge. This low groundwater table has been determined from long-term groundwater level hydrographs in such a way so that groundwater returns to its original position during the peak time of the monsoon.

Upazila-wise potential recharge has been estimated from model results simulated for monsoon period of 50% dependability. The end of April is the end of irrigation period when the lowest water table generally occurs, after that water table starts rising due to recharge to groundwater from rainfall. Recharge is the net storage in saturated and unsaturated. The components that influence the groundwater storage after April are mainly rainfall, runoff, overland flow, overland storage, drain to river, evapo-transpiration, boundary inflow and outflow. Using the water balance obtained from model simulation as shown in Figure 10-1, potential recharge for the Ajmiriganj Upazila has been estimated as an example: Potential Recharge = 955 mm (for SZ-Storage change) + 146 mm (for UZ-Storage change) = 1101 mm.

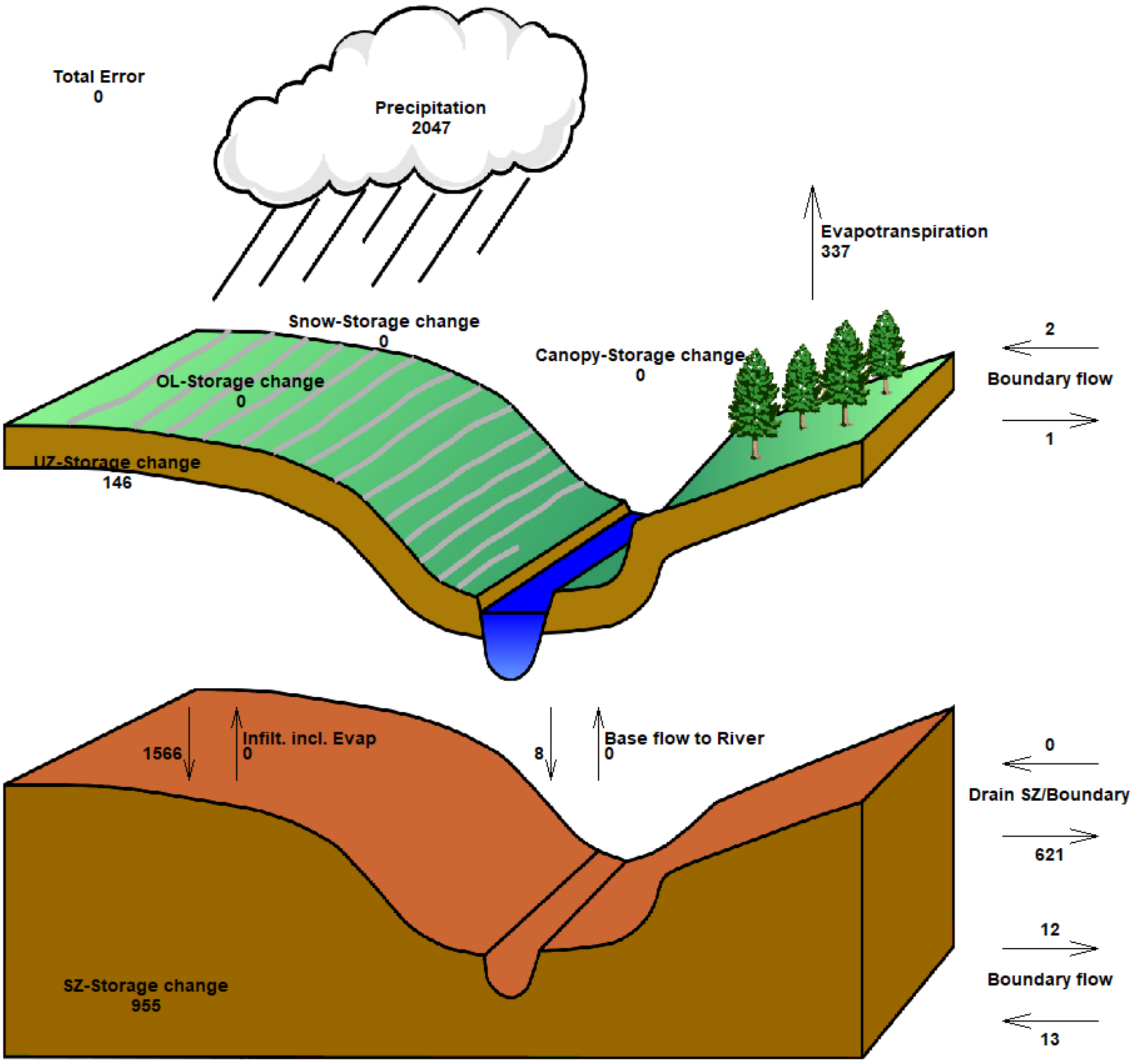


Figure 10-1: Water Balance Components of Ajmiriganj Upazila: May -October

The estimated potential recharge has been compared with the potential recharge of MPO and NWMP study as shown in Table 10-1 and Figure 10-2. The comparisons indicate that IWM result has good conformity and consistency with those of MPO and NWMP study.

Table 10-1: Comparison of Potential Recharge

SL No	District	Upazilla	NWMP Potential Recharge PR1	NWMP Potential Recharge PR2	Potential Recharge UNICEF-DPHE (1994)	IWM
1	Habiganj	Baniachong			2479	1219
2	Habiganj	Nabiganj			1419	612
3	Habiganj	Ajmiriganj			2029	1101
4	Habiganj	Bahubal			832	689
5	Habiganj	Habiganj Sadar			967	426
6	Habiganj	Lakhai			1819	893
7	Habiganj	Chunarughat			763	679
8	Habiganj	Madhabpur			787	855
9	Kishoreganj	Itna	1376	1823		1234
10	Kishoreganj	Tarail	1287	1471		1126
11	Kishoreganj	Karimganj	1086	1275		1086
12	Kishoreganj	Kishoreganj Sadar	809	910		970
13	Kishoreganj	Hossainpur	811	918		914
14	Kishoreganj	Mithamain	1981	2509		1250
15	Kishoreganj	Nikli	1489	1985		1090
16	Kishoreganj	Austagram	2012	2643		1186
17	Kishoreganj	Pakundia	824	978		609
18	Kishoreganj	Katiadi	915	1110		1108
19	Kishoreganj	Bajitpur	1177	1617		770
20	Kishoreganj	Kuliar Char	950	1192		995
21	Kishoreganj	Bhairab	1177	1617		1097
22	Maulvibazar	Barlekha			1397	568
23	Maulvibazar	Kulaura			1124	718
24	Maulvibazar	Rajnagar			859	642
25	Maulvibazar	Maulvi Bazar Sadar			1032	690
26	Maulvibazar	Kamalganj			1183	490
27	Maulvibazar	Sreemangal			999	860
28	Netrakona	Durgapur	973	1045		897
29	Netrakona	Kalmakanda	1498	1463		458
30	Netrakona	Purbadhala	1115	1115		865
31	Netrakona	Netrokona Sadar	1036	1084		973
32	Netrakona	Barhatta	1206	1225		932
33	Netrakona	Mohanganj	1359	1487		938
34	Netrakona	Atpara	1223	1306		1013
35	Netrakona	Khaliajuri	1374	1588		1043
36	Netrakona	Kendua	973	1034		713

SL No	District	Upazilla	NWMP Potential Recharge		Potential Recharge UNICEF-DPHE (1994)	IWM
			PR1	PR2		
37	Netrakona	Madan	1140	1300		958
38	Sunamganj	Tahirpur			1695	606
39	Sunamganj	Dharampasha			1087	932
40	Sunamganj	Bishwambarpur			2112	554
41	Sunamganj	Dowarabazar			1923	543
42	Sunamganj	Sunamganj Sadar			1609	1042
43	Sunamganj	Chhatak			1041	582
44	Sunamganj	Jamalganj			1373	961
45	Sunamganj	Derai			1587	1199
46	Sunamganj	Jagannathpur			1373	973
47	Sunamganj	Sulla			1297	1022
48	Sylhet	Jaintiapur			1241	577
49	Sylhet	Gowainghat			1447	635
50	Sylhet	Companiganj			1531	584
51	Sylhet	Kanaighat			1271	687
52	Sylhet	Kotwali			1332	705
53	Sylhet	Zakiganj			1175	626
54	Sylhet	Beani Bazar			1511	600
55	Sylhet	Bishwanath			751	520
56	Sylhet	Golabganj			1343	462
57	Sylhet	Balaganj			1327	658

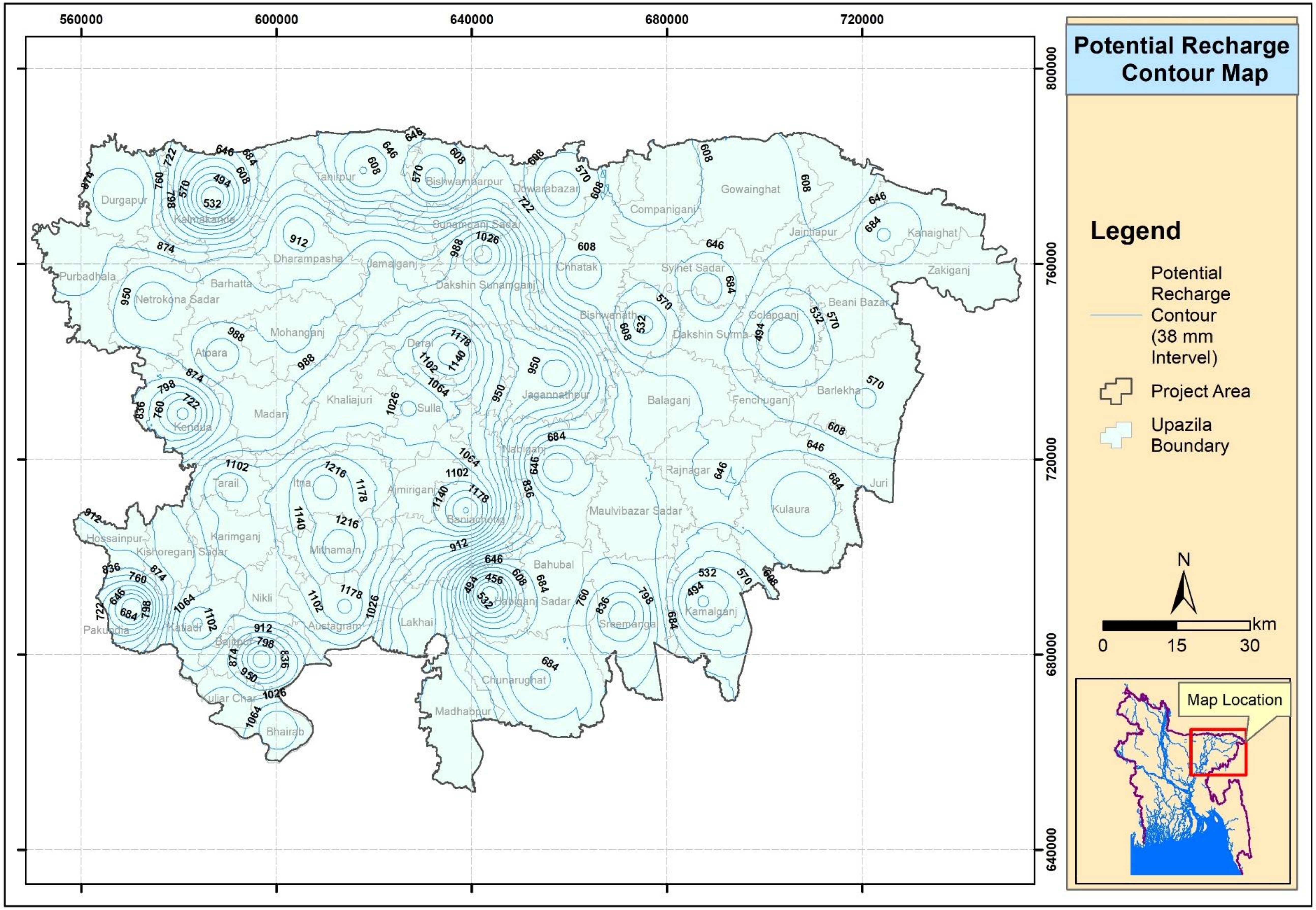


Figure 10-2: Spatial Distribution of Potential Recharge in the Study Area

10.2 Application of Model for Future Development

10.2.1 Selection of Design Year

Normally irrigation projects are planned considering average hydrological conditions. In the present study, design year has been selected based on return period of mean annual rainfall of the study area. The mean annual rainfall has been obtained from the average of 37 stations falls in and around the study area. Observed annual rainfall for a period of 30 years (1988-2018) has been considered for statistical analysis. Data has been fitted to 3-parameter Log Normal distribution to find out the average dry year. The statistical software HYMOS 4.0 has been used for this purpose. The results of the analysis are presented in Table 10-2. It is quite obvious that due to the randomness of rainfall events, all rainfall events for each station will not represent a unique design year and thus a design year on the basis of stations has been selected as shown in Table 10-2.

Table 10-2: Selection of Design Year

ID	ID	Avg Annual Sum of Rainfall (mm)	Matching Year (1 in 2.33)
1	CL64	7770	1999
2	CL77	7536	1998
3	CL105	7826	2007
4	CL110	7467	1995
5	CL111	7687	1995
6	CL101	7854	2003
7	CL61	7844	1990
8	CL71	7778	2011
9	CL104	6810	1990
10	CL108	6688	2001
11	CL114	7299	2011
12	CL117	7098	1996
13	CL65	7563	2011
14	CL75	7386	1996
15	CL73	7543	1997
16	CL109	6096	2014
17	CL107	5265	1992
18	CL229	7258	1991
19	CL126	7366	2009
20	CL122	7564	2002
21	CL119	6937	2007
22	CL118	6038	2002
23	CL68	7087	2014
24	CL63	6603	2011
25	CL123	6956	1996
26	CL121	7255	2008
27	CL115	7120	1989
28	CL129	7016	2006

ID	ID	Avg Annual Sum of Rainfall (mm)	Matching Year (1 in 2.33)
29	CL130	5354	1997
30	CL228	5112	2007
31	CL103	7956	2005
32	CL131	8113	2009
33	CL132	7908	1999
34	CL102	4810	1992
35	CL116	4203	1990
36	CL125	5553	1996
37	CL128	5602	2015

10.2.2 Formulation of Options

Various technical options/alternatives have been investigated to address the study objectives and finally to make comprehensive water management plans for the study area. Options were formulated in consultation with the project officials and beneficiaries of the project. Technicalities of the options are briefly described below:

Option 0: Base Condition i.e. Existing Situation with 50% dependable rainfall

- Hydrological condition for the design year (avg. condition).
- Crop coverage for existing condition.
- Irrigation demand for the existing cropping pattern and crop coverage.
- Domestic (rural & urban) and industrial demands for existing condition.
- Water application as per demand.

Option I: Future Option with all Existing SW Projects

- Hydrological condition for the design year (avg. condition).
- Crop coverage for future condition
- Irrigation demand for future cropping pattern and crop coverage considering 80% area under HYV Boro.
- Domestic (rural & urban) and industrial demands for future condition.
- Water application: as per crop demand and irrigation coverage

Option II: Future Option with all Existing and Proposed SW Projects

- Same as Option I and including proposed SW based irrigation projects along the major rivers/ khals by constructing water control structures.

Option II: Future Option with all Existing and Proposed SW Projects under Extreme Drought Situation

- Same as Option I but hydrological year is considered for extreme drought situation.

10.2.3 Model Setup and Simulations

Hydraulic parameters such as hydraulic conductivity, transmissivity, specific yield, storage coefficient etc. obtained through calibration are kept unchanged for options simulations. Number of geological and computational layers with their top and bottom elevations, soil properties, soil moisture retention curves, DEM of the study area, crop data base (leaf area index, root depth, crop growth stages and growing season) of individual crops are also kept same. Meteorological data (rainfall, evaporation, temperature, humidity etc), hydrological data (river water level and discharge at the boundary locations) and hydrogeological data (groundwater level at boundary locations) are provided according to the hydrological year considered for different option simulations. Changes that were considered in different option simulations are as follows:

- Land use and crop coverage
- Water abstractions

With the above necessary changes, the calibrated and validated surface water groundwater interaction model has been applied for all the options.

10.3 Technical Evaluation of Options

Results of the option simulations are analyzed, presented and compared with the base condition in the following manner:

- Groundwater level hydrographs
- Groundwater depth map

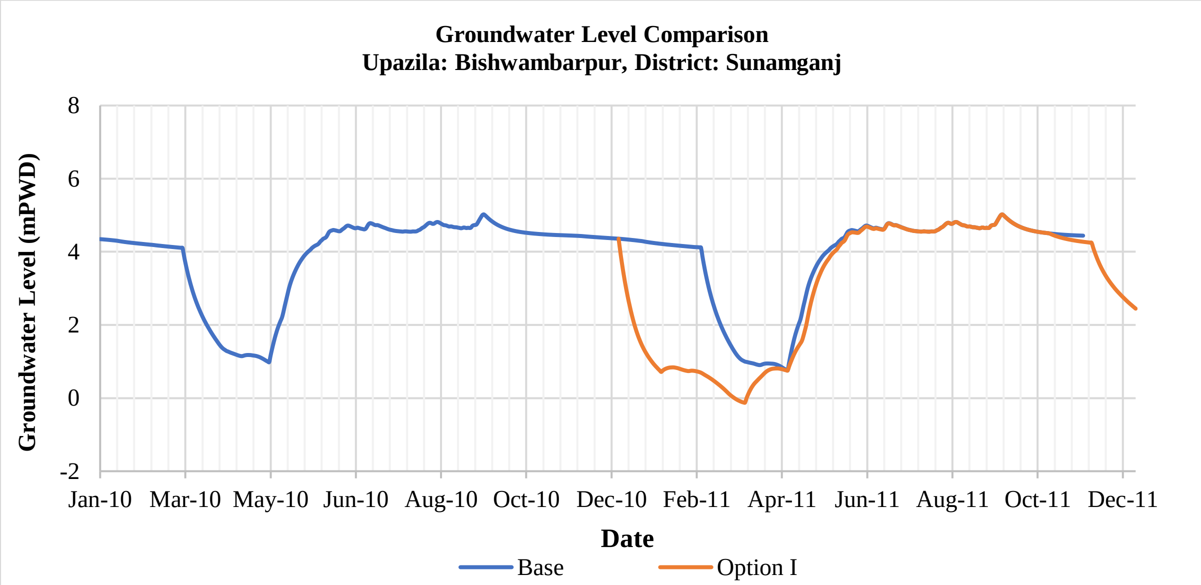
10.3.1 Option 0 and Option I: Existing and Future Situation with Average Year Condition

The main purpose of the base option is to understand the present state of project under design year in terms of volume of water presently being used, whether it crosses the potential recharge of the aquifer

The purpose of Option I is to assess the impact of future development on the present state of water and environment with respect to the groundwater tables whether it will crosses the safe yield of the aquifer.

Hydrograph Analysis of Option 0 and Option I

Hydrographs of simulated groundwater level of Option I (future scenario) have been compared with simulated groundwater level of Option 0 (existing scenario) at some pre-selected locations. Sample comparison plots of hydrographs are shown in Figure 10-3. It reveals that, in some places, groundwater level drops down by about 0.5m to 9m compared to the groundwater level of Option 0 during irrigation period. This situation occurred due to higher abstraction in the Option I compared to Option 0. However, hydrograph shows that groundwater level returns to its original position during the peak time of the monsoon. However to see the impact on the entire area, groundwater depth maps have been analyzed.



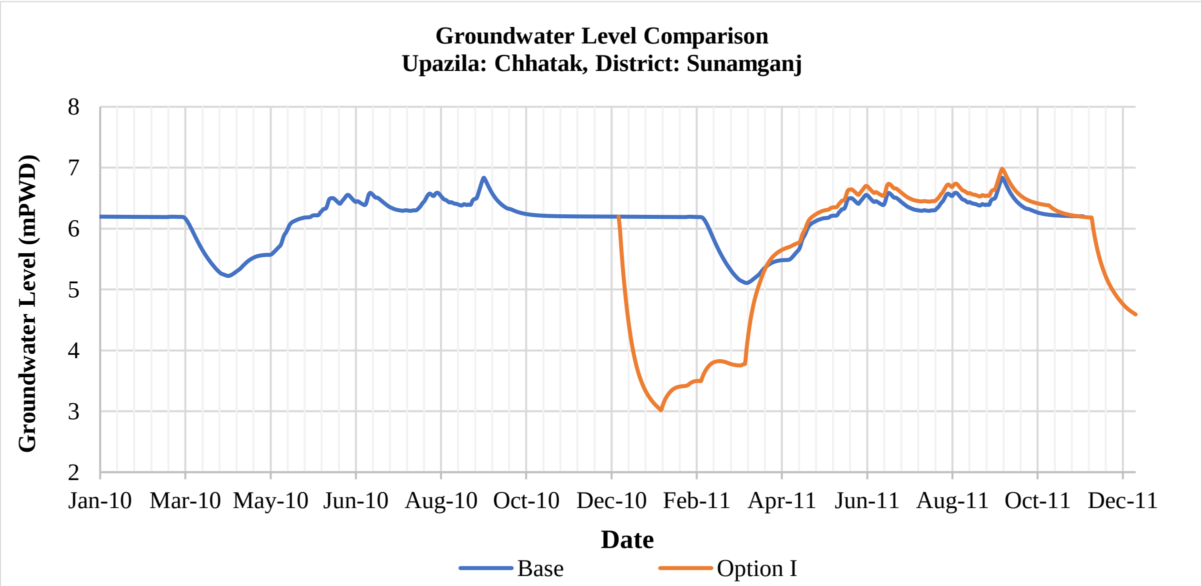


Figure 10-3: Groundwater Level Comparison; Option 0 and Option I

Groundwater Depth Map of Option 0 and Option I

In order to investigate the impact of increased abstraction on the entire study area, spatial distribution of impact maps (Option 0 – Option I) of maximum and minimum depth to groundwater tables were prepared for 1st May and 1st October as shown in Figure 10-4 to Figure 10-9. It is observed from Figure that in some areas, groundwater table drops down by about 0.1m to 1.0m compared to the groundwater table of Option 0. Groundwater table drops down upto 9m in Habiganj and Bahubal Upazilla where new abstraction has been imposed for industries. However, groundwater tables under Option I returns to its original position during the peak time of the monsoon in most of the areas. This phenomenon reveals that aquifer system from where increased abstraction is being carried out has the potential for further development.

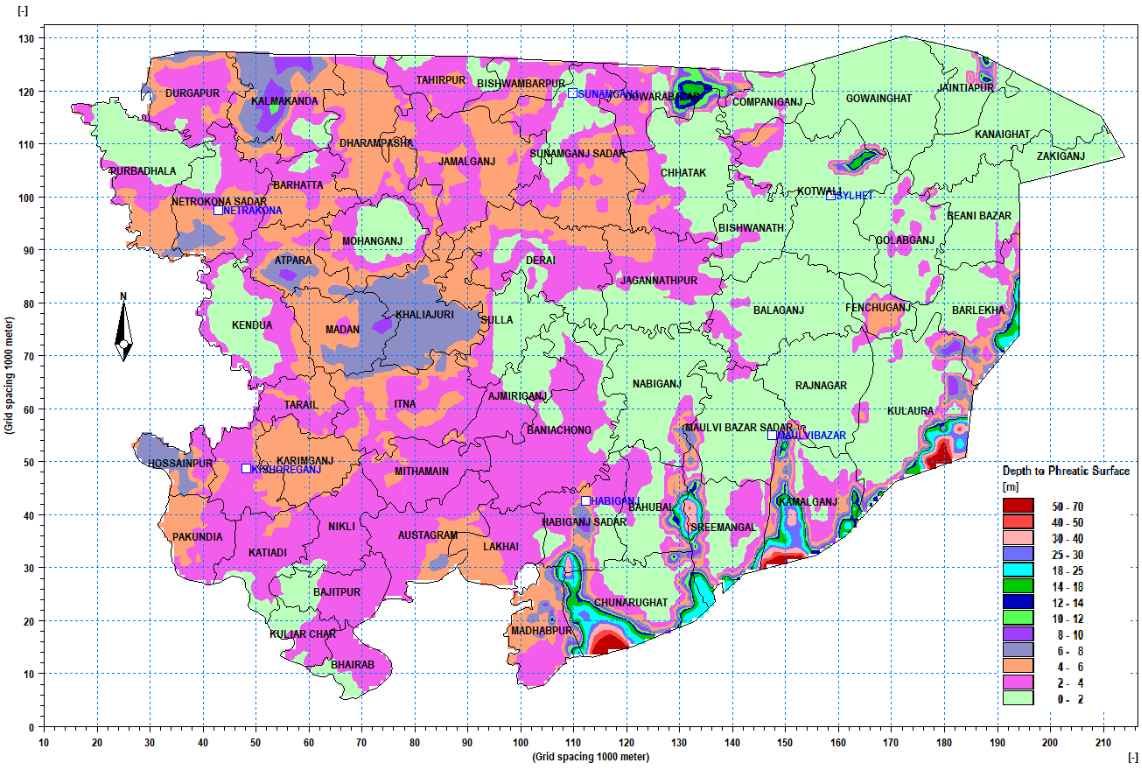


Figure 10-4: Maximum Depth to Groundwater Table on 1st May (Base Condition)

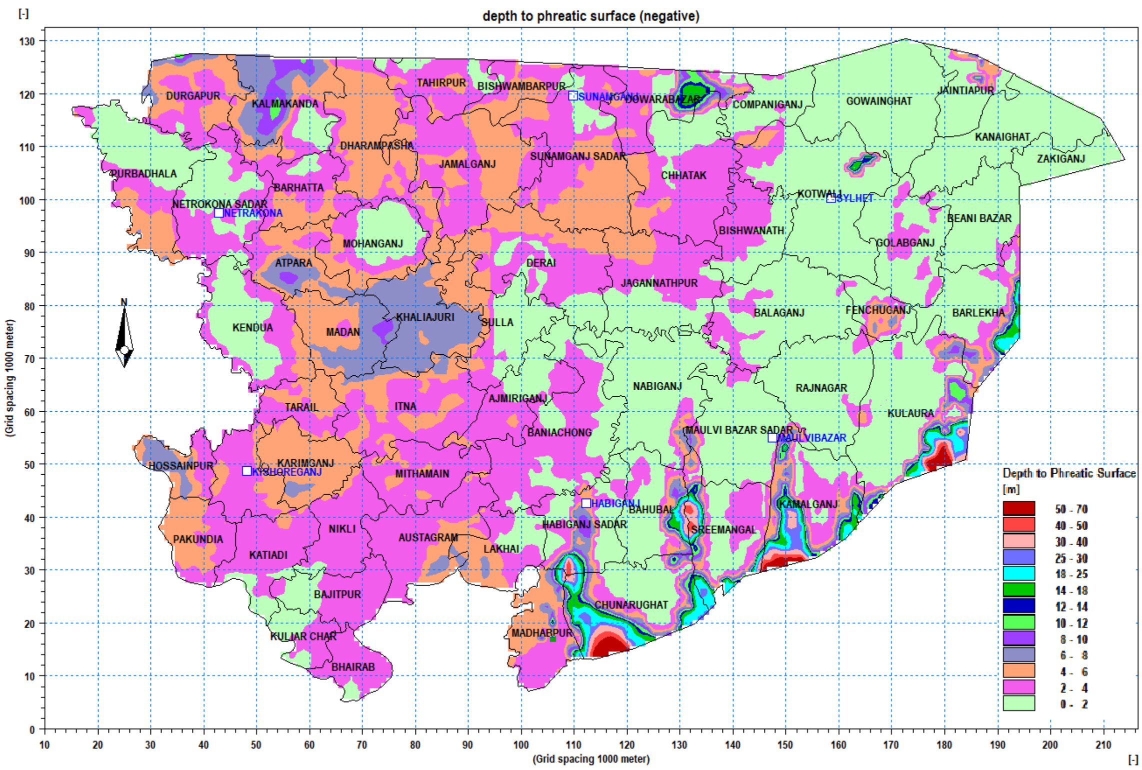


Figure 10-5: Maximum Depth to Groundwater Table on 1st May (Option I)

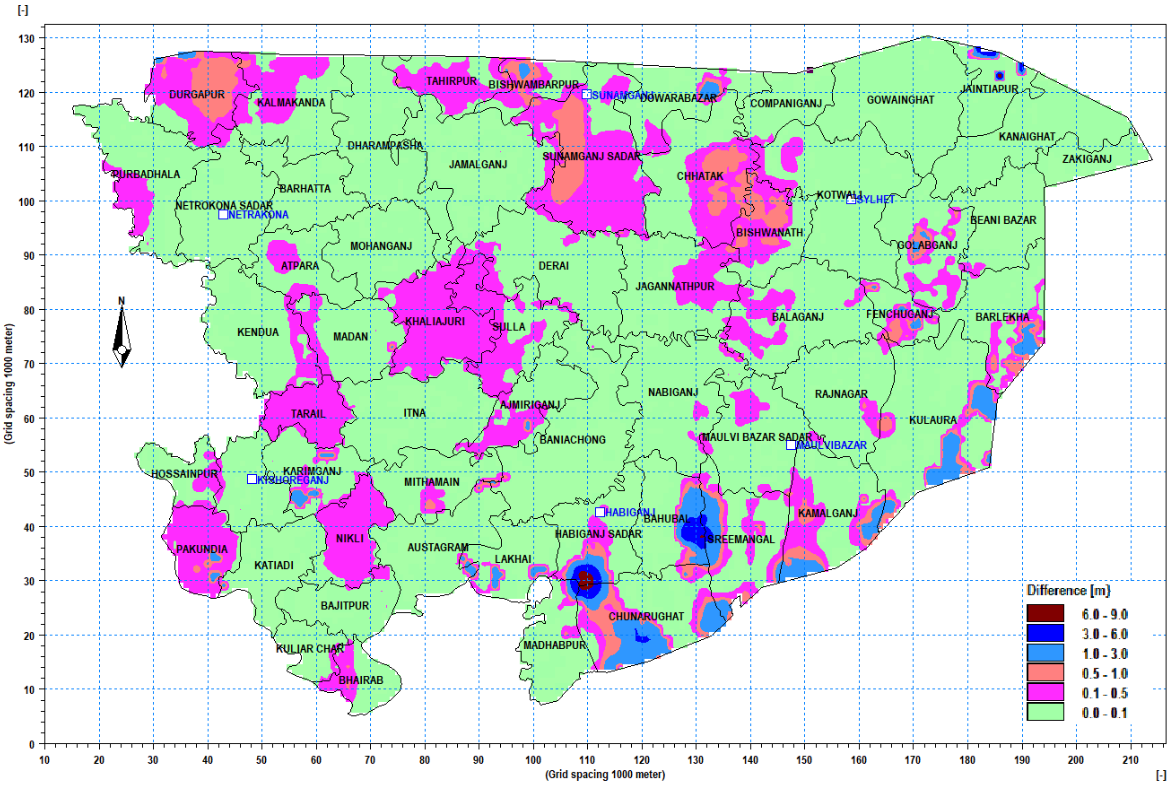


Figure 10-6: Impact Map (Option 0 – Option I) of Maximum Depth to GW Table

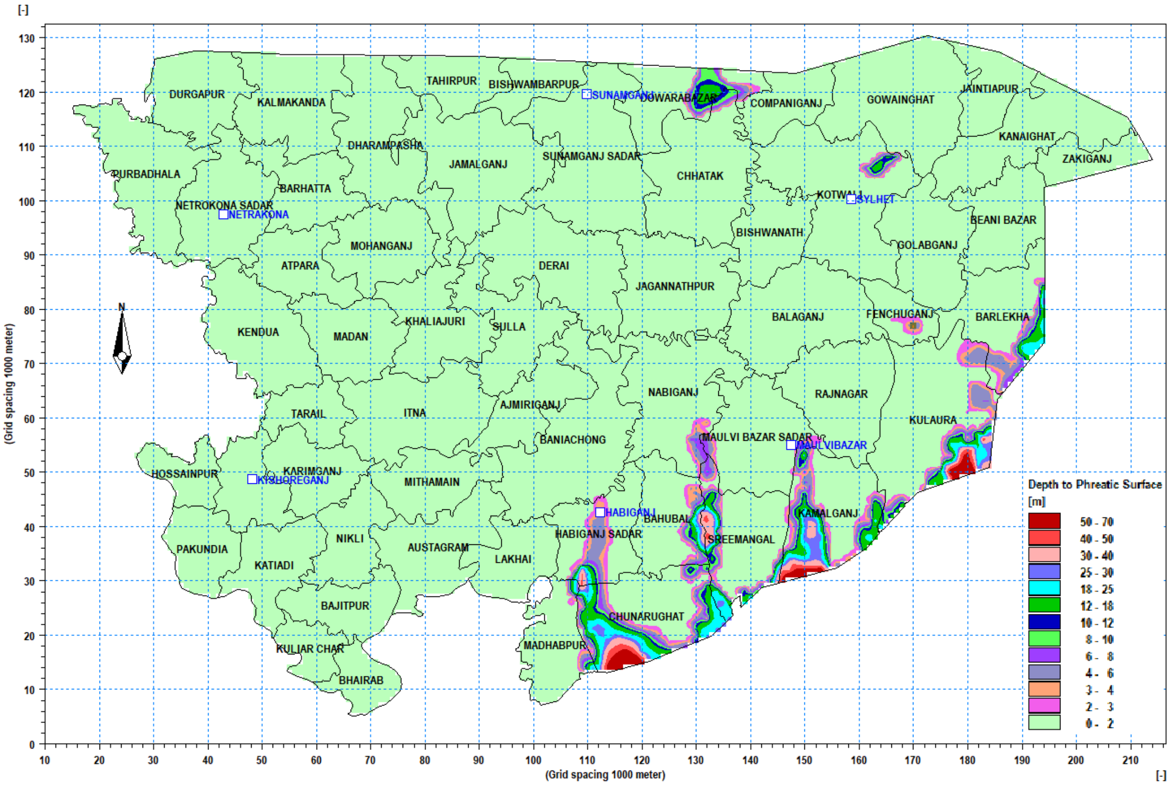


Figure 10-7: Minimum Depth to Groundwater Table on 1st October (Base Condition)

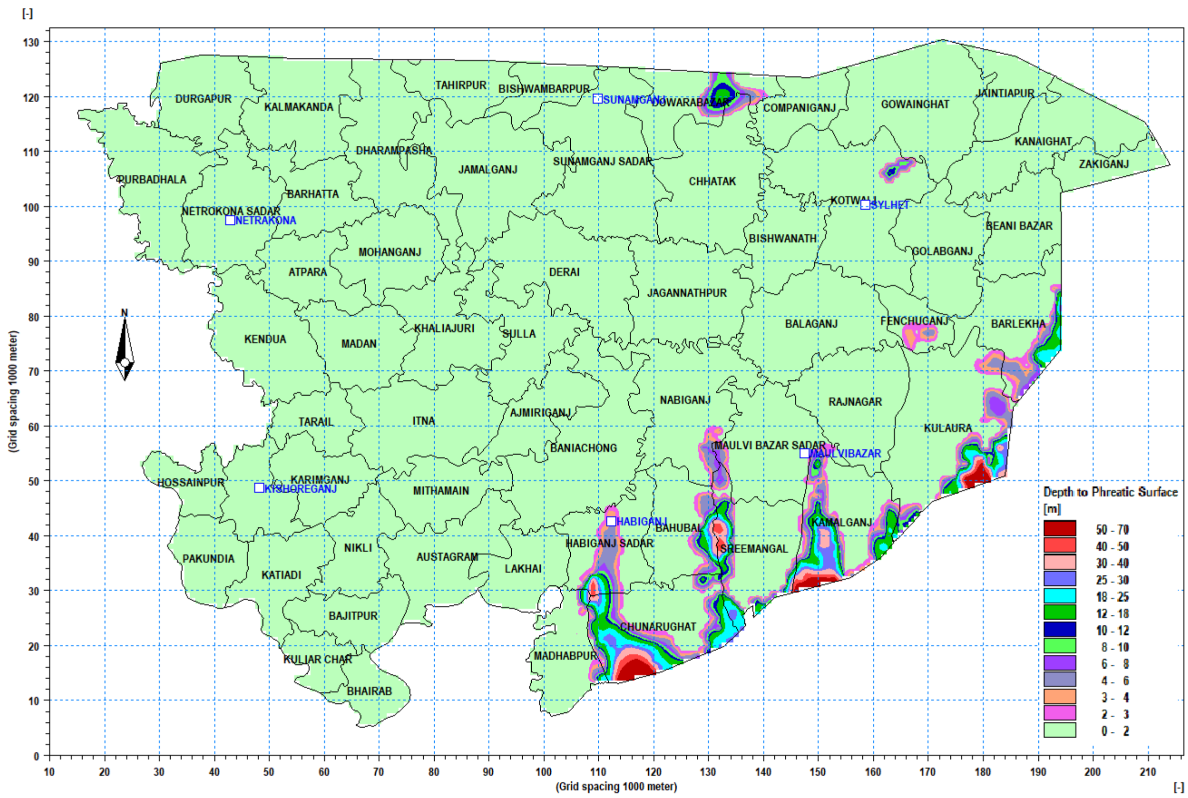


Figure 10-8: Minimum Depth to Groundwater Table on 1st October (Option I)

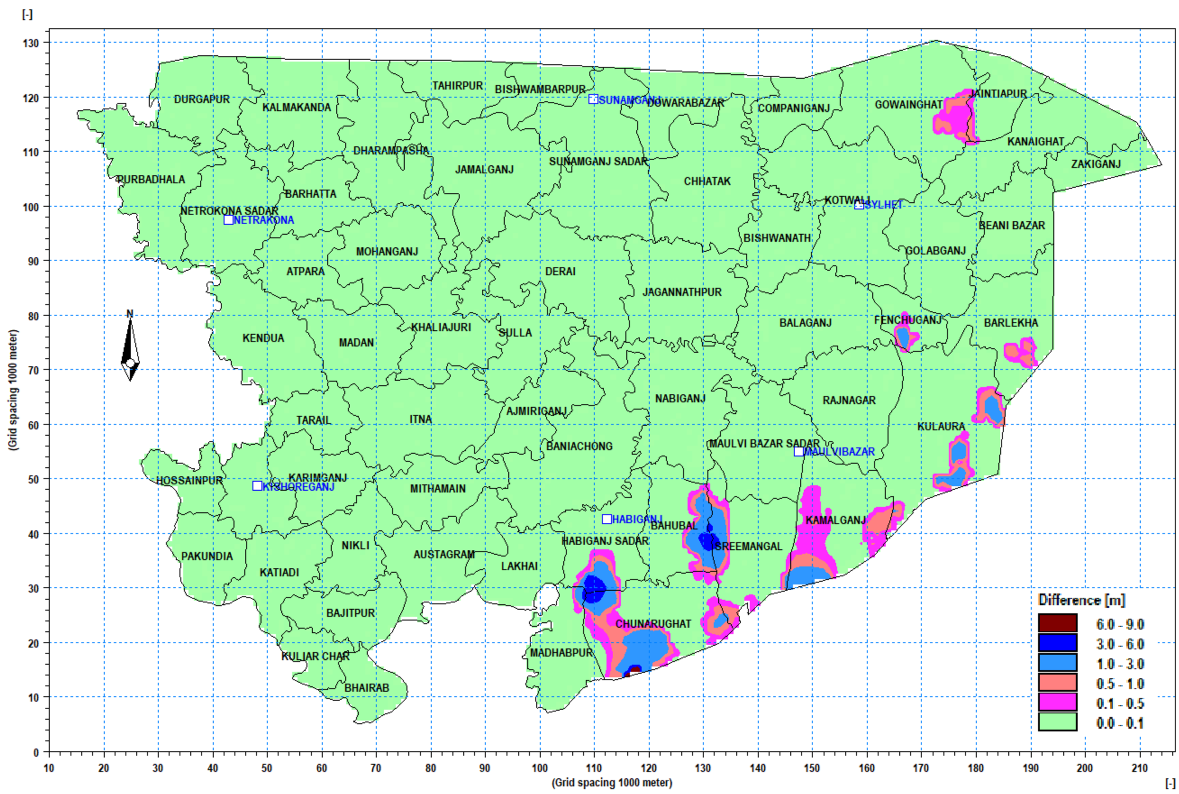


Figure 10-9: Impact Map (Option 0 - Option I) of Minimum Depth to GW Table

Water Balance

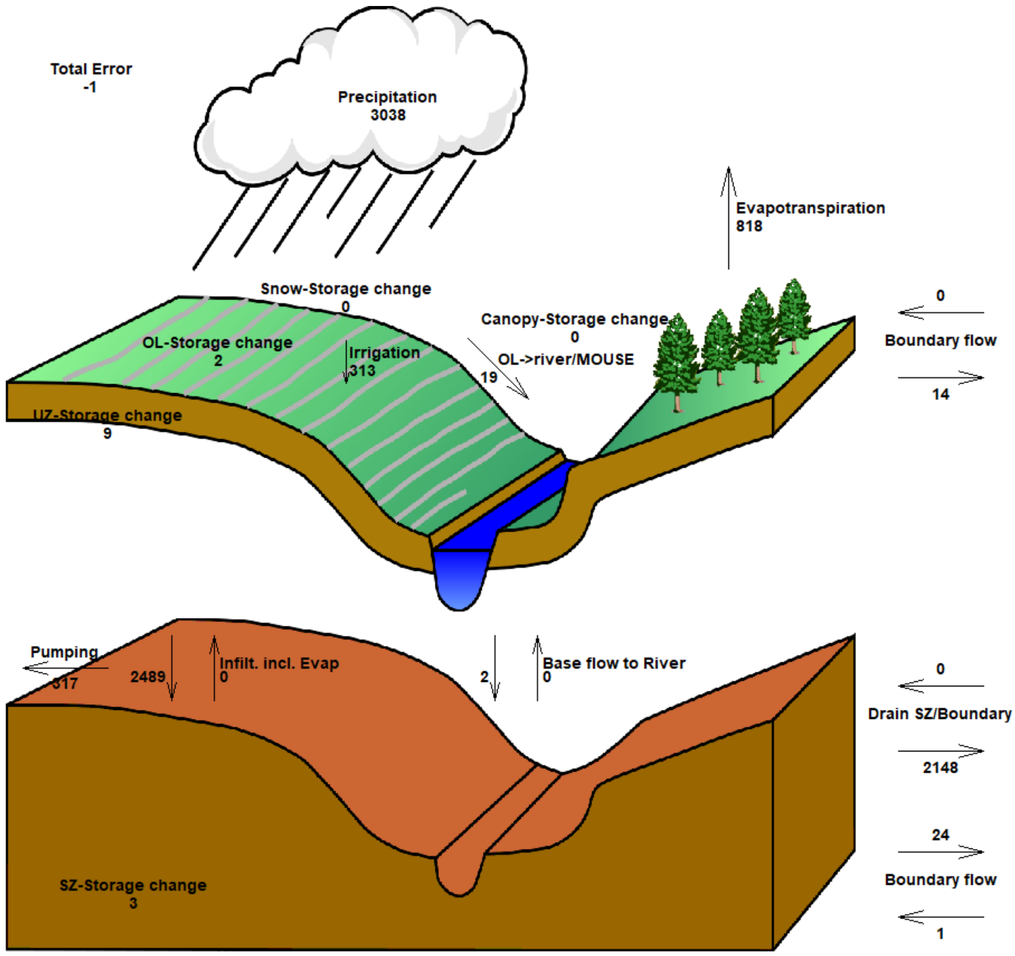


Figure 10-10: Water Balance Components for Base Condition

Table 10-3 Water Balance Components for Base Condition

Sl. No.	Components	Unsaturated Zone(UZ)		Saturated Zone (SZ)		River System		GW Recharge/Discharge	
		Inflow (mm)	Outflow (mm)	Inflow (mm)	Outflow (mm)	Inflow (mm)	Outflow (mm)	Recharge (mm)	Discharge (mm)
1	Rainfall	3038	—	—	—	—	—	—	—
2	Evapotranspiration(ET)	—	818	—	—	—	—	—	—
3	Abstraction	—	—	—	317	—	—	—	—
4	Irrigation	313	—	—	—	—	—	—	—
5	Capilary rise & ET from SZ to UZ	0	—	—	0	—	—	—	—
6	Deep Percolation from UZ to SZ	—	2489	2489	—	—	—	2489	0
7	Boundary Flow	0	14	1	24	—	—	0	23
8	Base Flow	—	—	2	0	0	2	2	0
9	Overland flow to river	—	19	—	—	19	—	—	—
10	Drain flow to river	—	—	0	0	0	0	0	0
11	OL storage Change	0	2	—	—	—	—	—	—
12	Drain SZ/Boundary	—	—	0	2148	—	—	0	2148
Total		**3351**	**3342**	**2492**	**2489**	**19**	**2**	**2491**	**2171**
Net Balance=Inflow-Outflow		**9**		**3**		**17**		**320**	
Explanation		**Inflow/Outflow of SZ**		**Change in Storage**		**River/Aquifer Interaction**		**Net Recharge /Discharge**	

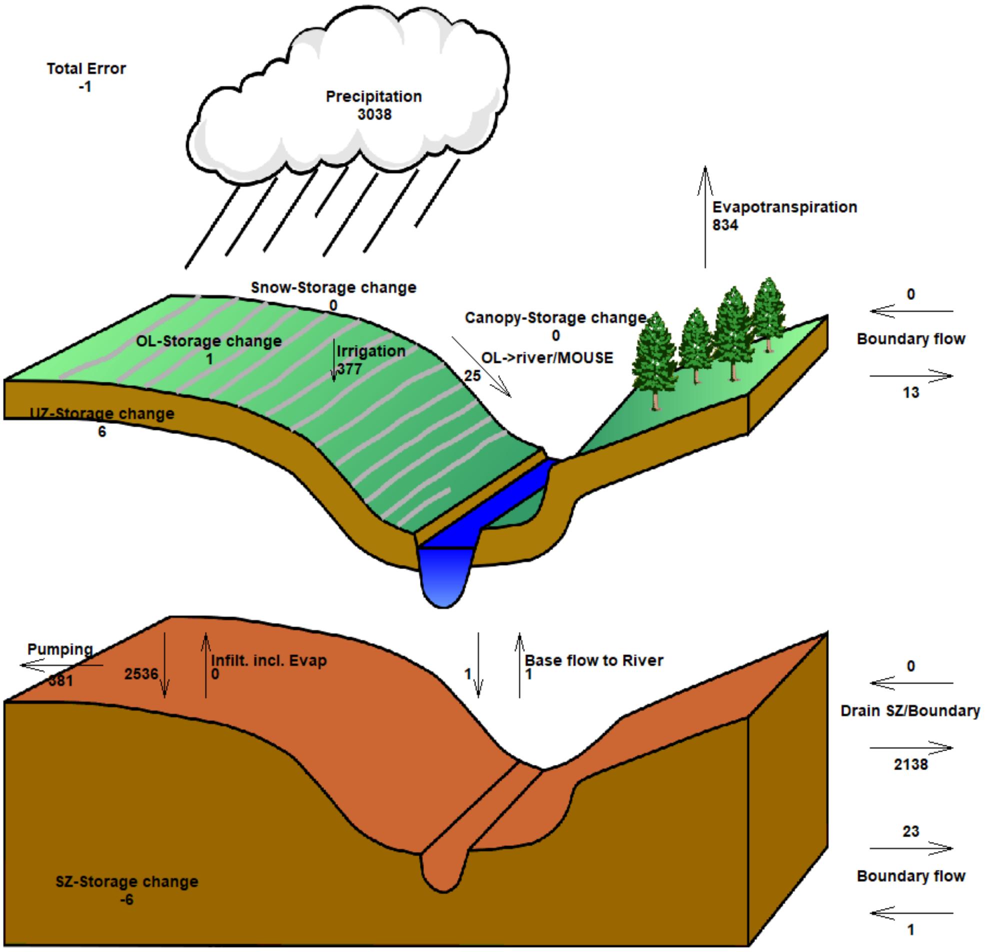


Figure 10-11: Water Balance Components for Option I

Table 10-4 Water Balance Components for Option I

Sl. No.	Components	Unsaturated Zone(UZ)		Saturated Zone (SZ)		River System		GW Recharge/Discharge	
		Inflow (mm)	Outflow (mm)	Inflow (mm)	Outflow (mm)	Inflow (mm)	Outflow (mm)	Recharge (mm)	Discharge (mm)
1	Rainfall	3038	—	—	—	—	—	—	—
2	Evapotranspiration(ET)	—	834	—	—	—	—	—	—
3	Abstraction	—	—	—	381	—	—	—	—
4	Irrigation	377	—	—	—	—	—	—	—
5	Capilary rise & ET from SZ to UZ	0	—	—	0	—	—	—	—
6	Deep Percolation from UZ to SZ	—	2536	2536	—	—	—	2536	0
7	Boundary Flow	0	13	1	23	—	—	0	22
8	Base Flow	—	—	1	1	1	1	0	0
9	Overland flow to river	—	25	—	—	25	—	—	—
10	Drain flow to river	—	—	0	0	0	0	0	0
11	OL storage Change	0	1	—	—	—	—	—	—
12	Drain SZ/Boundary	—	—	0	2138	—	—	0	2138
Total		**3415**	**3409**	**2538**	**2543**	**26**	**1**	**2536**	**2160**
Net Balance=Inflow-Outflow		**6**		**-5**		**25**		**376**	
Explanation		**Inflow/Outflow of SZ**		**Change in Storage**		**River/Aquifer Interaction**		**Net Recharge /Discharge**	

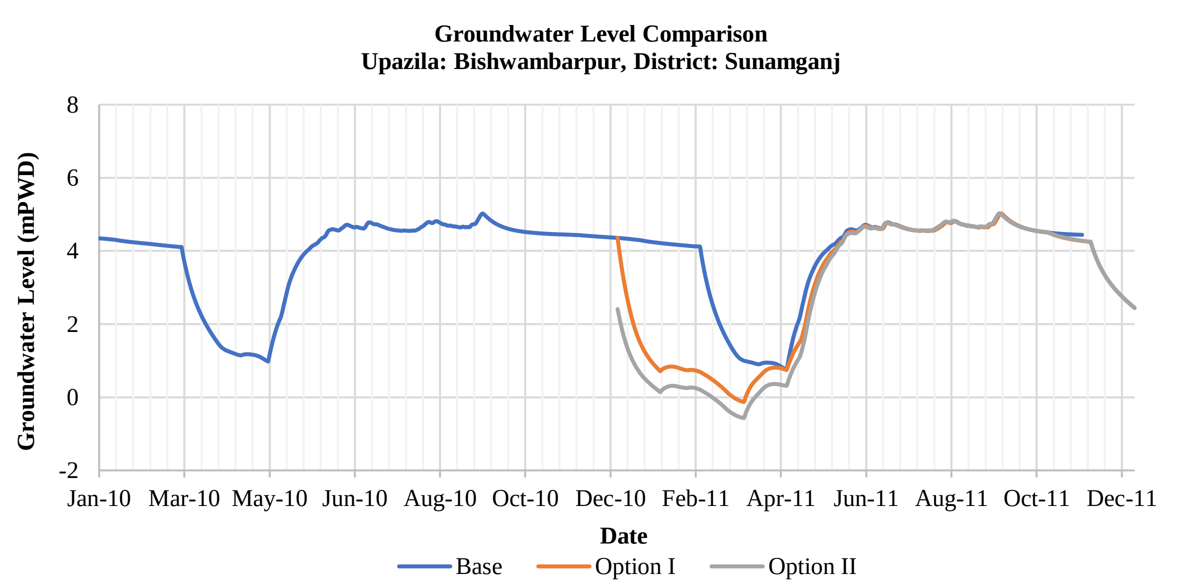
Water balance for Option I is graphically shown in Figure 10-11 and presented in Table 10-4. It appears from the table that in UZ, 3415mm water enters while 3409mm water goes out with a net balance of 6mm. The values of ET under Base and Option I are 818mm and 834mm respectively. This increase of ET by 16mm is due to the change of landuse pattern. The net balances in UZ under Base and Option I are 9mm (Table 10-3) and 6mm (Table 10-4) respectively. In SZ, 2538mm water enters and 2543 mm goes out from SZ resulting to a negative change of storage of 5mm for Option I. It can be seen from Table 10-3 and Table 10-4 that annual recharge increases by 56mm in Option I which is due to the increased return flow and additional space in aquifer for lowering of groundwater due to increased abstraction. Abstraction increases in Option I than that of the Base case by the amount of 64mm, which increases groundwater recharge by 56mm. This implies that aquifer has potential for receiving more recharge if provision is made.

10.3.2 Option 0 and Option II: Existing and Future Situation with Extreme Dry Condition

As stated earlier, Option 0 is the existing condition with average hydrological year. Option II is the exactly the same as Option I but model simulation has been carried out for extreme drought year condition. The main purpose of this option is to see the impact of drought on the groundwater situation of the proposed future abstraction. The average hydrological condition has been assumed after a drought year condition in this option.

Hydrograph Analysis

Hydrographs of simulated groundwater tables of Option II have been compared with simulated groundwater tables of the Option 0 at some pre-selected locations. Sample comparison plots of hydrographs are shown in Figure 10-12. It reveals that, groundwater level further drops down upto 0.5m from Option I in some places. However in some places the water level in Option I and II is same. This situation may occur, where the effect of drought is insignificant. However, during monsoon, the groundwater level regains its original position which further investigated by comparing groundwater depth map.



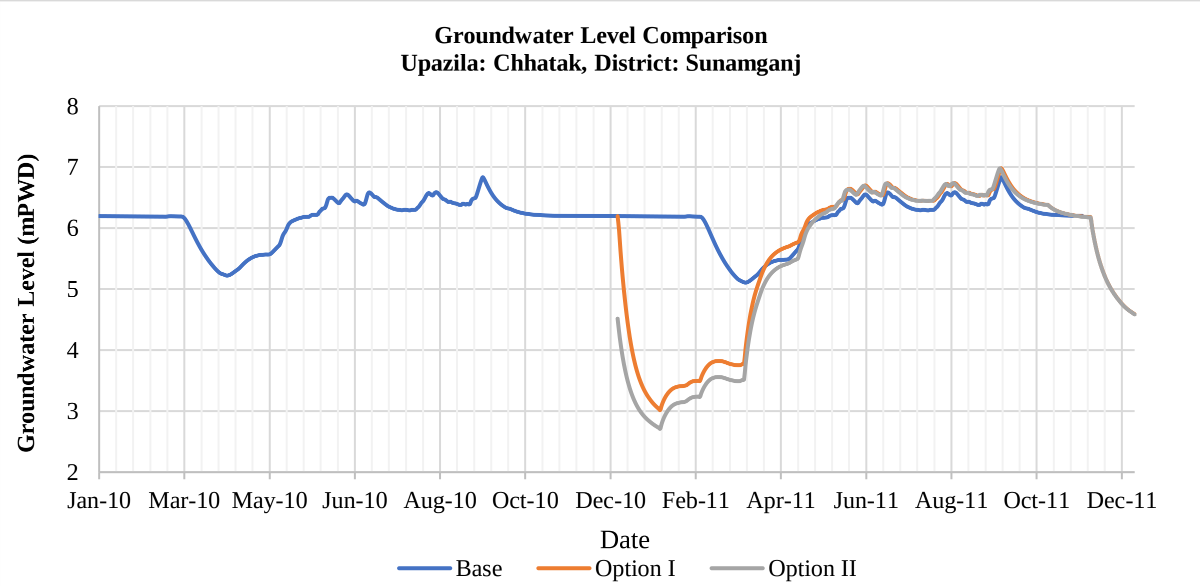


Figure 10-12: Sample Comparison Plots of Hydrographs

Groundwater Depth Map

In order to see the impact on the entire study area, spatial distribution of impact maps (Option 0 – Option II) of maximum and minimum depth to groundwater tables were prepared for 1st May and 1st October as shown in Figure 10-13 to Figure 10-16. It is observed from Figure 10-14 that in most of the areas of Netrokona and Kishorganj districts groundwater table drops down from 0.5 to 2m compared to the groundwater table of Option 0. The drop down area will be increased to a large extent in dry condition compared to the average condition. However, during monsoon, most of the areas regain its original position.

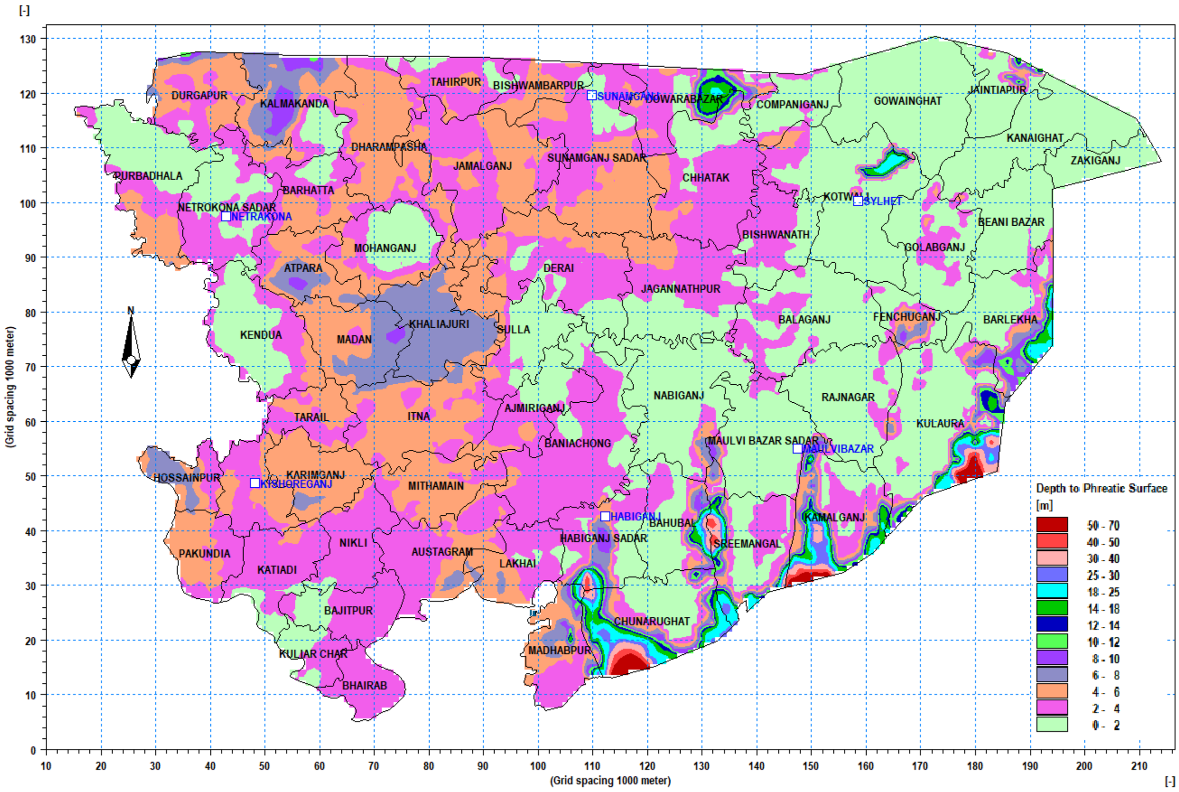


Figure 10-13: Maximum Depth to Groundwater Table on 1st May (Option II)

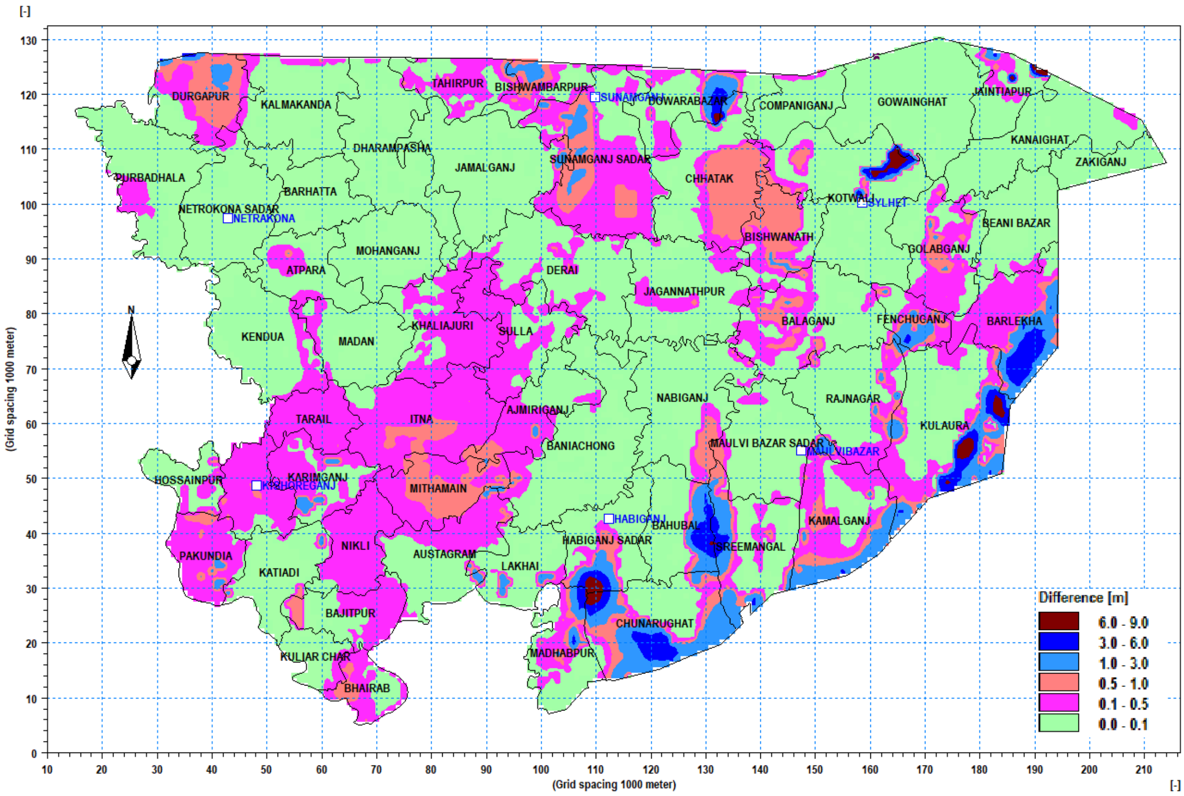


Figure 10-14: Impact Map (Option 0 - Option II) of Maximum Depth to GW Table

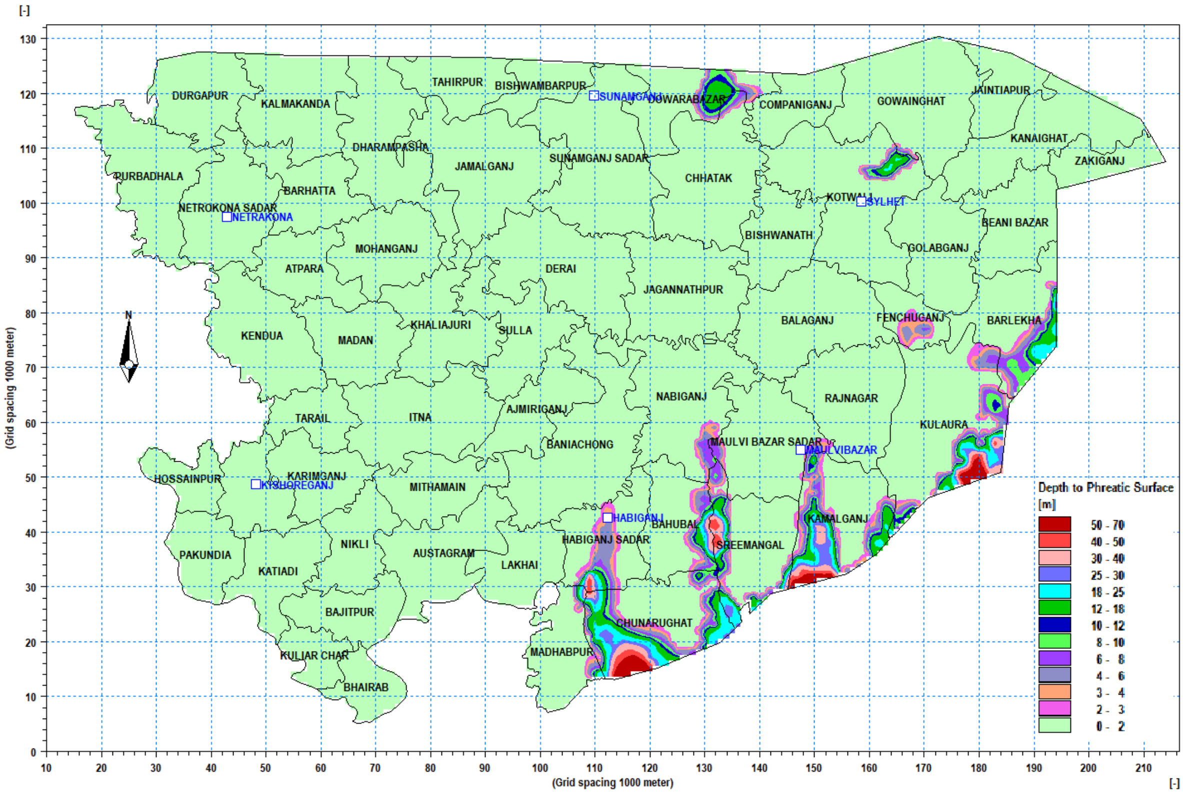


Figure 10-15: Minimum Depth to Groundwater Table on 1st October (Option II)

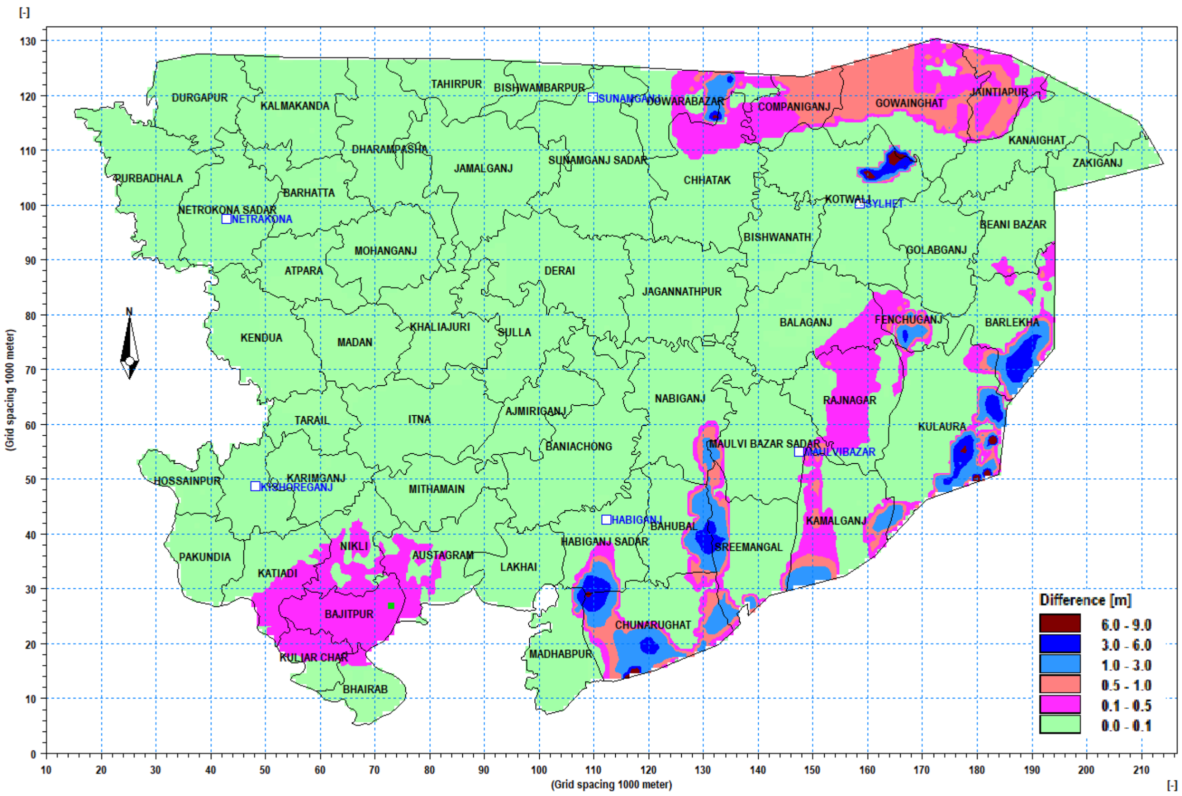


Figure 10-16: Impact Map (Option 0 - Option II) of Minimum Depth to GW Table

10.4 Zoning for Future Irrigation Expansion

The analysis on irrigation requirement and resource as discussed above indicates that there is scope for irrigation expansion in the study area. A model simulation has been carried out in Option I with the future irrigation expansion by increasing Boro crop upto 80% in Upazilas where possible.

A simulated groundwater depth map has been prepared at the end of irrigation season that is at the end of April. It is observed that groundwater level remains within 7m from the surface in most of the Upazilas. However, groundwater depth upto 7m is considered for suction limit of STW and HTW without constraint. Hence these areas are suitable for STW irrigation. Based on this criterion, the study area is divided into shallow and deep from groundwater abstraction point of view. The depth greater than 7m from surface is considered as deep zone as suction mode will not be applicable in this zone.

To increase the extent of surface water irrigation in the study area, rubber dam/water control structure option was formulated and potential sites has been identified. The maximum gross area that can be irrigated is determined considering 1.5 km strip of lands along each bank of river up to which the ponded water extends. This area has been presented as proposed surface water irrigation zone. The zoning map for future irrigation expansion considering the mode of irrigation is shown in Figure 10-17. Where as the zoning map for each district is presented in Figure 10-18 to Figure 10-23.

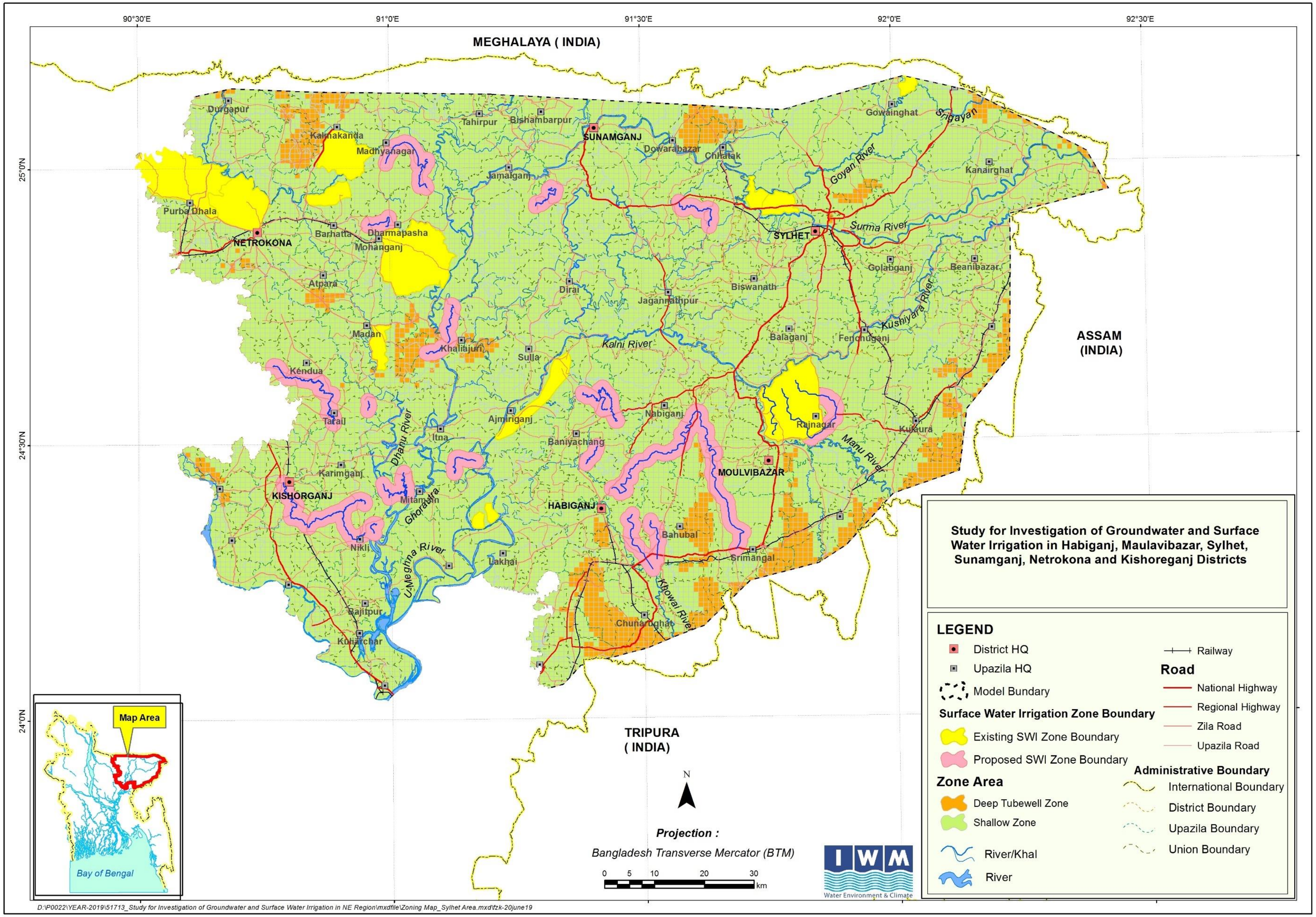


Figure 10-17: Zoning Map for Future Irrigation Expansion

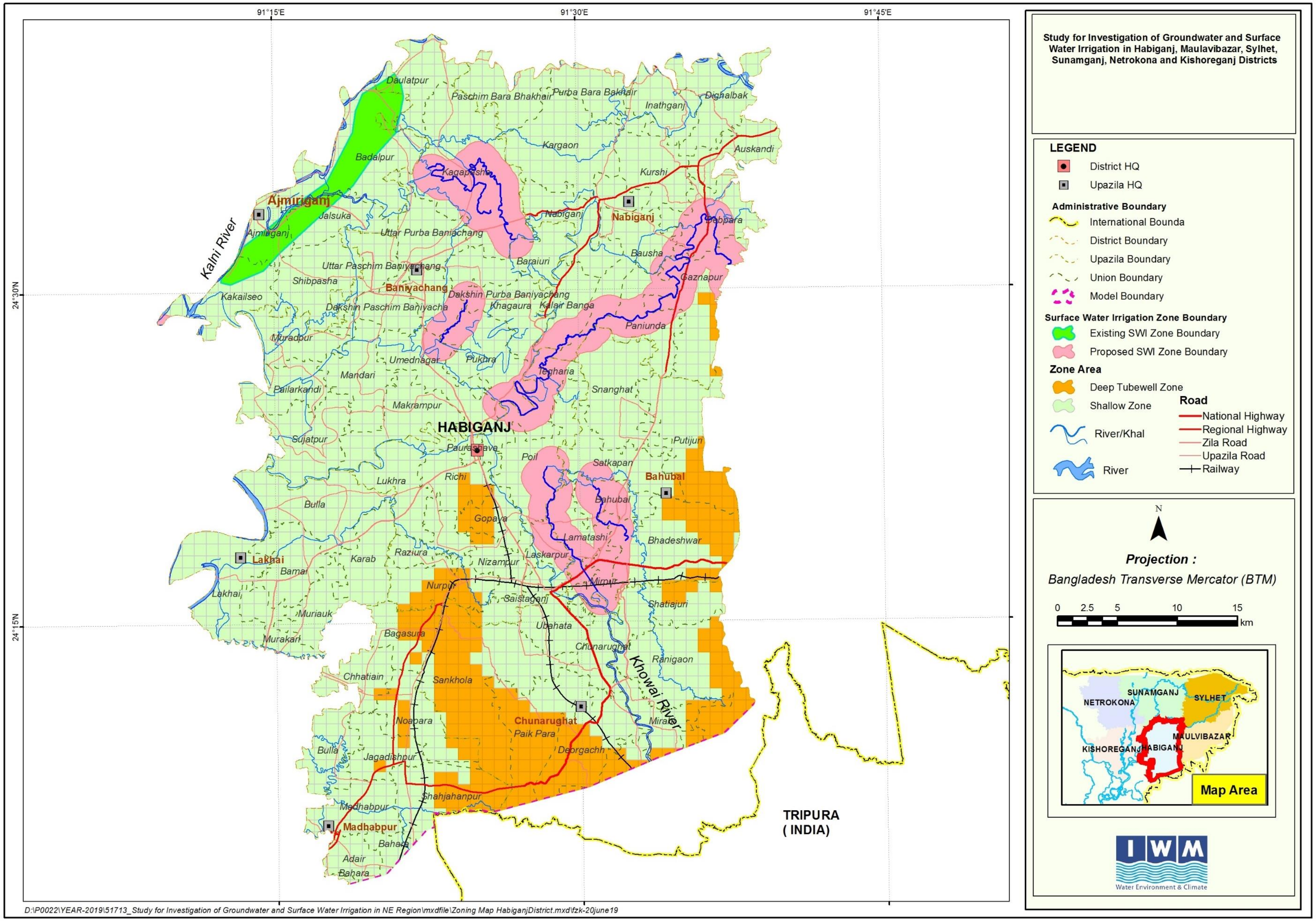


Figure 10-18: Zoning Map of Habiganj Districts

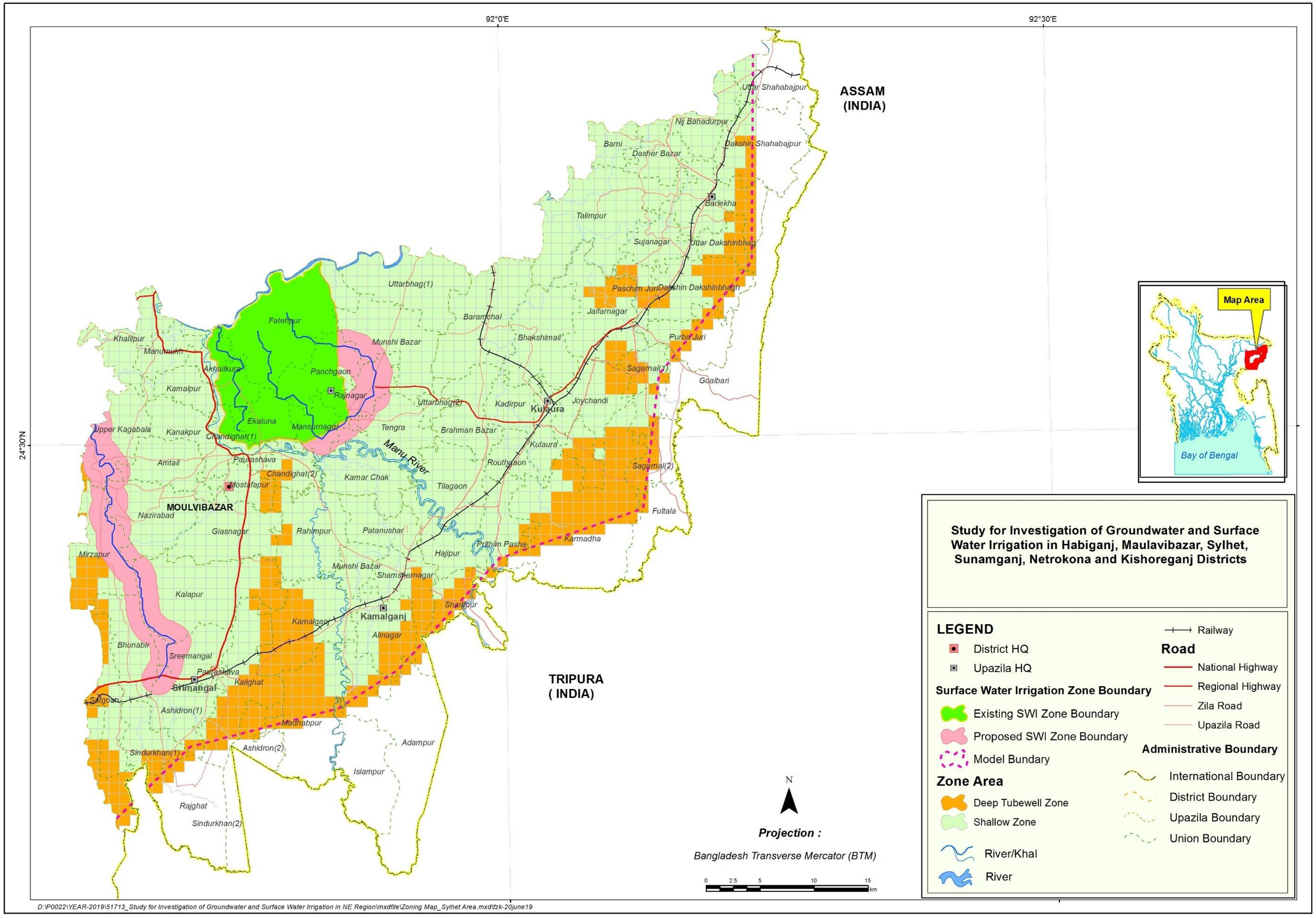


Figure 10-19: Zoning Map of Maulavibazar Districts

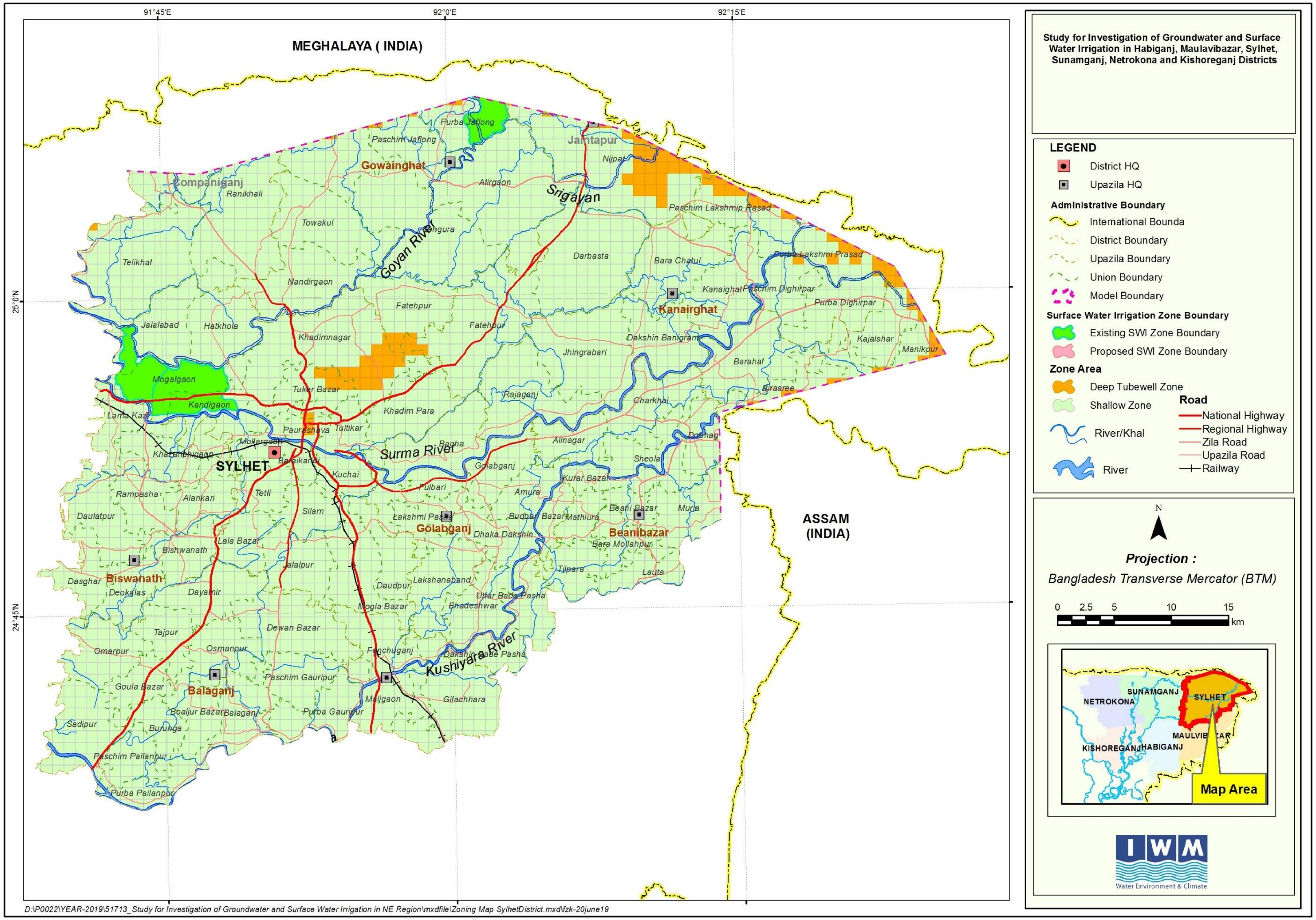


Figure 10-20: Zoning Map of Sylhet Districts

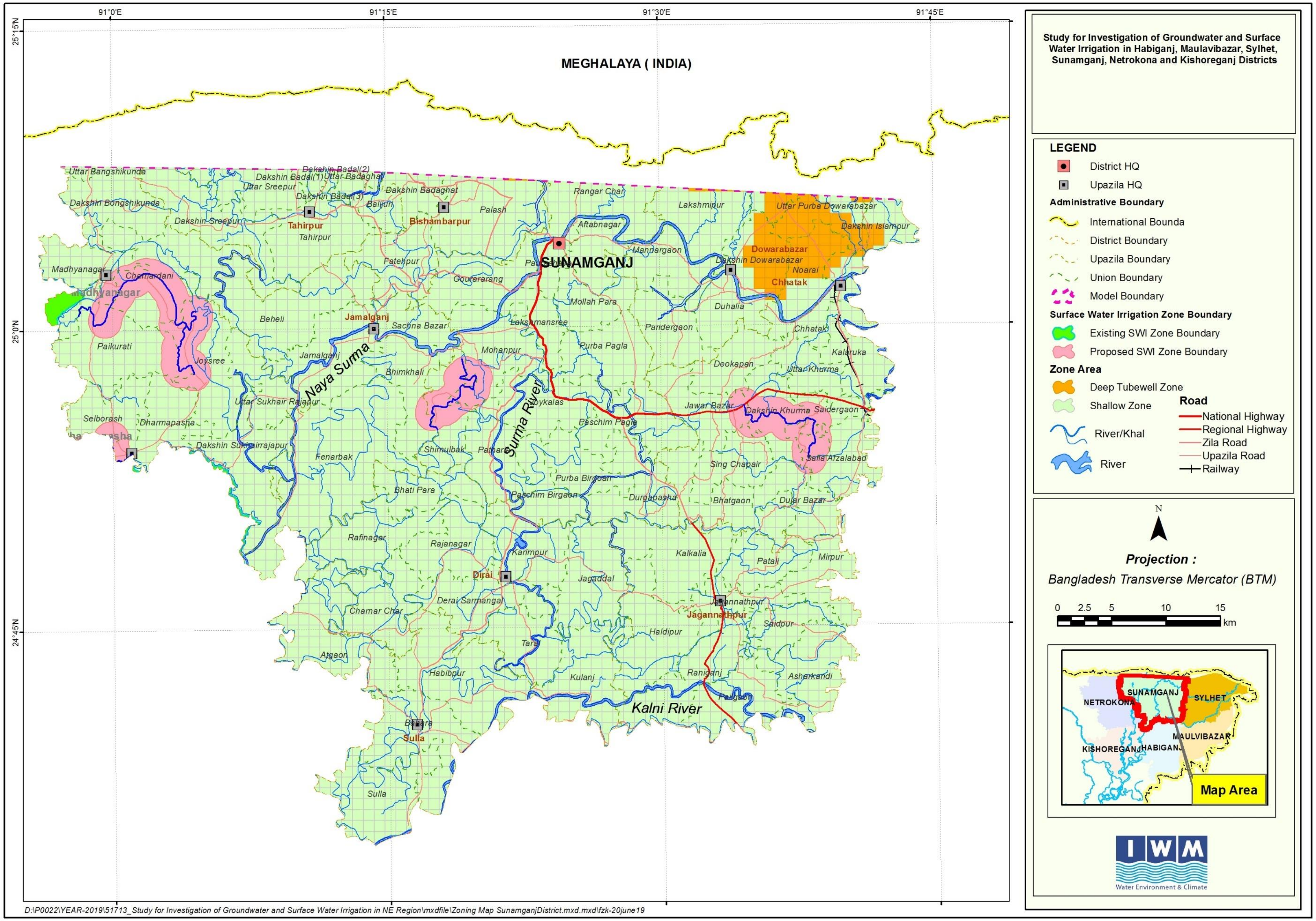


Figure 10-21: Zoning Map of Sunamganj Districts

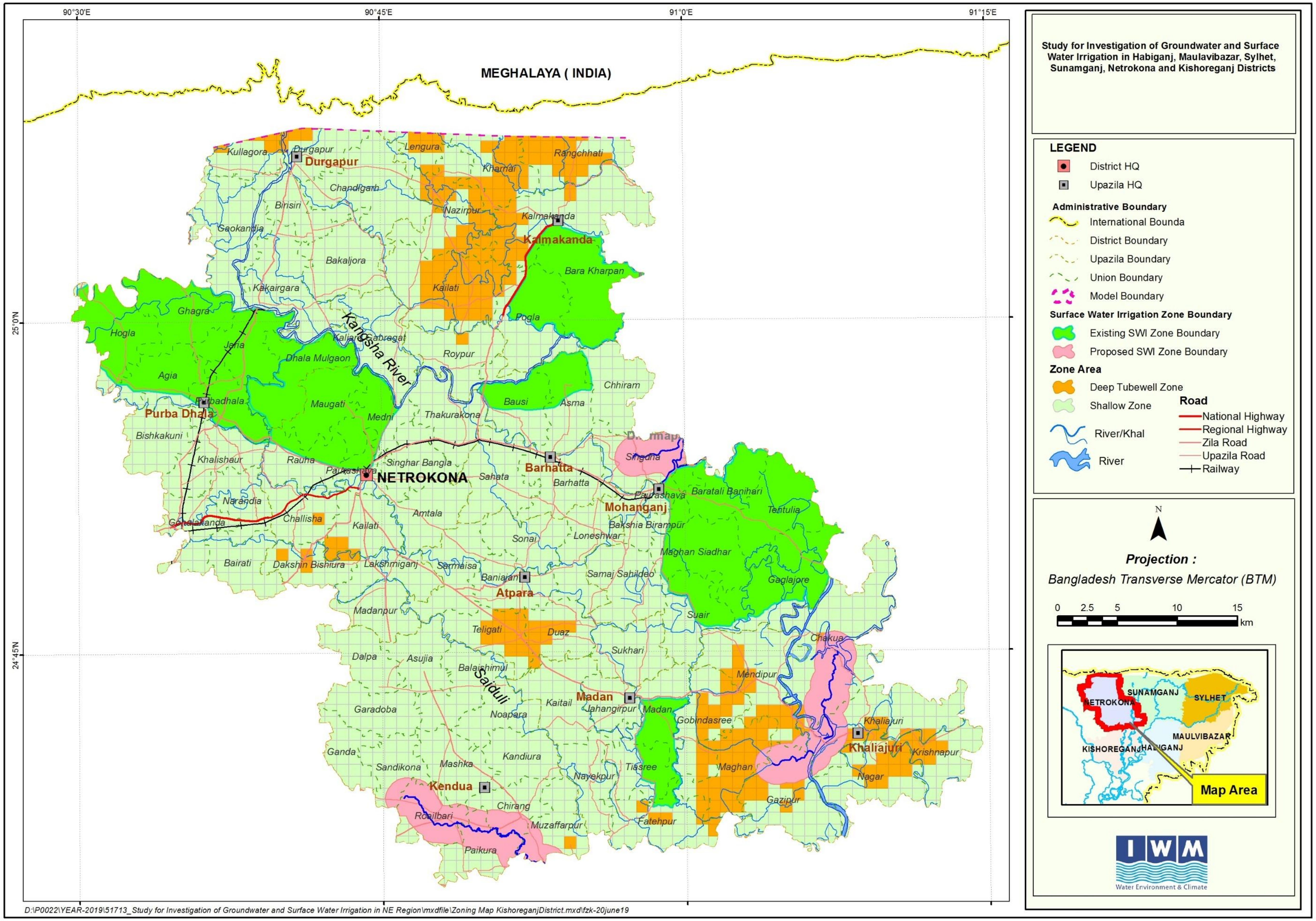


Figure 10-22: Zoning Map of Netrokona Districts

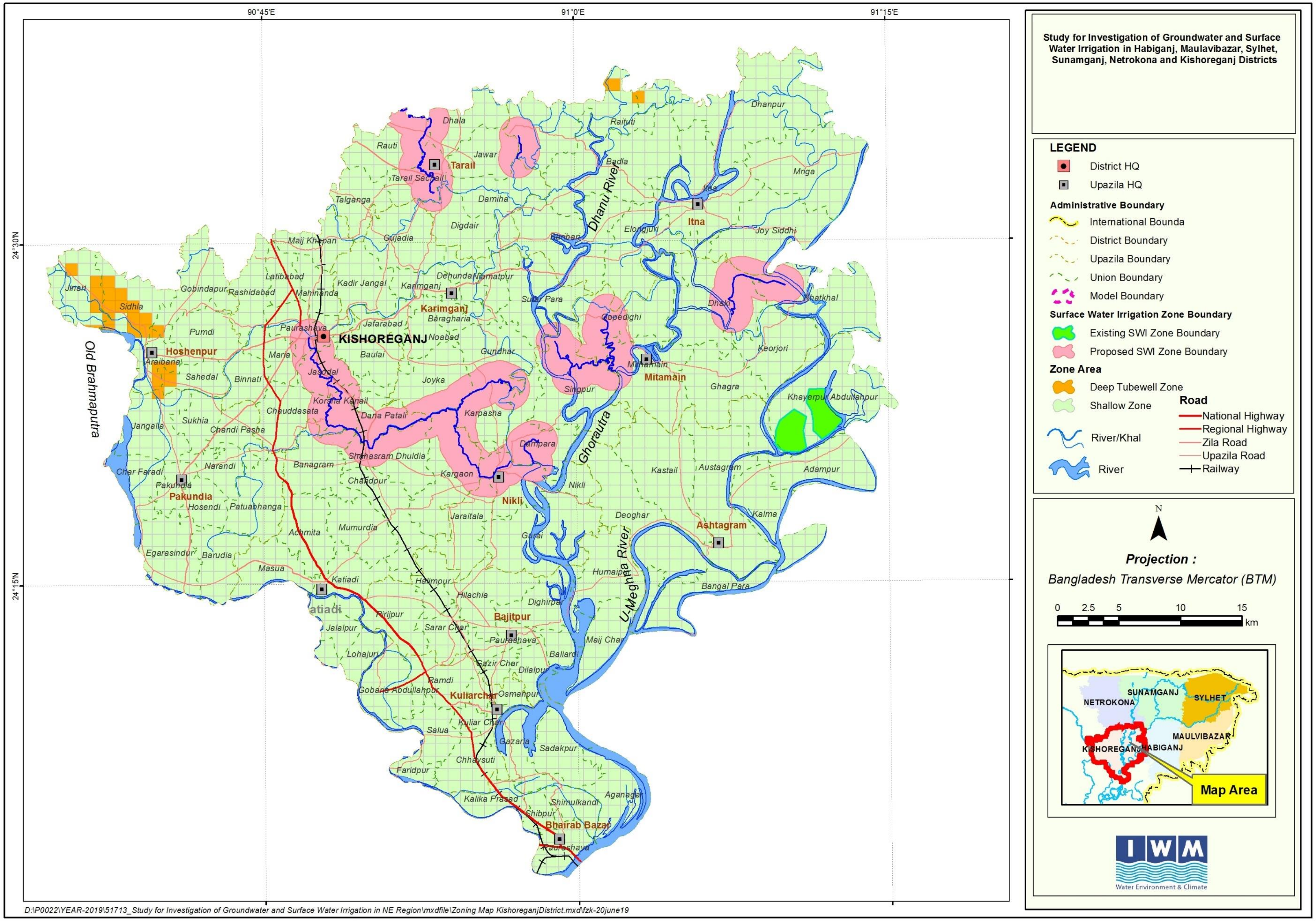


Figure 10-23: Zoning Map of Kishoreganj Districts

11 INTERACTIVE INFORMATION SYSTEM (IIS)

11.1 Introduction

Interactive Information System (IIS) is one of the deliverables of the Study for Investigation of Groundwater and Surface Water Irrigation in Habiganj, Moulvibazar, Sylhet, Sunamganj, Netrokona and Kishoreganj Districts". IIS is an Interactive Web GIS based Information System can be used as a groundwater monitoring tool for the study area.

11.2 Objectives

One of the objectives of the study was to develop an Interactive Information System (IIS) for storing, visualizing, manipulating, maintaining and managing a huge volume of hydrological, hydro-geological, meteorological hydro-geochemical, topographical, physiographical, soils and agricultural data for both spatial and spatio-temporal for the project area.

11.3 Output

The service has generated a number of specific outputs as follows:

The Web-GIS Application: The IIS has been developed with the current technology trend in ICT field. Several open source components and software solutions for web GIS based application development have been used. This opensource solutions are Geoserver for GIS Service creation and management, PostGreSQL database with post GIS for Spatial and non-spatial database development, and OpenLayer framework for GIS data visualization & management, JavaScripts, JQuery, bootstrap etc. have been.

The IIS comprises of several components and modules for supporting data management, visualization, data analysis, data retrieval and reporting. Hydrology and Hydro-meteorological data were the main components, which included various types of datasets such as Surface Water, Groundwater, Meteorological and geological time series and discrete datasets. The web application has been facilitated with Administrative Panels and general user interfaces providing different user's access privileges.

A number of application modules and components have been developed in the IIS application which are:

- GIS Core Module (GIS Maps & Layers)
- Hydrographs and Charts
- Data Import and Export
- Interface with online Base maps
- User Administration

Source Code and Executables: Repository of source codes of essential web application elements and executables.

11.4 Scopes of Works

During the project inception several scope of works and tasks have been identified according to Terms of Reference (ToR) for the study. The study has generated huge volumes of hydrological, hydrogeological, meteorological time series and related discrete data. To manage and maintain these datasets an Interactive Information System (IIS) is required for visualization through GIS, graphs, charts and reports, data entry, modifications and data export, data storage and management etc. The developed IIS will be used as a groundwater monitoring tool to the department. In order to develop the system following scope of works have been identified and accordingly carried out each activities which was set out in the scope. The scopes are:

- Identification Data, Sources & data Collection
- Database Development
- Web GIS Application Development

11.5 Approach and Methodology

A well-defined IIS development approach and methodology was carried out during IIS development lifecycle, which is shown in Figure 11-1.

11.5.1 Review Similar IIS Systems

IWM team reviewed several developed IIS for other similar studies/projects, this task included the following systems/IIS were reviewed:

- Management Information System (MIS) for Gorai River Restoration Project for BWDB
- Water Resources Database Management System in relation with the WARPO Water Resources database development.
- Management Information System (MIS) for Gorai River Restoration Project for BWDB
- MIS for Mathematical Modelling Study on Saline Water Intrusion to Assess Salinity Intrusion, Salinity Level, Sea Level Rise due to Climate change, Movement of Salinity

The concepts and the knowledge of the above systems were utilized in developing for current IIS development.

11.5.2 Requirement Analysis

A detail requirement analysis has been done after consultation with Client and study team during the inception period. The requirement analysis covered into three areas, which were the functional requirement of IIS, data resources, and software and hardware requirements to make the full functional of the IIS system.

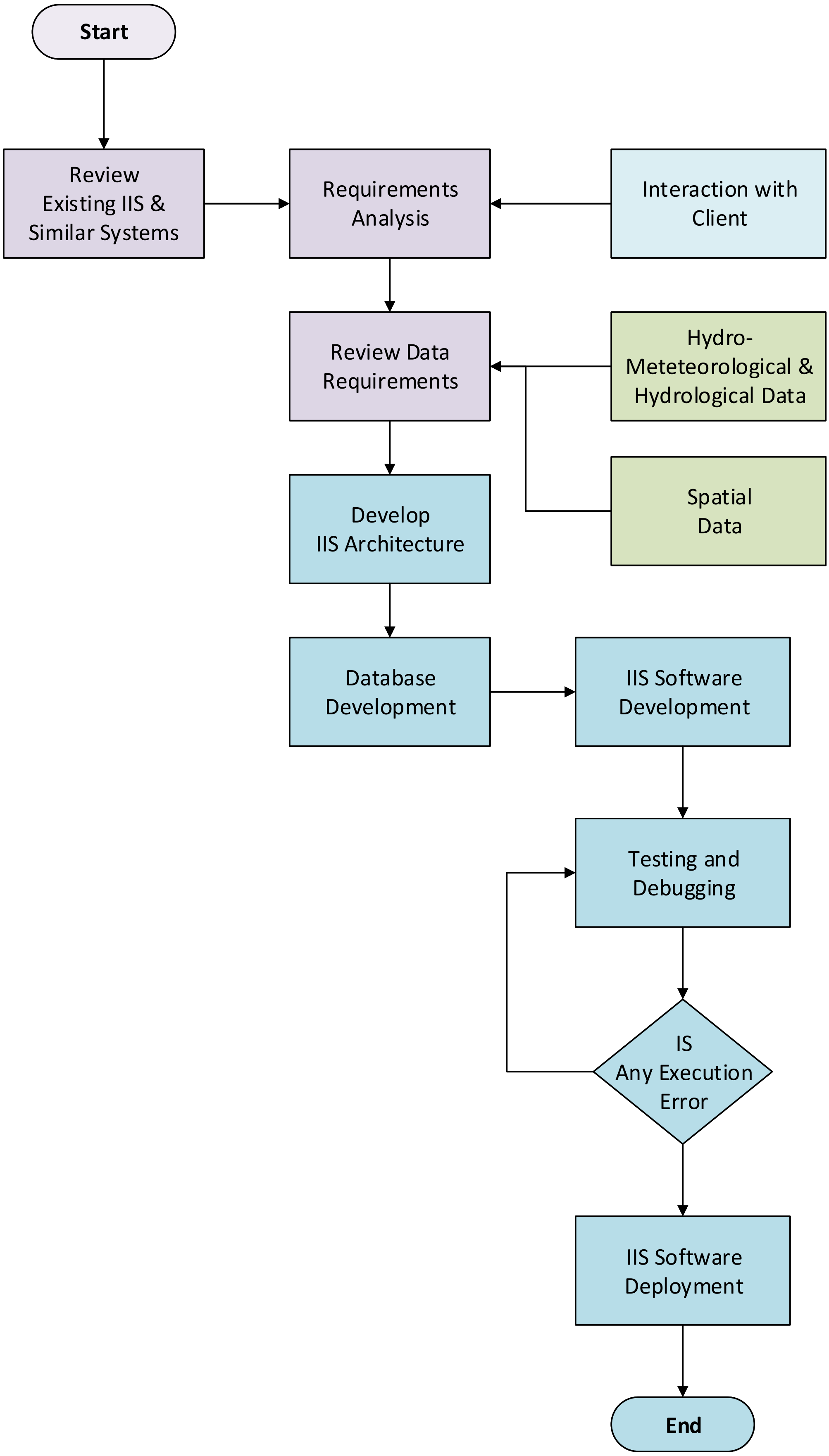


Figure 11-1: IIS Development Approach

11.5.3 Identification of Data Sources and Review Secondary Datasets

The required secondary datasets have been collected from different sources and processed them for IIS database. The following table illustrates the identified secondary data with their respective sources:

Table 11-1: Secondary Datasets

Sl. No.	Data Items	Data Types	Data Sources
1	**Hydrological data**		
1.1	*Water Level Observation Station*	Spatial	BWDB
1.2	*Time Series Water Level Data*	Tabular	BWDB
1.3	*River Discharge Location*	Spatial	BWDB
1.4	*Time Series River Discharge*	Tabular	BWDB
1.5		Tabular	BWDB
2	**Groundwater**		
2.1	*Groundwater Monitoring Well*	Spatial	BWDB
2.2	*Groundwater Table*	Tabular	BWDB
2.3	*Groundwater Quality*	Tabular	
3	**Hydro-meteorological**		
3.1	*Rainfall Observation Location*	Spatial	BWDB
3.2	*Rainfall Time Series Data*	Tabular	BWDB
4	**Geological**		
4.1	*Existing Borehole Lithology*		
4.2	*Aquifer Test Location Old (13)*		
4.3			
5	**Land Use**		
5.1	*Haor Settlement Location*	Spatial	
5.2	*Land Use*	Spatial	
6	**Soil Resources**		
6.1	*Soil Distribution*	Spatial	
7	**General Administrative Boundaries & Head Quarters**		
7.1	*District Boundaries*	Spatial	WARPO
7.2	*Upazila Boundaries*	Spatial	WARPO
7.3	*Union Boundaries*	Spatial	BBS
7.4	*District Head Quarters*	Spatial	LGED
7.5	*Upazila Head Quarters*	Spatial	LGED
7.6	*Union Headquarters*	Spatial	LGED
8	**Road Network**		
8.1	*Highways*	Spatial	RHD
8.2	*Rural Roads*	Spatial	LGED
8.3	*Bridge & Culverts*	Spatial	RHD & LGED
9	**Natural**		
9.1	*Seasonal Wetlands (dry and wet)*	Spatial	DBHWD
9.2	*River Network*	Spatial	WARPO/DBHWD
9.3	*Topographic land Level*	Spatial	SoB

Sl. No.	Data Items	Data Types	Data Sources
9.4	Physiographic units	Spatial	AEZ Maps, BARC
10	Population census	Tabular	BBS

11.5.4 Collection of Primary Datasets

The study project carried out extensive field survey for collecting several types of hydrological, geological and geo-physical datasets. All these datasets were processed and performed validation checks and uploaded into the developed IIS database. A list of these datasets is illustrated in the following Table 11-2.

Table 11-2: Primary Datasets

Sl. No.	Data Items	Data Types	Data Sources
1	**Hydrological data**		
1.1	*Surface Water Quality*	Spatial	Field Survey
2	**Groundwater**		
2.3	*Groundwater Quality*	Spatial	Field Survey
	Drilling Station Location (40)	Spatial	Field Survey
	New Production Tube Well Location (12)	Spatial	Field Survey
4	**Geological**		
4.1	*Aquifer Test Location New (12)*	Spatial	Field Survey
	Seepage Percolation Location (50)	Spatial	Field Survey
5	**Geo-physical**		
5.1	*Geophysical Detail Location (60)*	Spatial	Field Survey

11.5.5 Data Processing

The collected datasets have been reviewed for finding data gaps and inconsistencies, IWM team has corrected the errors, conducted validation checks, removed inconsistencies and inadequate and incomplete data to fulfill the project requirements and finally uploaded into the database systems. And finally, the uploaded data have been tested with the developed IIS system.

11.5.6 Database Development

The IIS database includes both spatial and tabular data in PostgreSQL database. The spatial data in-terms of shapefile were uploaded in the database using data importing tools based on the open GIS consortium (OGC). OGC is a worldwide spatial data standard and PostgreSQL supports this standard. Similarly, the tabular data have also been uploaded in to the database following the completion of database design and structuring. The required integrity rules were implemented in the database objects and tables.

11.5.7 Spatial Database Development

Spatial database design is a process which includes conceptual, logical, and physical design phases. Each of these phases ends in the creation of a product called a database model. A database model is used to populate a database. The design considered the spatial data storage and management techniques in database objects in PostgreSQL such as tables of spatial features and storage management. The term Spatial means something which are related to the earth surface. The spatial data combine the spatial (geographic/real-world coordinates) information with the attribute information of features in the database. So, the spatial reference system is vital for database creation, here in this case, WGS84 universal coordinate system has been implemented. All the spatial data and layers have been processed and uploaded into the database system.

Table 11-3: List of Spatial Datasets

Sl. No.	Data Items	Data Types	Descriptions
1	**Hydrological data**		
1.1	*Water Level Observation Station*	Spatial	Location of River Gauge Station
1.2	*Time Series Water Level Data*	Tabular	Time Series Water Level data
1.3	*River Discharge Location*	Spatial	Location of River Discharge
1.4	*Time Series River Discharge*	Tabular	Time Series data of River Water Discharge
1.5	*Surface water Quality*	Tabular	Surface water quality
2	**Groundwater**		
2.1	*Groundwater Monitoring Well*	Spatial	Location of Monitoring Well
2.2	*Groundwater Table*	Tabular	Groundwater Table
2.3	*Groundwater Quality*	Tabular	Groundwater Quality
2.4	*Drilling Station Location (40)*	Spatial	Location of new monitoring well
2.5	*New Production Tube Well Location (12)*	Spatial	Location of new production well
3	**Hydro-meteorological**		
3.1	*Rainfall Observation Location*	Spatial	Rainfall observation station
3.2	*Rainfall Time Series Data*	Tabular	Timeseries of rainfall data
4	**Geological**		
4.1	*Existing Borehole Lithology*	Spatial	Location of existing borehole
4.2	*Aquifer Test Location Old (13)*	Spatial	Old Aquifer Test Location
4.3	*Aquifer Test Location New (12)*		New Aquifer Test Location
4.4	*Seepage Percolation Location (50)*	Spatial	*Location of groundwater Seepage Percolation*
5	**Land Use**		
5.1	*Haor Settlement Location*	Spatial	Settlement Area
5.2	*Land Use*	Spatial	Land use map
6	**Soil Resources**		
6.1	*Soil Distribution*	Spatial	Soils distribution
7	**General Administrative Boundaries & Head Quarters**		

Sl. No.	Data Items	Data Types	Descriptions
7.1	*District Boundaries*	Spatial	District boundaries
7.2	*Upazila Boundaries*	Spatial	Upazla boundaries
7.3	*Union Boundaries*	Spatial	Union boundaries
7.4	*District Head Quarters*	Spatial	District headquarter
7.5	*Upazila Head Quarters*	Spatial	Upazila headquarter
7.6	*Union Headquarters*	Spatial	Union headquarter
8	**Road Network**		
8.1	*Highways*	Spatial	Highway Road Network
8.2	*Rural Roads*	Spatial	Rural roads
8.3	*Bridge & Culverts*	Spatial	Location of Bridges and culverts
9	**Natural**		
9.1	*Seasonal Wetlands (dry and wet)*	Spatial	Seasonal Wetlands
9.2	*River Network*	Spatial	River Network
9.3	*Topographic land Level*	Spatial	Topographic land height
9.4	*Physiographic units*	Spatial	AEZ Maps, BARC
9.5	*Geophysical Detail Location (60)*		Geophysical sample Location

11.5.8 Non-Spatial Database

This section outlines the steps for designing non-spatial database particularly Schemes and relations, which have been followed during the database development stage. Conceptual data model determines logical understanding the datasets. The database design and development consist of conceptual design, Logical Design, Physical Design, database development and implementation.

The steps for physical data model design are as follows:

- Specification of all possible tables and columns.
- Foreign keys have been used to identify relationships between tables.
- Allowed de-normalization, which was required based on different categories of datasets.
- Physical data model is quite different from logical data model

Physical data model based on PostgreSQL Database System since that the database have been developed with PostgreSQL database System.

- Identifying entities and converted them into tables.
- Identifying relationships among tables and defined Primary and foreign keys.
- Identifying attributes and defined them into columns.
- Creation of Physical data model based on physical constraints / requirements.

According to the database modelling, database design and structuring has been completed with the implementation of Entity Relationship among database objects (data integrity rules). The development of non-spatial data covered the datasets illustrates in the Table 11-4.

Table 11-4: List of Non-Spatial Datasets

Sl. No.	Data Items	Data Types	Descriptions
1	**Hydrological data**		
1.2	*Time Series Water Level Data*	Tabular	Time Series Water Level data
1.4	*Time Series River Discharge*	Tabular	Time Series data of River Water Discharge
1.5	*Surface water Quality*	Tabular	Surface water quality
2	**Groundwater**		
2.2	*Groundwater Table*	Tabular	Groundwater Table
2.3	*Groundwater Quality*	Tabular	Groundwater Quality
3	**Hydro-meteorological**		
3.2	*Rainfall Time Series Data*	Tabular	Timeseries of rainfall data
4	**Geological**		
4.1	*Existing Borehole Lithology (material code and quantity)*	Tabular	Location of existing borehole
4.2	*Aquifer Test Location Old (13)*	Tabular	Old Aquifer Test Location
4.3	*Aquifer Test Location New (12)*	Tabular	New Aquifer Test Location
7	**Population Census**		
7.1	*District*	Tabular	District boundaries
7.2	*Upazila*	Tabular	Upazla boundaries
7.3	*Union*	Tabular	Union boundaries

11.6 IIS Software Design and Development

11.6.1 IIS Software Design Approach

The objective of this section is to provide an IIS Software design framework or architecture for hydrology, hydro-meteorological and related data management tool for the project area. The conceptual framework presents the fundamental design principles of scientific visualization and reporting tool, data processing and data management. A conceptual framework was considered for integration of available and project generated data. Also, the framework considered the sustainability of the system as well as the possibility of further development and upgrading of all components and tools and as well as database updating.

The followings components and modules were recognized as the fundamental requirements of the developed IIS:

- An effective and properly designed hydrology, hydro-meteorological, hydro-geological, hydor-geochemical system reflecting the hydrologic and climate characteristic of the project area.
- Data visualization and reporting, data management and storing system.

- A groundwater monitoring system, which supports the information needs for the project and as well as the department.
- The developed IIS is an efficient data and information collecting, processing, and disseminating system to support decision-making functions of government as well as for effective guidance for groundwater usage and increased safety for groundwater use for Irrigation purposes in the project area.

The developed IIS comprised of several components which enable users to support for data management, visualization, data analysis, data retrieval and reporting. These components are described in a high-level data model is shown in Figure 11-2, which indicates the developed functions and activities specifically have required to build the IIS system.

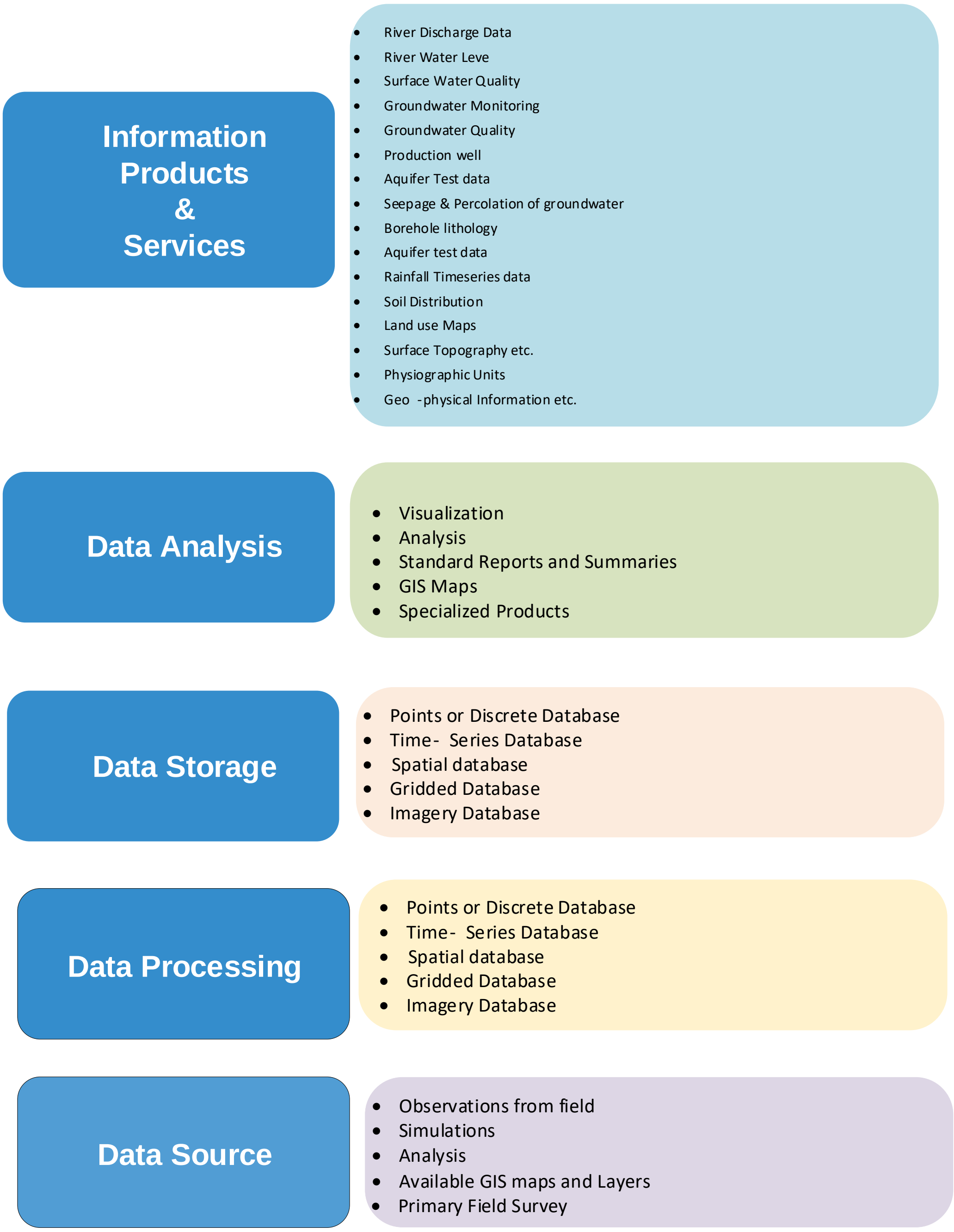


Figure 11-2: High Level Data Model in IIS

GIS Mapping: The developed IIS include interface with a web GIS mapping. GIS modules is a center point on which the user can interact with all the datasets and layers. The spatial query, spatial analysis, is used in this mapping module. The GIS module interface with the online base maps such as Open Street maps.

GIS mapping module is populated with the standard GIS functionality tools of Pan, Zoom, Identify, Query Selections, Scale change etc. A layout section is also be embedded with this mapping module.

11.6.2 IIS Software Development Life Cycle

Agile Software Development Life Cycle (SDLC) has been utilized to develop the IIS. Agile SDLC model as shown in Figure 11-3 is a combination of iterative and incremental process models with focus on process adaptability and customer satisfaction by rapid delivery of working software product. Agile methods break the product into small incremental builds. These builds are provided in iterations.

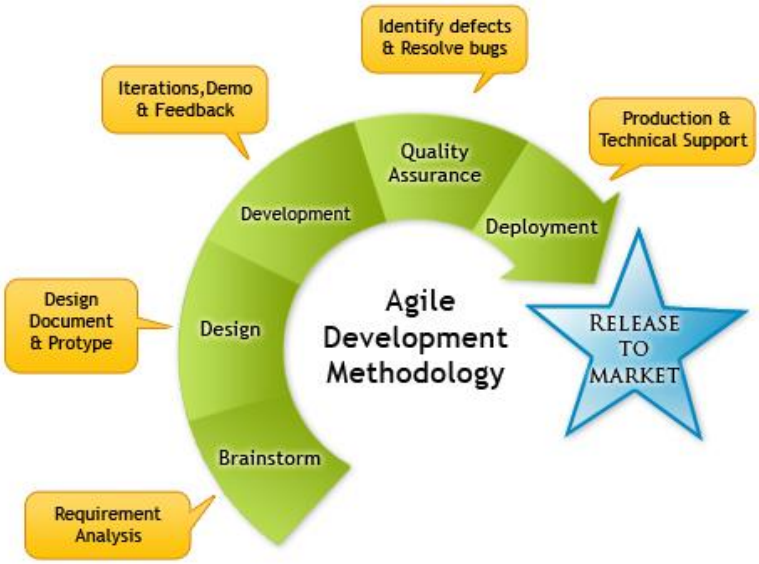


Figure 11-3: Agile Software Development Life Cycle

11.6.3 Testing and Debugging

The objective of software testing and debugging is to ensure that all the system elements have been properly integrated and perform allocated functions as per the requirements specifications.

A test environment has been established in production environment. The software operating system, database server and required runtime software application similar to the final IIS system with same version was created in the test environment. Server operating system, web server, database server and web application of same version is used to create the test environment. To verify and validate the application software developed with respect to its functional, technical and environmental requirements black box system testing has been carried out in the testing environment. Features and functionality were tested in a fully integrated manner. All the defects identified during the test were listed in a log sheet and passed it to the programmer for removing bugs and defects.

11.6.4 Software & Hardware Platform

The developed IIS system have been developed and implemented with the following software and tools are indicated in the following Table 11-5:

Table 11-5: Software Platform

Sl. No.	Software Specification	Type	Purpose
1	Open Layer	Web Framework	GIS functionalities
2	Java Scripts, API, JQuery, HTML5, CSS, Bootstap	Front End	Web Forms & Functionalities
3	Geoserver	Server (backend)	GIS Server
4	PostgreSql with Post GIS	Database System	Database System, capable of handling GIS layers
5	Windows Operating System (Latest version for Windows Server)	OS	Operating System

11.7 System Deployment and Handover

The developed web GIS based IIS system has been deployed at the head office premises of DBHWD after the installation of required Hardware and Software. Following the deployment of the System, the System is brought into user access to use. Once the developed IIS is free of any bugs and errors and up and running well in WWW, the developed IIS is handed over to the client.

11.8 Screenshots from Web GIS Based IIS

The following few snapshots were taken from website of IIS. Web GIS map interface is shown in Figure 11-4; Figure 11-5 shows the web interface of all layers in the IIS; Figure 11-6 shows the identification of any layer feature in web GIS map and the Figure 11-7 illustrates Water Level Hydrograph of a selected water level Gauge station.

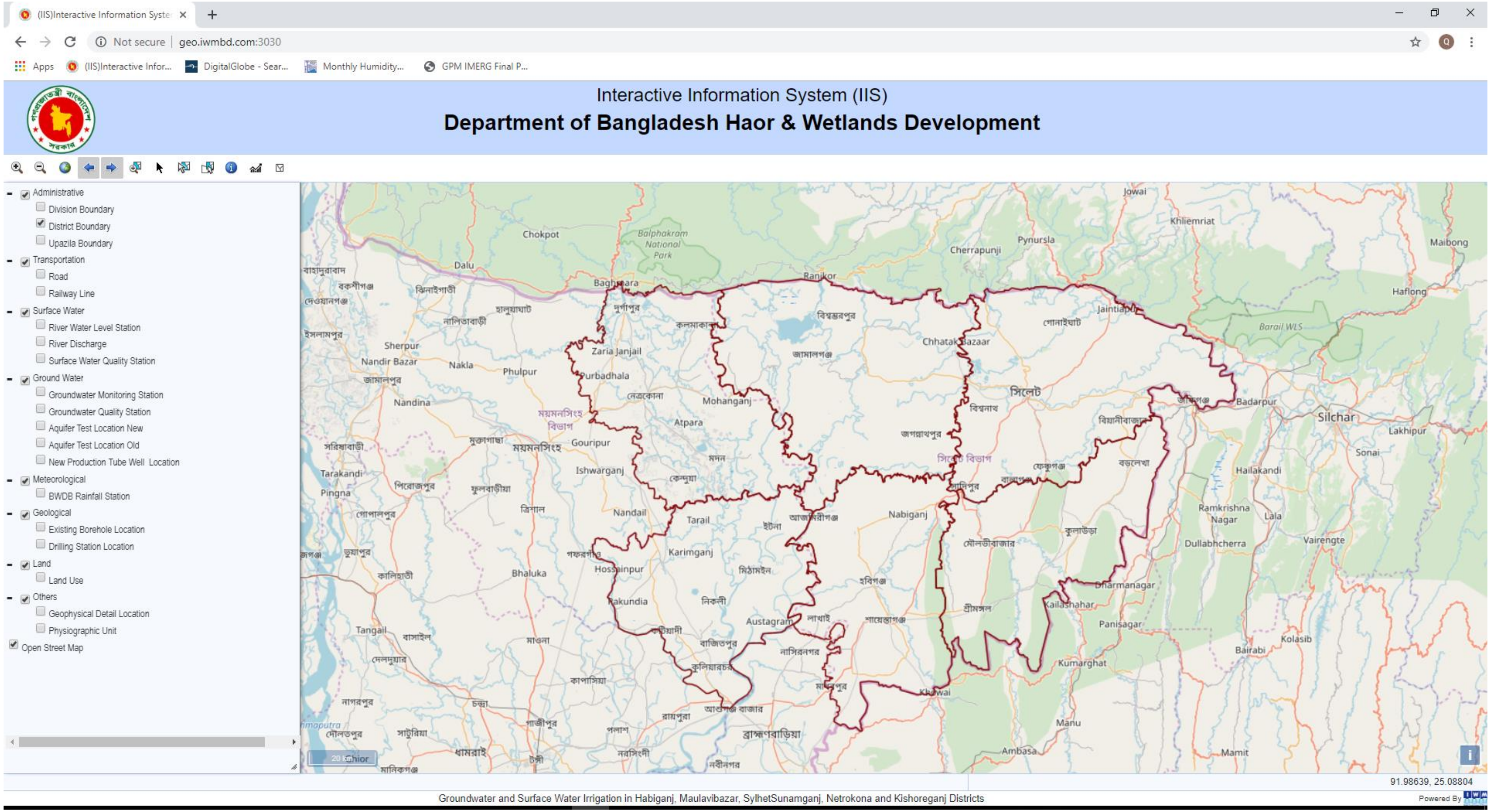


Figure 11-4: Web GIS Map Interface of Developed IIS

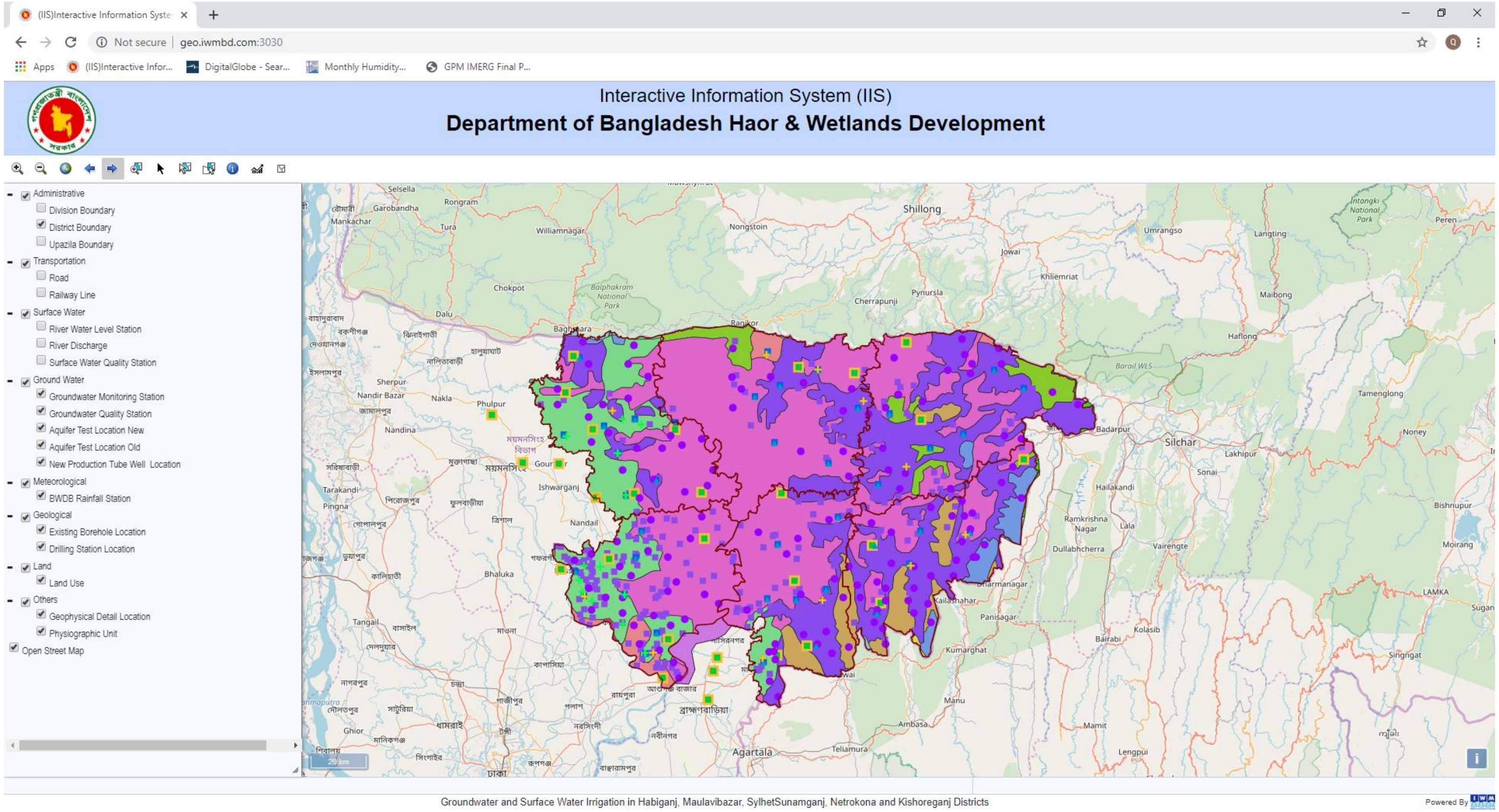


Figure 11-5: All GIS Layers in Web GIS Interface of IIS

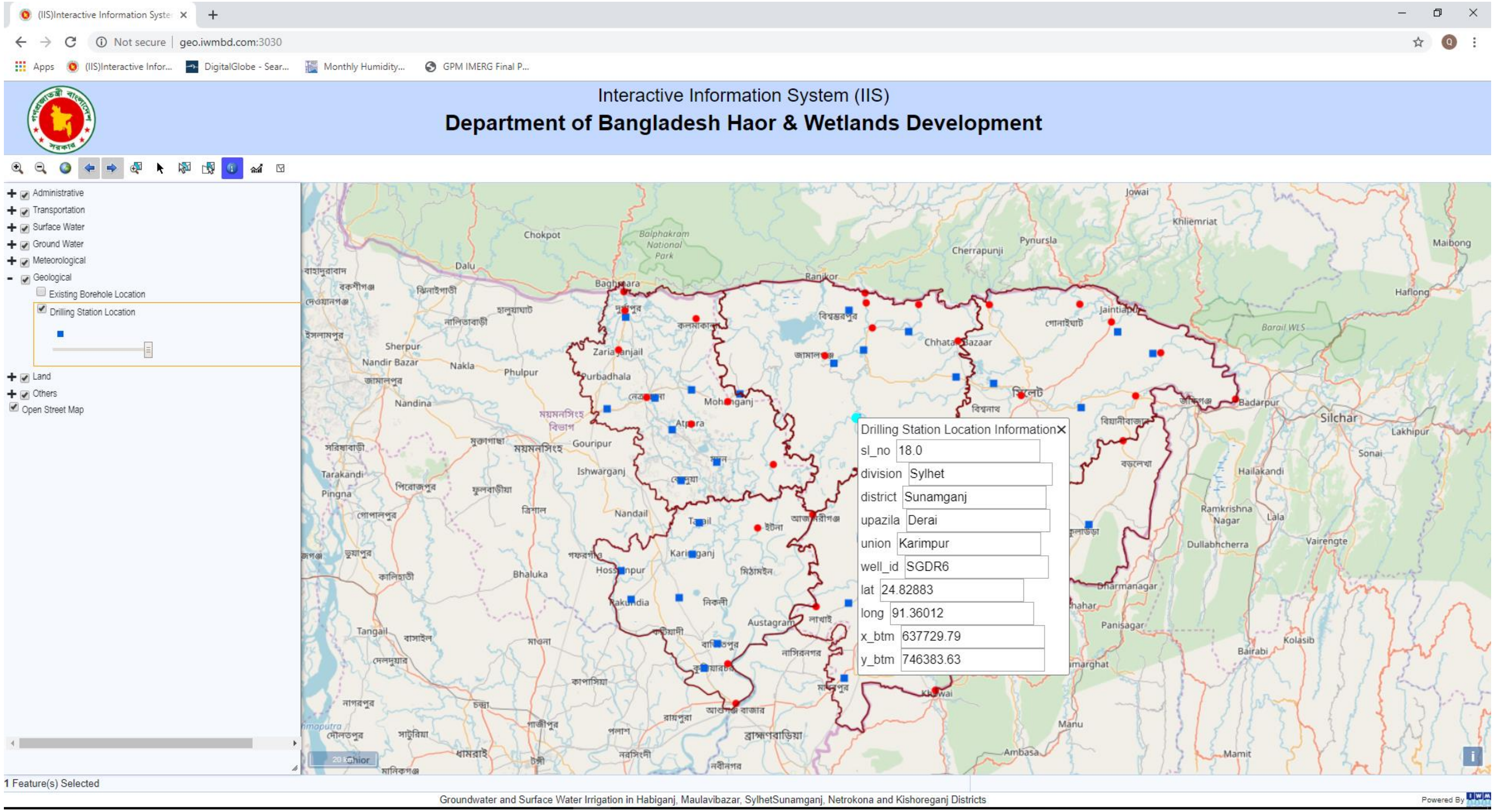


Figure 11-6: Identify Feature on Web GIS Map in IIS

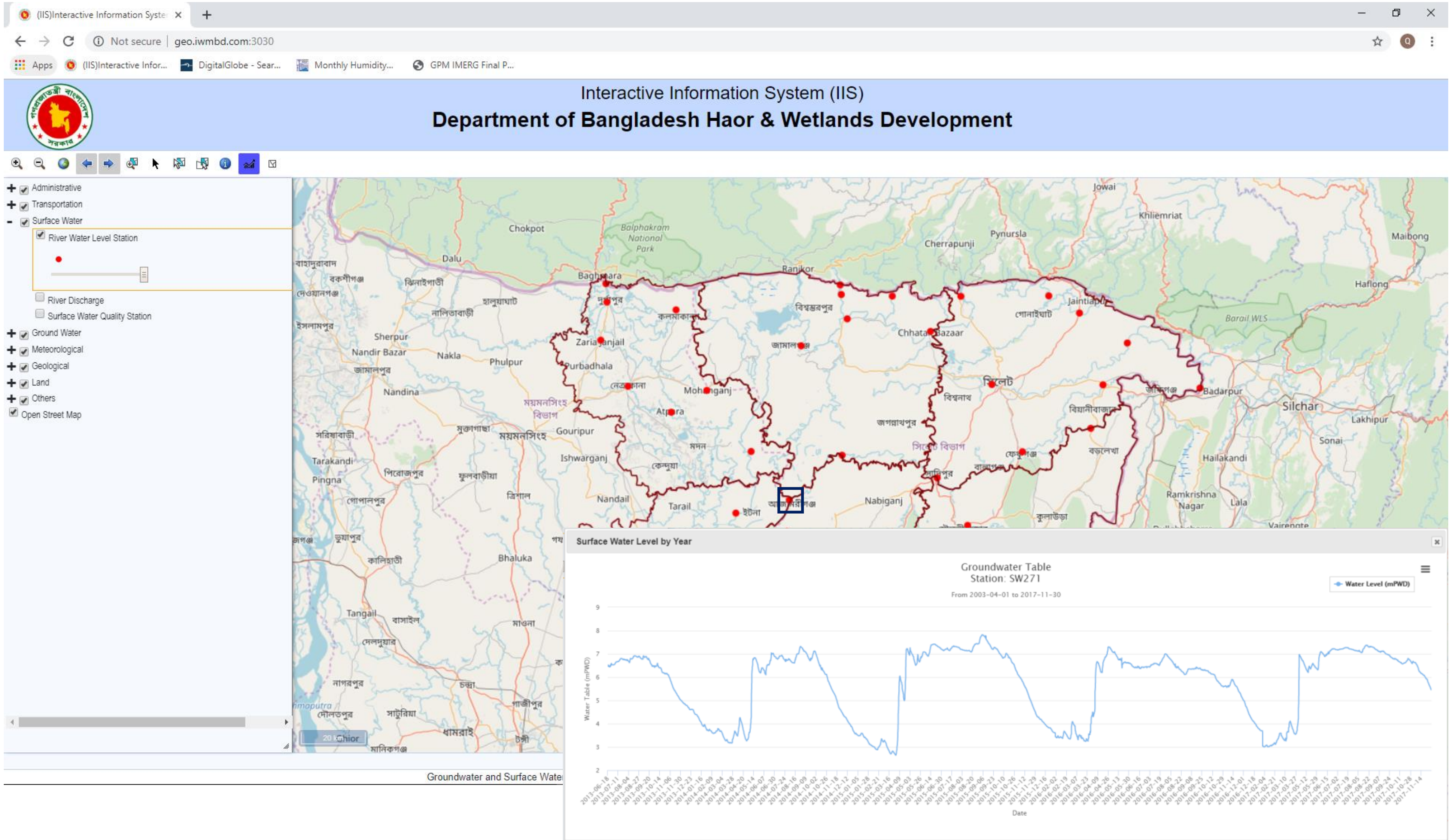


Figure 11-7: Showing Water Level Hydrograph for a Selected Gauge Station in IIS

12 WORKSHOP AND TECHNOLOGY TRANSFER

12.1 Workshop

According to the provision of the ToR, workshops have been arranged in the local level as well as national level with all the stakeholders to disseminate and share the study results. Because, decisions regarding water resources management can affect nearly every sector of the economy and the public as a whole, and stakeholder participation should be established in a form that elicits direct input from people at all levels of engagement. Stakeholder involvement should be an integral part of water resources management, at all stages of the project cycle. Towards that objective there should be complete orientation of the institutions for increasing the role of stakeholders and the civil society in decision making and implementation of water projects.

12.1.1 Workshops at Local Level

Six numbers of people’s participatory workshops have been arranged in the field level covering the project area for exchanging ideas and views with stakeholders and hence disseminating and sharing study findings with the clients, beneficiaries and decision makers as shown in Figure 12-1 to Figure 12-6. The detailed list of workshops has been presented in Table 12-1. All the workshops have been organized jointly by DBHWD and IWM at different locations. The list of the participants has been presented in Volume-II, Appendix L. The Draft Final Report was prepared incorporating the comments and suggestions of the local workshops. The comments and suggestions as well as the compliance from IWM have been illustrated in Table 12-2.

Figure 12-1: Workshop at Netrokona

Figure 12-2: Workshop at Kishoreganj

Figure 12-3: Workshop at Maulavibazar

Figure 12-4: Workshop at Habiganj

Figure 12-5: Workshop at Sylhet

Figure 12-6: Workshop at Sunamganj

Table 12-1: Details of Workshops

Sl. No.	Date	Venue
1	April 17, 2019	Conference Room of Deputy Commissioner, Netrokona
2	April 18, 2019	Conference Room of Deputy Commissioner, Kishoreganj
3	April 29, 2019	Conference Room of Deputy Commissioner, Maulavibazar
4	April 30, 2019	Conference Room of Deputy Commissioner, Habiganj
5	May 12, 2019	Conference Room of Deputy Commissioner, Sylhet
6	May 13, 2019	Conference Room of Deputy Commissioner, Sunamganj

Table 12-2: Comments and Compliance of Local Level Workshops

Sl. No.	Comments and Suggestions	IWM Compliance
Workshop at Netrokona		
Md. Khairul Islam, Upazila Chairman, Atpara		
01	During infrastructure development in hoar area there should have navigation facilities.	Agreed and mentioned in Section-13.2.
02	Conservation of surface water with in natural reservoir (beel, haor etc.) and use of this water for irrigation purpose through rationing can be done which will reduce the dependency on groundwater.	Agreed
Upazila Chairman, Netrokona Sadar		
01	Is there any change in hydrologic cycle in the study area due to climate change?	The impact assessment of climate change is very crucial needs but its beyond the ToR and necessary inputs are not provided.

K. M Shafiqul Haque, Upazila Chairman, Mohonganj		
01	Dry season irrigation facilities can be achieved through the dredging of Kongso River.	A comprehensive study can be taken to investigate the feasibility of dredging to enhance dry season irrigation facilities.
02	Re-excavation of major khals is highly desirable.	Agreed and mentioned in Section-13.2.
03	Possibility of SW based irrigation should be investigated through technical expert.	Possibility of SW based irrigation has been investigated but for implementation detail design and feasibility study is needed.
04	There should have coordination among different organization, department such as BIWTA, BWDB, BADC, LGED, DPHE, DAE etc.	Agreed and mentioned in Section -13.2.
Salma Akther, Additional Deputy Director (Crop), DAE		
01	Crop diversification can be suggested for less water demanding crop such as Maize, Wheat.	Agreed and mentioned in Section-13.2.
02	Formulation of project should be based on considering the problems of Haor area.	Agreed
Moinul Islam, Deputy Commissioner, Netrokona		
01	The present study is relevant to the goal with SDG-6.	Agreed
02	Proper coordination is required among different organization and department.	Agreed and mentioned in Section-13.2.
03	Large scale dredging through technical study and monitoring is necessary in haor area.	Agreed and mentioned in Section-13.2.
04	Proper planning is required to protect the bio-diversity of haor area.	Agreed
Md. Majibur Rahman, Director General, DBHWD		
01	The study has been formulated in haor area as there was no comprehensive study for assessment of surface water and groundwater earlier.	------
02	As per government policy surface water based irrigation is encouraged.	Agreed and mentioned in Section-13.2.
03	The actual recharge of haor region is estimated under this study which will be helpful for planner and decision maker.	Agreed
K M Abdul Wadud, Project Director		
01	The report should be well conversant and understandable for all the stakeholders.	Agreed and prepared accordingly.
02	The relevant comments from this workshop should be incorporate in the Draft Final Report.	Agreed and comments from the workshop has been incorporated in the Draft Final Report.
Workshop at Kishoreganj		
Saiful Islam, AC (Land), Eitna, Kishoreganj		
01	Possibilities of loop cutting for river can be investigated.	River should allow to maintain their natural route rather than loop cutting or other interventions of rivers.

02	Is there any plan to construct irrigation canal for surface water based irrigation?	As there is a huge loss in irrigation canal so buried pipe is recommended as mentioned in Section-13.2.
Md. Shamsul Haque, Senior Information Officer, Kishoreganj		
01	How the database, developed under this study, will be used in field level?	DBHWD will take initiatives to disseminate the database as per their organizational rules.
02	Is there any future projection has been studied for long term prediction?	Under this study an option has been studied considering future drought condition as mention in Section-10.3.2.
Istart Sadmin, UNO, Bhairab		
01	An integrated research for water quality of drinking and irrigation purpose should be investigated.	A comprehensive research can be taken to investigate the water quality as mentioned in Section-13.3.
Wahiudzzaman, AC (Land), Hossenpur		
	The report should incorporate the detail information so that the stakeholder/farmers may have an idea about the depth of tubewell.	A comprehensive finding on geological formation has been studied under this study and mentioned in Section-5.3.
	The study should take in consideration the geological formation of old Brahmaputra basin to assess the recharge pattern of the haor area.	Agreed and considered accordingly.
Md. Mostafa Ruhul Amin, Farm Manager, DoF		
01	Fish sanctuary should be identified.	A separate study can be proposed as it is beyond the scope of works under the present study as mentioned in Section-13.3.
02	For any infrastructure related project there should have coordination among different organization/department.	Agreed and mentioned in Section-13.2.
Abdul Wahab Ainuddin, Upazila Chairman, Kotiadi		
01	Uses of irrigation water are not in a planned way.	Agreed
02	Domestic water should be available for all the stakeholders.	Agreed
Md. Sarwar Morshed, Deputy Commissioner, Kishoreganj		
01	Proper coordination is required among different organization and department.	Agreed and mentioned in Section-13.2.
02	The database developed under this study will be useful for field level users.	Agreed
Md. Majibur Rahman, Director General, DBHWD		
01	The study has been formulated in haor area as there was no comprehensive study for assessment of surface water and groundwater earlier.	Agreed
02	As per government policy, surface water based irrigation is encouraged.	Agreed
03	The actual recharge of haor region is estimated under this study which will be helpful for planner and decision maker.	Agreed

04	As per government policy, river management practice will be done instead of river training works.	Agreed
K M Abdul Wadud, Project Director, DBHWD		
01	Less water demanding crop has to be encouraged.	Agreed and mentioned in Section-13.2.
02	Crop diversification can be suggested for less water demanding crop such as Maize, Wheat.	Agreed and mentioned in Section -13.2.
03	The relevant comments from this workshop should be incorporate in the Draft Final Report.	Agreed and comments from the workshop has been incorporated in the Draft Final Report.
Workshop at Moulvibazar		
Ashim Chandra Bonik, UNO, Juri		
01	The study will be helpful to allocate the tubewell for domestic and irrigation purposes.	Agreed
02	The study output should be easily understandable.	Agreed and prepared accordingly.
Md. Kamal Hossan, Upazila Chairman, Moulvibazar Sadar		
01	Master plan of Haor area should be for the duration of 50 years.	A comprehensive study to formulate Haor Master Plan considering 50 years duration is recommended as mentioned in Section-13.3.
Bohshi Iqbal, Convener, Manu Project and Haor Rokkha Committee		
01	Rehabilitation of pumps and other infrastructure of Manu Irrigation project are required.	Agreed and mentioned in Section-13.2.
02	A study for draining out of water from upstream of Kawa Digi Haor is necessary.	This study has been recommended in Section-13.3.
03	Manu River, Hakaluki Haor, Hail Haor has to be dredged.	This is beyond ToR.
04	New fish sanctuary has to be buildup.	A separate study can be proposed as it is beyond the scope of works under the present study as mentioned in Section-13.3.
Prof. Dr. M. Monowar Hossain, ED, IWM		
01	Haor area sinks and silted up each year which needs to address through a field survey and mathematical modelling study.	A comprehensive study is recommended to address the phenomenon of sedimentation and sink in haor area as mentioned in Section-13.3.
02	A hydrogeological study should be conducted to determine the spacing of tubewell and aquifer mapping.	A separate study can be proposed as it is beyond the scope of works under the present study as mentioned in Section-13.3.
03	Volume of water comes from transboundary river in hoar region has to be assessed.	A separate study can be proposed as it is beyond the scope of works under the present study as mentioned in Section-13.3.
Md. Majibur Rahman, Director General, DBHWD		
01	The study has been formulated in haor area as there was no comprehensive study for assessment of surface water and groundwater earlier.	Agreed

02	As per government policy, surface water based irrigation is encouraged.	Agreed
03	The actual recharge of haor region is estimated under this study which will be helpful for planner and decision maker.	Agreed
04	As per government policy, river management practice will be done instead of river training works.	Agreed
K M Abdul Wadud, Project Director, DBHWD		
01	Less water demanding crop has to be encouraged.	Agreed and mentioned in Section-13.2.
02	Crop diversification can be suggested for less water demanding crop such as Maize, Wheat.	Agreed and mentioned in Section -13.2.
03	Solid waste management is necessary.	A separate study can be proposed as it is beyond the scope of works under the present study as mentioned in Section-13.3.
04	The relevant comments from this workshop should be incorporate in the Draft Final Report.	Agreed and comments from the workshop has been incorporated in the Draft Final Report.
Workshop at Habiganj		
Azizul Islam, Executive Engineer, BADC		
01	Surface water irrigation has to be promoted.	Agreed and mentioned in Section-13.2.
02	Awareness program has to be conducted in the field to motivate farmer for cultivation of less water demanding crops.	Agreed and mentioned in Section-13.2.
03	Navigation facilities have to be improved to carry paddy by boat during dry season.	A separate study can be proposed as it is beyond the scope of works under the present study as mentioned in Section-13.3.
04	Flow of river has to be maintained through re-excavation.	Agreed
05	Buried pipe system for surface water irrigation should be recommended.	Agreed and mentioned in Section-13.2.
Shekh MD. Abu Zakir Sakendar, Executive Engineer, LGED		
01	Regulatory structure has to be constructed for proper drainage and navigation purposes.	Agreed and recommended in Section-13.2.
02	The findings from the study should be recommended for implementation.	Agreed.
Fazlul Zahid Pavel, ADC (G), Habiganj		
01	Long term haor master plan considering climate change and other human intervention should be adopted instated of existing short term haor master plan.	A comprehensive study to formulate Haor Master Plan considering climate change and other human interventions is recommended as mentioned in Section-13.3.
02	The findings from the study should be recommended for implementation.	Agreed.
03	Comprehensive study for Industrial Waste management especially for Habiganj, Sayestaganj and Madhbpur industrial area should be taken immediately.	Agreed and mentioned in Section -13.3.

Prof. Dr. M. Monowar Hossain, ED, IWM		
01	Re-excavation of major river/khal should be promoted for round the year boat transport facilities.	Agreed.
02	Regional co-operation should be promoted.	Agreed.
03	Present study should be further updated including climate change scenario.	Agreed and mentioned in Section-13.2.
Md. Majibur Rahman, Director General, DBHWD		
01	The study has been formulated in haor area as there was no comprehensive study for assessment of surface water and groundwater earlier.	Agreed.
02	As per government policy, surface water based irrigation is encouraged.	Agreed.
03	The actual recharge of haor region is estimated under this study which will be helpful for planner and decision maker.	Agreed.
04	As per government policy, river management practice will be done instead of river training works.	Agreed.
K M Abdul Wadud, Project Director, DBHWD		
01	Less water demanding crop has to be encouraged.	Agreed and mentioned in Section-13.2.
02	Crop diversification can be suggested for less water demanding crop such as Maize, Wheat.	Agreed and mentioned in Section-13.2.
03	Pollution control is necessary.	Agreed.
Workshop at Sylhet		
Pronjit Kumer Deb, Executive Engineer, BADC		
01	Expansion of irrigation area by constructing buried pipe through using of LLP.	Agreed and mentioned in Section-13.2.
02	A comprehensive study including Social, Environmental, and Ecological should be taken.	Agreed and mentioned in Section-13.3.
M. M. Elias, Deputy Director, DAE		
01	Groundwater contains high concentration of Iron and reduces the fertility of agricultural land as such a study has to be conducted for remedial as well as assessment of long term impact.	A comprehensive study has been recommended to investigate long term impact of iron on fertility and its remedial measures as mentioned in Section-13.3.
Minto Chowdhuay, UNO, Dhakin Surma		
01	Beel has to be re-excavated to store surface water for irrigation purpose.	Beyond the scope of works under the present study.
02	The uses of GW have to be reduced.	Agreed.
Biswjit Kumer Paul, UNO, Gowainghat		
01	90% of Beel has been silted up which need to be re-excavated to store surface water for irrigation purpose. This will also increase the fish production.	Beyond the scope of works under the present study.

Ayesha Haque, UNO, Fenchuganj		
02	Dreading of river should be in planned way.	Agreed.
03	Spoil management of dredged materials should be conducted in a proper way.	Agreed.
Md. Majibur Rahman, Director General, DBHWD		
01	The report should recommend the uses of combined harvester.	Agreed and mentioned in Section-13.2.
02	Surface water irrigation has to be increased through using LLP.	Agreed.
M. Kazi Emdadul Islam, Deputy Commissioner, Sylhet		
01	This research will enhance the development of Haor area.	Agreed.
Workshop at Sunamganj		
Md. Habibur Rahman, Sub-Assistant Engineer, BADC		
01	Only surface water based irrigation should be recommended for Sunamganj District.	------
02	For future study, collaboration between BADC and DBHWD is required.	Agreed.
Koruna Shindhu Chowdhury, Upazila Chairman, Tahirpur		
01	Fish sanctuary has to be protected.	A separate study can be proposed as it is beyond the scope of works under the present study as mentioned in Section-13.3.
02	Eco-tourism should be promoted for haor area.	Agreed.
03	Tanguar haor has to be management through a holistic approach.	Agreed.
04	Stakeholder’s involvement as beneficiaries should be included.	Agreed.
Kashmir Reza, Poribesh and Haor Unayan Shangsta		
01	Re-excavation of Haor should be recommended.	Beyond the scope of works under the present study.
02	Fish catching should be stop during fish breeding time.	Agreed.
03	A comprehensive socio-economic study only specific for Haor area is necessary to understand the socio-economic condition of Haor region.	Agreed and mentioned in Section-13.3.
Sima Rani Biswas, Senior Upazila Fisheries Officer, Fisheries Department, Sunamganj		
01	Fish industries has to be developed in the Haor region to store fish	Agreed.
02	Fish Research Institute is required in the Haor region.	Agreed.
Mozzammal Hossan Rokan, Upazila Chairman, Dharamapasha		
01	A rest house is necessary at Madhanagar.	Agreed.

Mohamned Amran Hassain, DDLG, DC, Office, Sunamganj		
01	A study is required to understand the changes of Bio-diversity before and after the re-excavation of Haor/Beel.	Agreed and mentioned in Section13.3.
02	A study to assess the sanitation, education, health and livelihood of Haor region should be recommended.	Agreed and mentioned in Section-13.3.

12.1.2 National Level Workshop on Draft Final Report

The final workshop on Draft Final Report (DFR) was held at CIRDAP conference room, Dhaka as shown in Figure 12-7. The workshop was attended by the participants from Planning Commission, IMED, Ministry of Water Resources, WARPO, DAE, BADC, DoE, DoF, BWDB, DBHWD and others. The list of the participants has been presented in Volume-II, Appendix L. The study objectives, methodologies, findings and recommendations have been presented in the workshop. Participants gave their comments and suggestions on the DFR. The Final Report has been updated incorporating the recommendations and suggestions of the workshop. The comments and suggestions as well as the compliance from IWM have been illustrated in Table 12-3.

Figure 12-7: Workshop at Dhaka

Table 12-3: Comments and Compliance of National Level Workshops at Dhaka

Sl. No.	Comments and Suggestions	IWM Compliance
Md. Mahfuzur Rahman, Director General, Bangladesh Water Development Board (BWDB)		
1	A research to quantify the groundwater flow from Meghalaya hill tracts needs to be conducted to understand the groundwater flow direction as well as flow volume.	A separate study can be proposed as metioned in Section-13.3.
2	Regarding the biodiversity issues in haor area it is necessary to monitor the effect of any interventions on biodiversity.	Beyond the scope of works under the present study.
3	Less water demanding crops has to be recommended in the final report.	Agreed and mentioned in Section-13.2.
4	Less abstraction from groundwater has to be encouraged and should be clearly mentioned in the final report.	Agreed and mentioned in Section-13.2.
Mahmudul Hasan, Director General, Water Resources Planning Organisation (WARPO)		
1	Critical analysis and findings of this project will be helpful for future project formulation.	Agreed
2	A copy of the final report needs to be share with WARPO.	Agreed
3	Stakeholders will be benefited from the outcome this study.	Agreed
Malik Fida A Khan, Executive Director, Center for Environmental and Geographic Information Services (CEGIS)		
1	Impact on ecosystem due to surface water irrigation needs to be investigated.	A separate study can be proposed as metioned in Section-13.3.
2	Research on irrigation efficiency and environmental flow analysis has to be conducted.	A research project has been proposed as metioned in Section-13.3.
Prof. Dr. M. Monowar Hossain, Executive Director, Institute of Water Modelling (IWM)		
1	The IIS developed under this project will be useful for all the stakeholders and MoWR will decide the data share policy.	Agreed
Azizun Nahar, Deputy-Chief, Planning Commission		
1	Morphological changes in the river in haor region need to be conducted.	A separate study has been proposed as metioned in Section-13.3.
2	Source of rainfall data should be mentioned in the final report.	Rinfall data ha been collected from BWDB as mentioned in Section-4.2
3	Methodology for proposed surface based irrigation should be mentioned in the final report.	Methodology for proposed surface based irrigation has been mentioned in Section-9.3 and Section-9.4
4	Co-ordination among different organization is necessary for any implementation project.	Agreed and mentoined in Section-13.2

Sl. No.	Comments and Suggestions	IWM Compliance
Md. Mizanur Rahman, Deputy Director, Department of Fisheries		
1	Linkage between Agricultural/Livestocks and others with ecosystem should be studied.	A separate study has been proposed as metioned in Section-13.3.
Md. Zafarullah, Additional Chief Engineer, BADC		
1	Groundwater level and water quality data from BADC may be used for model development.	Has been used accordingly.
2	Sustainable groundwater resources for future use have to be mentioned in the final report.	Sustainable groundwater resources mentoined in Section-10.1.2
Mahfuz Hossain Mirdah, Additional Director, DAE		
1	Future irrigation expansion plan should be mentioned in the report.	Future irrigation expansion plan has been presented in Section-10.4
Prof. Dr. Md. Fazlul Karim, Dean, SAU		
1	Less water demanding crops has to be recommended in the final report.	Agreed and mentoined in Section-13.2
Fazlur Rashid, Chief Planning, BWDB		
1	Future projection for different senior needs to be addressed.	Agreed and mentioned in Section-10.2.2
Kabir Bin Anwar, Secretary, MoWR		
1	Regular monitoring of water quality should be promoted.	Agreed and mentioned in Section-13.2
2	Natural reservoir should be used to store excess rainwater during rainy season.	Agreed and mentioned in Section-13.2
3	Intervention of wise use of wetlands and best wetland management practices for restoration of ecosystem in haor area should be adopted.	Agreed and mentioned in Section-13.3
4	Environmental flow analysis for Major River should be studied.	Agreed and mentioned in Section-13.3
5	Groundwater abstraction should be planned wise considering water act.	Agreed and mentioned in Section-13.2

12.2 Technology Transfer

Technology transfer through training is an essential component of the study for smooth operation and management of the project. IWM has organized training programmes on the following components:

- Specialized training on hydro-geological data collection and groundwater management for DBHWD/GoB officials during field investigations.
- Mathematical modelling concepts, development and its application for DBHWD/GoB official at Dhaka
- Training on IIS for DBHWD officials.

As per the ToR, there is a provision of on the job training on hydrogeological investigations for DBHWD/GoB officials. Accordingly, training was conducted on hydrogeological investigations during the field data collection program. The on the job training on hydrogeological investigation was conducted during exploratory drilling as shown in Figure 12-8. The main objective of the training was to train the DBHWD officials on hydrogeological investigation techniques and interpretation of collected data. During the training program, the professionals participated actively with a view to understand the hydrogeological data collection process.

Figure 12-8: On the Job Training on Hydro – geological Data Collection

Training on IIS and Mathematical Modelling

The main objective of the training was to train the DBHWD officials on understanding and using the Modelling software along with the operating of IIS. Training program focused on the use and implementation of Modelling using MIKE SHE and MIKE 11 software. The training has been held from 14^{th} May to 19^{th} May 2019 as shown in Figure 12-9. The programme covered concepts of introduction to mathematical Modelling with considerations of basic knowledge on seepage and percolation measurement, conjunctive use of SW–GW, full hydrologic cycle, geology and hydrogeology and computation of water requirement. Mathematical Modelling also covered the modelling techniques with MIKE 11 and MIKE SHE modelling software.

Figure 12-9: Training on IIS and Mathematical Modelling

13 CONCLUSIONS AND RECOMMENDATIONS

The study aims at (i) assessing the availability of sustainable water resources and (ii) dividing the study areas into different zones in terms of different mode of abstractions to meet the future water demands for various uses. During this study a comprehensive field data collection program has been conducted which includes:

- Exploratory drilling (upto 200m depth) at 40 selected locations
- Construction of production tubewells at 12 locations
- Long term (3 days) aquifer tests at 13 selected locations using existing shallow tubewells or deep tubewells.
- Long term (3 days) aquifer tests at 12 selected locations in newly installed production wells.
- Installation and monitoring of 40 groundwater observation wells including BM connection.
- Water quality sampling and analysis at 50 locations.
- Seepage and percolation measurements at 50 selected locations.
- Geophysical survey at 60 locations.

Groundwater model, surface water model and SW-GW interaction model have been developed to achieve the study objectives. The models have been calibrated for the period of 2012-2016 and validated for the periods of 2017-2018. The calibrated models have been applied for various development scenarios. Based on the study findings, conclusion and recommendations are summarized below.

13.1 Conclusions

The major study findings from hydrogeological investigations are illustrated below:

- The data collected from the secondary sources as well as from field investigations reveals that three major aquifers encountered upto 200m depth throughout the study area with some exception in Sylhet, Maulvibazar and Sunamganj districts. Thickness of the first aquifer ranges from 9-115m, second aquifer ranges from 13-152m and third aquifer ranges from 11-88m. The thickness of the aquifers is thicker in Netrokona, Sunamganj, Kishoreganj and Habiganj districts rather than that of Sylhet and Maulvibazar districts. The aquifers are mostly composed of fine sand, medium sand and coarse sand materials with a semi confined in nature.
- Depth to groundwater level/table from ground surface for the project installed observation wells in the study area reveals that the minimum depth of water level is observed during August and maximum during March or April. Groundwater level starts to decline in September and reaches to the maximum depth in March-April and then moves upward again in monsoon to regain the static water level in July-August.

The maximum and minimum depth to groundwater table along with fluctuation for different districts is presented below:

District	Depth to Groundwater Table		
	Minimum	**Maximum**	**Fluctuation**
Kishoreganj	1.5 to 5.0m	4.5 to 11.0m	2.5 and 7.0m
Netrokona	1.5 to 4.5m	4.5 to 11.0m	4.0 and 19.0 m
Sylhet	3.5 m	5.5 m	2.0m
Maulavibazar	1.0 to 1.5 m	2.5 to 3.5 m	1.0 and 1.5 m
Habiganj	1.5 to 5.0 m	6.0 to 10.5 m	4.5 and 5.5 m
Sunamganj	2.0 to 8.0 m	6.5 to 9.0 m	1.0 and 8.0 m

- The geophysical investigations revealed that in the study area 3 nos. of aquifers separated by aquitard exist upto the depth of 200m which is similar to the borelog data.
- The top geological unit is aquitard shows resistivity range from 11Ωm to about 24Ωm which is clay or silty clay.
- The next unit is Aquifer-1 also termed to be shallow aquifer shows resistivity variation in the range of 25Ωm to 164Ωm. Thicknes of this unit varies from 4m to 104m. Maximum thickness of Aquifer-1 is about 104m at Atpara, Kishoreganj and minimum thickness is about 4m at Madan, Netrokona.
- Aquifer-2 also shows the same resistivity range. Thicknes of this unit varies from 3m to 135m. Maximum thickness of Aquifer-2 is about 134m at Madhabpur, Habiganj and minimum thickness is about 3m at Bajitpur, Kishoreganj.

Maximum depth of the lower boundary of Aquifer-3 is about 171m at Madhabpur. Habiganj and minimum depth is about 100m at Mohanganj, Netrokona.

- Hydraulic properties obtained from aquifer tests conducted in installing production wells are given below:

SL No.	District	Upazila	Latitude	Longitude	Well Depth (m)	Strainer Position (m)	Transmissivity (m^2/day)
1	Habiganj	Bahubal	24.32082	91.529585	60.98	35.67-53.35	380
2	Sylhet	Balaganj	24.750651	91.826652	145.43	123.78-143.90	347
3	Sunamganj	Bishwambarpur	25.109018	91.331422	100	79.87-96.95	70.86
4	Sunamganj	Chhatak	24.959974	91.674454	80.49	60.37-77.44	1241.76
5	Sunamganj	Dowarabazar	25.061507	91.513586	79.27	54.88-76.21	996.7
6	Netrokona	Kendua	24.650789	90.73543	121.95	99.09-119.51	2697.28
7	Habiganj	Madhabpur	24.133174	91.317786	132.93	117.07-131.71	982.7
8	Netrokona	Netrokona Sadar	24.92976	90.78699	146.74	126.02-143.7	1090.03
9	Kishoreganj	Pakundia	24.33247	90.68894	94.88	68.67-91.84	1059.86
10	Kishoreganj	Kuliar Char	24.151159	90.931561	118.9	92.68-115.85	1128.90
11	Maulvibazar	Kamalganj	24.431566	91.842153	108.23	78.96-104.57	270.68
12	Maulvibazar	Kulaura	24.531552	92.035999	150.3	128-148	853.06

- Hydraulic properties from aquifer tests conducted by IWM using existing production wells are given in table below:

SL No.	District	Upazila	Latitude	Longitude	Well Depth (m)	Strainer Position (m)	Transmissivity (m^2/day)
1	Kishoreganj	Hossainpur	24.384963	90.670189	24.39	9.45-24.39	976.33
2	Kishoreganj	Pakundai	24.347127	90.680394	18.29	9.45-18.29	2906.00
3	Kishoreganj	Hossainpur	24.431675	90.686672	27.44	16.77-27.44	381.33
4	Kishoreganj	Pakundai	24.317144	90.714931	18.29	4.87-18.29	1268.33
5	Kishoreganj	Katiadi	24.244321	90.824074	18.29	8.17-18.29	1116.33
6	Kishoreganj	Katiadi	24.338581	90.830665	19.81	9.14-19.81	452.67
7	Kishoreganj	Kishoreganj	24.42832	90.743163	28.96	12.07-28.96	673.33
8	Netrokona	Kendua	24.659028	90.83409	21.34	5.18-21.34	988.33
9	Kishoreganj	Kuliar Char	24.150566	90.902424	21.34	14.33-21.34	647.00
10	Netrokona	Purbadhala	24.847156	90.624749	17.37	3.65-17.37	3093.00
11	Netrokona	Barhatta	24.88526	90.888705	20.42	4.57-20.42	1120.67
12	Netrokona	Barhatta	24.902348	90.82222	26.82	10.36-26.82	498.33
13	Netrokona	Atpara	24.793216	90.805503	21.34	15.24-21.34	263.67

- The maximum and minimum S&P rate for different districts is presented as bellows:

District	S&P Rate (mm/day)	
	Minimum	Maximum
Kishoreganj	3.6	13.0
Netrokona	3.0	11.0
Sylhet	7.1	11.4
Maulavibazar	5.3	10.9
Habiganj	5.1	12.0
Sunamganj	8.6	14.6

Major findings from water quality sampling and analysis based on 40 nos. samples collected under study are as bellows:

- pH values range from 5.68 to 6.96, indicating neutral to slightly acidic conditions. Ec values ranges from 110 µs/cm to 1537µs/cm, TDS values range from 55 mg/l to 578 mg/l and salinity value varies from 0.0 ppt to 0.7 ppt and temperature of groundwater samples ranges from 23.5^{0}C to 29^{0}C. But in Dowarabazar upazila of Sunamganj district, the groundwater possesses slightly higher temperature and found 34.2^{0}C.
- Manganese concentrations vary from 0.01mg/l to 2.65mg/l. The maximum concentration (2.65mg/l) found at Kendua upazila. There are 32 samples (80%) that exceed Bangladesh Drinking Water Standards 1997 guideline limit of Manganese. Therefore, the study area has a potential threat of Manganese contamination.
- Calcium concentrations vary from 156.80mg/l to 2.88mg/l. Only 1 sample at Kendua upazila of Netrokona district exceeds Bangladesh Drinking Water Standards guideline.

- Iron concentrations vary between 0.09mg/l to 30.05mg/l with mean, median and standard deviation of 4.29mg/l, 2.65mg/l and 5.14mg/l, respectively. Bangladesh Standard is from 0.3mg/l to 1.0mg/l. Maximum Iron concentration is found in Kanaighat upazila of Sylhet district. Considering the Bangladesh Drinking Water Standards 83% samples show concentrations above taste limit.
- Phosphate concentrations vary between 0mg/l and 12.67mg/l. Bangladesh Drinking Water Standards follows 6mg/l maximum allowable concentration based on the taste threshold. All the samples except Balaganj and Golapganj upazila of Sylhet district are within safe limit.
- Salinity index for irrigation water quality found that all the samples collected is categorized under medium to low salinity classes except the groundwater from Jahangirpur and Chandigor union of Netrokona districts.
- The Sodium Adsorption Ratio (SAR) values of 98% of the samples are found to be less than 10. Groundwater classified based on SAR as being excellent for irrigation (i.e., S1 category) except the groundwater from Mannargaon union of Doarabazar upazila in Sunamganj District which is fall in good category.
- The classification of groundwater samples with respect to percent sodium for irrigation uses is found that 70% samples belong to permissible category. Maximum Na% found for the groundwater from Mannargaon union of Doarabazar upazila in Sunamganj District which is unsuitable for irrigation.
- In the study area, the magnesium hazard (MH) values for irrigation water quality analysis have been calculated in the range of 17.27% to 70.71%. 88% of the samples showed magnesium index value below 50%, suggesting their suitability, while 12% fall in the unsuitable category with MH more than 50%, indicating their adverse effect on crop yield.
- Surface water quality analysis indicates the presence of E-coli in river water whereas it is free from heavy metal (Mercury, Cadmium, and Lead).

Major Findings from the Mathematical Modelling Study:

- Available groundwater resource has been calculated based on useable recharge which is 75% of potential recharge. The estimated potential recharge for different upazila is given below:

SL No	District	Upazilla	Potential Recharge (mm)
1	Habiganj	Baniachong	1219
2	Habiganj	Nabiganj	612
3	Habiganj	Ajmiriganj	1101
4	Habiganj	Bahubal	689
5	Habiganj	Habiganj Sadar	426
6	Habiganj	Lakhai	893
7	Habiganj	Chunarughat	679
8	Habiganj	Madhabpur	855
9	Kishoreganj	Itna	1234

SL No	District	Upazilla	Potential Recharge (mm)
10	Kishoreganj	Tarail	1126
11	Kishoreganj	Karimganj	1086
12	Kishoreganj	Kishoreganj Sadar	970
13	Kishoreganj	Hossainpur	914
14	Kishoreganj	Mithamain	1250
15	Kishoreganj	Nikli	1090
16	Kishoreganj	Austagram	1186
17	Kishoreganj	Pakundia	609
18	Kishoreganj	Katiadi	1108
19	Kishoreganj	Bajitpur	770
20	Kishoreganj	Kuliar Char	995
21	Kishoreganj	Bhairab	1097
22	Maulvibazar	Barlekha	568
23	Maulvibazar	Kulaura	718
24	Maulvibazar	Rajnagar	642
25	Maulvibazar	Maulvi Bazar Sadar	690
26	Maulvibazar	Kamalganj	490
27	Maulvibazar	Sreemangal	860
28	Netrakona	Durgapur	897
29	Netrakona	Kalmakanda	458
30	Netrakona	Purbadhala	865
31	Netrakona	Netrokona Sadar	973
32	Netrakona	Barhatta	932
33	Netrakona	Mohanganj	938
34	Netrakona	Atpara	1013
35	Netrakona	Khaliajuri	1043
36	Netrakona	Kendua	713
37	Netrakona	Madan	958
38	Sunamganj	Tahirpur	606
39	Sunamganj	Dharampasha	932
40	Sunamganj	Bishwambarpur	554
41	Sunamganj	Dowarabazar	543
42	Sunamganj	Sunamganj Sadar	1042
43	Sunamganj	Chhatak	582
44	Sunamganj	Jamalganj	961
45	Sunamganj	Derai	1199
46	Sunamganj	Jagannathpur	973
47	Sunamganj	Sulla	1022
48	Sylhet	Jaintiapur	577
49	Sylhet	Gowainghat	635
50	Sylhet	Companiganj	584
51	Sylhet	Kanaighat	687
52	Sylhet	Kotwali	705
53	Sylhet	Zakiganj	626
54	Sylhet	Beani Bazar	600

SL No	District	Upazilla	Potential Recharge (mm)
55	Sylhet	Bishwanath	520
56	Sylhet	Golabganj	462
57	Sylhet	Balaganj	658

- Due to the future abstraction considering 80% area of cultivable land under HYV Boro, it is observed that in most of the areas, groundwater table drops down by about 0.1m to 1.0m compared to the groundwater table of present condition. However, groundwater table drops down upto 6m in Habiganj and Bahubal Upazilla where most probably abstraction has been imposed for industries.
- The study reveals that due to extreme drought condition most of the areas of Netrokona and Kishoreganj districts, groundwater table drop down from 0.5m to 2m in comparison with the base condition.
- Due to the increment of abstraction the groundwater recharges also increase which implies that aquifer has potential for receiving more recharge if provision is made.
- Available surface water resources in the selected khals after controlling the water by water control structure is given below:

District	Haor Name	Khal Name	Length of Khal (Km)	Volume (m^3) of Water to be Irrigated
Kishoreganj	Boro Haor	Digha Nadi	6	504500
		Baniajan Gang	7	122000
		Singua Khal	12	178000
	Noapara Haor	Pania Khal	3	341000
	Naogaon Haor	Khaiyar Khal	7	351000
		Markhali Khal	5	900000
		Nandir Khal	6	299000
	Dakhshiner Haor	Shankir Khal	6	242500
	Sunair Haor	Suti Khal	16	1590000
	Chatal Haor	Noaparakhali	1.8	324000
Netrokona	Khaliajuri-4	Putia Khal	5	165000
	Khaliajuri-2	Naiyari Khal	8	889000
Sunamganj	Jaliar Haor	Rauli Khal	6	71500
		Dora Nadi	8	42500
	Dhakua Haor	Muktakhai Khal	12	670000
	Dharmapasha Haor	Manai Khal	16	680000
		Dahar Gang	7	132500
		Agunia Khal	8	221500
Moulvibazar	Hail Haor	Lunglabijna	24	2145000
	Kawardighi Haor	Lash Gang	12	525000
		Sampad Khal	9	630000
		Udna Gang	12	531000
Habiganj	Mokhar Haor	Medhabeel Khal	5	304500
		Old Kushiyara-2	18	948000
		Rajendrapur Khal	5	118500

District	Haor Name	Khal Name	Length of Khal (Km)	Volume (m^3) of Water to be Irrigated
	Gangajuri	Teli Khal	6	214000
		Shashya Nadi	10	118000

- Sufficient surface water resources are available in Dhanu, Baulai, Ghorautra rivers for round the year irrigation while limited resources are available in Saidulbaruni, Mogra, Kangsha rivers in dry period but sufficient water is available in October for supplemental irrigation.
- Based on the surface water availability and its development constraints, the maximum possible irrigation area expansion has been determined and future water demand has been estimated. Areas under HYV Boro have been estimated to be about 87500 ha for surface water based irrigation.

An Interactive Information System (IIS) for storing, visualizing, manipulating, maintaining and managing a huge volume of hydrological, hydro-geological, meteorological hydro-geochemical, topographical, physiographical, soils and agricultural data for both spatial and spatio-temporal for the project area has been developed which enables users to support for data management, visualization, data analysis, data retrieval and reporting

13.2 Recommendation

- Crop diversification is recommended i.e cultivation of crop with less crop water requirement can be increased instead of HYV Boro crop for improve water management and crop yield.
- Coordination among the different stakeholders working in the haor area should be well established. There should have a strong coordination among different organizations, departments such as DBHWD, BIWTA, BWDB, BADC, LGED, DPHE, DAE etc.
- During infrastructure development in hoar area, there should have navigation facilities. For any infrastructure related project, coordination among different organizations/departments is highly recommended.
- Re-excavation of major khals is highly desirable. Large scale dredging through technical study and monitoring is recommended.
- Water is limited, and its uses should be appropriate and efficiently. As per government policy surface water-based irrigation is encouraged. As such, to reduce the dependency on groundwater, surface water-based irrigation is recommended under this study. To reduce the conveyance and other losses, buried pipe system using LLP is highly recommended.

- During stakeholder's consultation and field workshops, the beneficiaries asked for the rehabilitation of pumps and other infrastructure of Manu Irrigation project. So, steps should be taken to rehabilitate the existing pumps.
- The transportation system of haor area during rainy season is not good enough to bring the crops from field to high lands. As such the combined harvester is recommended here to reduce time and the cost of labor as well as reduce the risk of crop damage.
- Regulatory structure has to be constructed for ensuring the proper drainage and navigation.
- Regular monitoring of water quality in Haor region is recommended.
- Natural reservoir may be used to store excess rainwater during rainy season.
- Plan wise groundwater abstraction considering water act is recommended.
- The future climate change scenarios need to be addressed since due to changing of rainfall pattern, more complicated flooding situation may arise.
- As per ToR, this study covers only the technical part. So detailed feasibility study considering environmental viability, economic feasibility and social acceptability needs to be addressed before implementation of the project.

13.3 Way Forward

In the stakeholder's consultation, PIC meeting, local level workshops and final workshops at Dhaka several study projects have been suggested to take for the sake of the improvement of haor livelihood. As such a comprehensive integrated study considering the following issues is highly recommended under this study:

- The quality of the model can further be improved undertaking a comprehensive study on geological formation, aquifer properties, and recharge pattern and groundwater abstraction rate. A further study is needed to formulate different land and water management options for a long-term planning.
- Assessment of detailed water quality for drinking and irrigation purpose.
- Protection of fish sanctuary as well as establishment of new sanctuary in the haor area is also recomanded.
- Solid waste management for reducing the risk of contamination of surface water.
- Industrial waste management especially for Habiganj, Sayestaganj and Madhbpur industrial area.

- Update existing Haor Master Plan considering climate change scenarios and other human interventions for the duration of next 100 years in line with Bangladesh Delta Plan 2100.
- Address the Social, Environmental and Ecological factors holistically.
- Identification of changes of bio-diversity before and after the re-excavation of haor/beel.
- Investigation of the long-term impact of iron on land fertility and its remedial measures.
- Assessment of the sanitation, education, health and livelihood of haor region.
- Establishment of draining out of water from upstream of Kawa Digi Haor.
- Study for assessment of groundwater flow from Meghalaya hill tracts to understand the groundwater flow direction as well as flow volume.
- Study for assessment of the impact on ecosystem due to surface water irrigation.
- Research on irrigation efficiency and environmental flow analysis of major rivers.
- Study to assess the morphological changes in the river system of haor region in Bangladesh.
- A study on establishment of linkage between Agricultural/Livestocks and others with haor ecosystem.
- A study on wise use of wetlands and best wetland management practices for restoration of ecosystem in haor area.
- Research on sedimentation and sink for haor area.
- A hydrogeological study to determine the spacing of tubewell and aquifer mapping.
- Assessment of volume of water comes from transboundary river in hoar region.
- Study to improve the navigation facilities for transportation of paddy by boat during dry season.

13.4 Limitations of the Study

The model results provide a preliminary understanding of the hydrogeological processes that are involved in the groundwater – surface water interactions for the study area. Findings of the study can in many instances be extrapolated but care should be taken in the application as there are a lot of uncertainties in the input data and parameters involved during the model calibration. Some of the limitations of this study are as follows:

- The model results are indicative and mainly depend on accuracy of the conceptual model of the hydrogeological system. The study area is geologically diverse and complex, and the composition and structure of regional aquifers are highly variable which needs well distributed boreholes to define the geological formations.
- There is also considerable uncertainty on water abstraction data as because there is lot of unauthorized tubewells.
- The conceptual description of the model layers might not be sufficient for the whole study area. The availability of pump test data is not sufficient enough to define the layer properties.
- The distribution and numbers of groundwater as well as surface water sampling locations are not sufficient to derive the base line status of water quality.
- The future climate change scenarios need to be addressed since due to changing of rainfall pattern, more complicated flooding situation may arise.

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