URBAN DEVELOPMENT DIRECTORATE (UDD)

Ministry of Housing and Public Works

Government of the People's Republic of Bangladesh

Interim Report On HYDRO-GEOLOGICAL SURVEY UNDER MIRSHARAI DEVELOPMENT PLAN (MUDP)

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1. Introduction

Water is the most important constituent of life. Every human activity requires water. The Mirashrai Upazila of Chittagong district is likely to experience rapid industrialization and urbanization in the near future as the largest economic zone in Bangladesh is proposed to be developed in this Upazila. Both industrialization and urbanization have large impacts on water as these activities increases demands of water as well as poses threat to water contamination. To characterize the current water situation, to identify suitable locations for water resources development, and to identify risk of water contamination the Urban Development Directorate (UDD) have initiated a hydrogeological investigations throughout the Upazila. 'Center for Geoservices and Research' was employed by UDD to carry out the study in the Upazila.

The aim of hydrology and hydro-geological study for the study areas of Mirshari Region is to identify the surface water body and aquifer of the region including its seasonal variation. The study is also intended to identify the availability fresh ground water, which would be required for the additional people including tourists after implementation of the project, i.e. the foundation of the economic zone. This study comprises of Hydro-geological and geophysical investigations and ground water modeling, water quality mapping, surface water distribution and its management planning by using those data.

1.1. Location and Accessibility

Mirsharai Upazila (Chittagong District) is located between 22˚39′ and 22˚59′ north latitudes and between 91˚27′ and 91˚39′ east longitudes and has an area of 482.88 km^2 (BBS). It is bounded by the Feni River in the North, Sitakunda upazila in the south, Chittagong hill tracts in the east, and the Sandwip Chanel in the west. Mirsharai Thana was founded in 1901 and it was turned into an Uapazila in 1983. Mirsharai Upazila consists of 2 Municipality, 16 Union and 113 Mouza with a total population of 398,716 (Three Lakh Ninety Eighty Thousand Seven Hundred Sixteen).

The Upazila is located at a distance of 192.2 km from Dhaka. It can be accessed by both train and bus from the capital city Dhaka. Both mode of transport takes about 4 and half hours to reach there. 4.5 hours long bus journey. It can also be accessed from the Chittagong Divisional headquarters which is located about 56 km to the south of the Upazila and takes 1.5 hour travel by either bus or train. The Bangladesh Road Transport Corporation introduced a direct bus service from Dhaka to Mirsharai via Comilla (Source: Bangalapedia, 2012).

Mirsharai, the combination of lake and hilly area contains attractive scenic beauty on the southeastern part of Bangladesh. The most important attraction of the upazila is that one can travel Mohamaya Chara Lake by speed boat and explore hilly area and can enjoy Khoyachora, Baghbani, Napitachora, Sonaichora, Mithachora and Boyalia waterfalls.

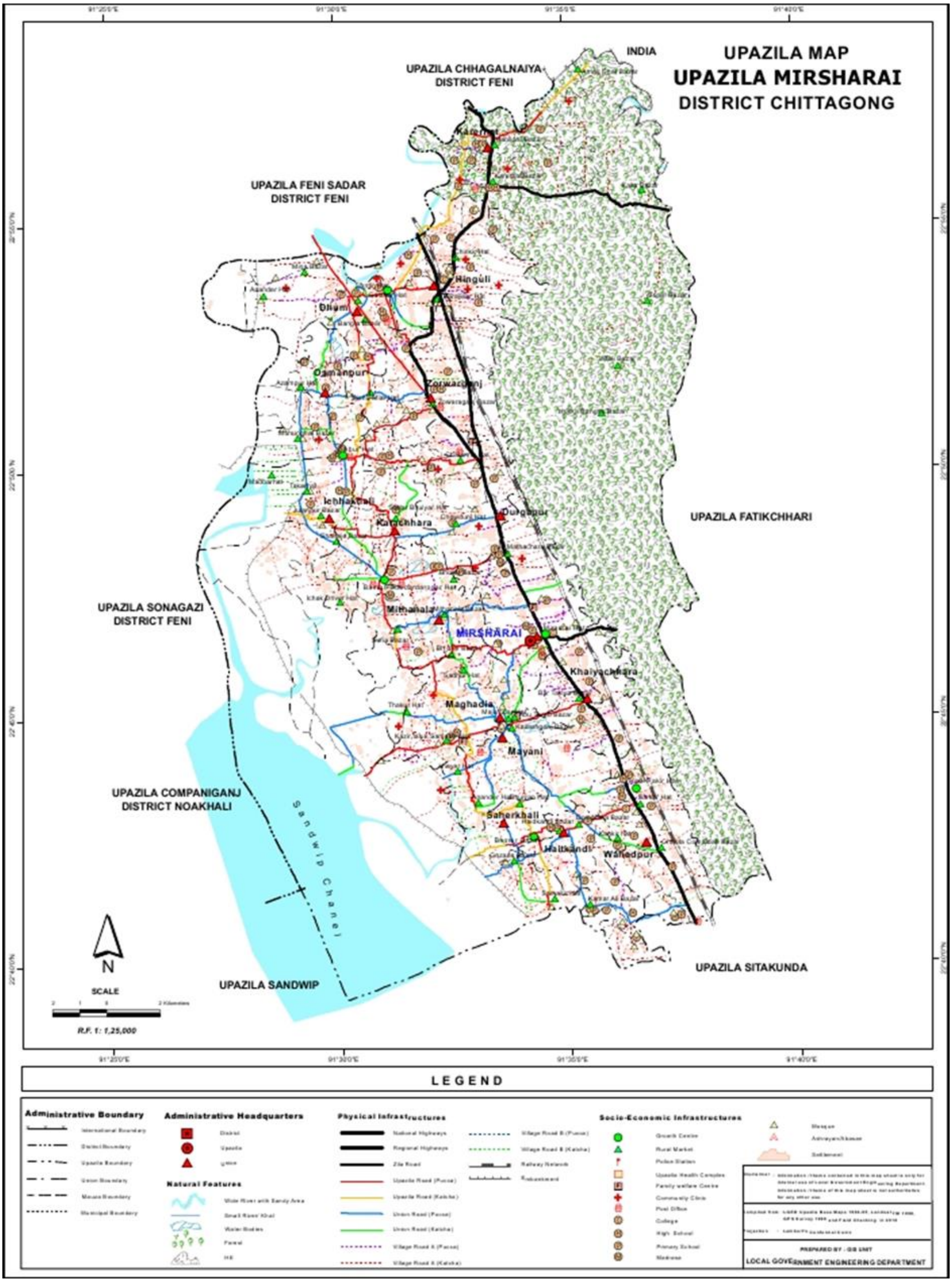

Figure 1: Map Showing Location and Accessibility (Source: LGED)

1.2. Topography and Relief

Topographically the Upazila contains both hilly areas and plain lands. Approximately, one half of the Upazila lies in the low lying hills of the Chittagong hill tracts in the east. The hilly region has high relief and is sparsely populated. The highest elevation in the hills is about a100 m and the lowest elevation in the hills is about 30 m. The western half of the area is plain lands with an average elevation of only about 5 m above mean sea level. This area is heavily populated. Numerous small streams crossed the hilly region and flows towards Sandwip Channel across the plain land (Figure 1).

2. Methodology

This study utilizes both field and laboratory procedures to assess the hydrological and hydrogeological conditions of the study area. Field study includes- a) drilling of boreholes at 5 locations for lithological sample collection for laboratory analysis as well as installation of monitoring wells, b) electrical resistivity survey, c) water quality survey including field measurement of important water quality parameters as well as sample collection for laboratory analysis, d) measurement of the depth to groundwater levels, and d) slug test to determine aquifer properties. Details of each of the above mentioned field activities are discussed in the subsequent sections.

2.1. Field Investigations

2.1.1. Drilling and Installation of Monitoring Wells

A total of 5 boreholes were drilled at different locations within the study area (Figure-2 and Table-1) for direct assessment of subsurface geological conditions with depth and space as well as to install wells to monitor groundwater level and water quality. Locations of the boreholes/monitoring wells were chosen carefully to ensure their distribution throughout the Upazila and to maximize the data coverage.

Table 1: Details of the boreholes and monitoring wells.

Borehole ID	Latitude	Longitude	Total Drilling Depth [m]	Screen Depth [m]
MW-01	22.88738	91.5546	219	165
MW-02	22.82665	91.48352	222	210
MW-03	22.78856	91.55094	204	195
MW-04	22.73395	91.50329	216	201
MW-05	22.70814	91.56847	159	156

Reverse circulation conventional drilling method was used in drilling the monitoring wells (Figure-3). Subsurface Geological variation with depth were recorded at each drilling locations during the time of the drilling by investigating the drilling cuttings at a regular interval of 3.0 m. The information was then recorded using a standard data recording format in Appendix-I. Additionally, the drilling cuttings were sampled at every 3.0 m and approximately 500 gm (Figure-3) of sample from each depth points were preserved in a polybag for transporting to a lab for grain size analysis.

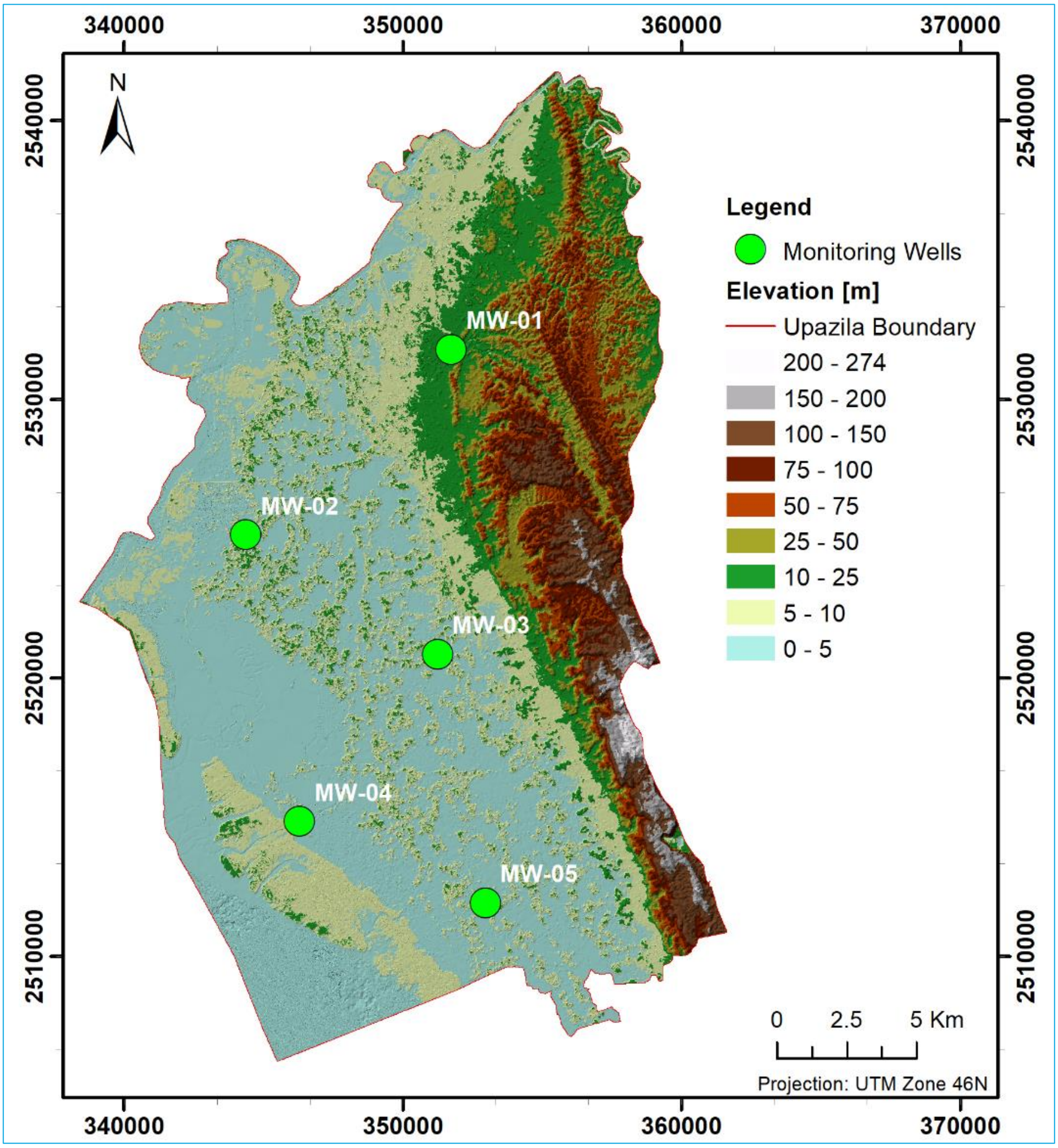

Figure 2: Digital Elevation Model of the study area (Source:UDD) along with the locations of the monitoring wells and drilling sites.

Monitoring well was installed at each borehole site. After careful investigation of the drillers log prepared during the drilling, a suitable aquifer zone was chosen at each site for well screen. At each location, 9.0 m long screen with 1.5 inches diameter were installed.

Figure 3: Monitoring well drilling and Wash samples.

The borehole depth interval between the top of the screen to the land surface was cased using 1.5 inches PVC pipe except in two locations. The exceptions were in areas where the water table was relatively deeper than other areas. In these locations 40.0 m long and 3 inches diameter housing were installed (Figure-4). After installation of a monitoring well it was washed properly following standard procedure.

Figure 4: Established Monitoring well with 3 Inches Housing Pipe.

2.1.2. Electrical Resistivity Survey

Vertical Electrical Sounding (VES) is by far the most used method for geo-electric surveying, because it is one of the cheapest geophysical method and it gives very good results in many area of interest.

The field measurements technique is adjustable for the different topographic conditions and the interpretation of the data can be done with specialized software, with a primary interpretation immediately after the measurements. The results of **VES** measurements can be interpreted qualitatively as well as quantitatively.

The principle of this method is to insert a electric current, of known intensity, through the ground with the help of two electrodes (power electrodes – AB) and measuring the electric potential difference with another two electrodes (measuring electrodes – MN) (Figure-5). The investigation depth is proportional with the distance between the power electrodes.

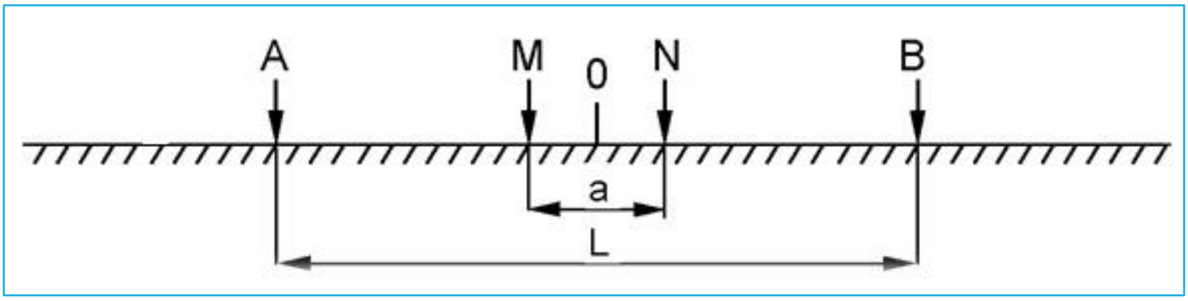

Figure 5: Schulumberger array of VES.

Since direct investigation of the surface geology by drilling boreholes is costly and usually done in widely distributed locations, the information gap in-between drill sites is usually fulfilled using various geophysical surveys. In this study vertical electrical sounding (VES) method was used to deduce the subsurface lithological/hydrogeological variation with depth at a number of locations distributed all over the study area (Figure-6).

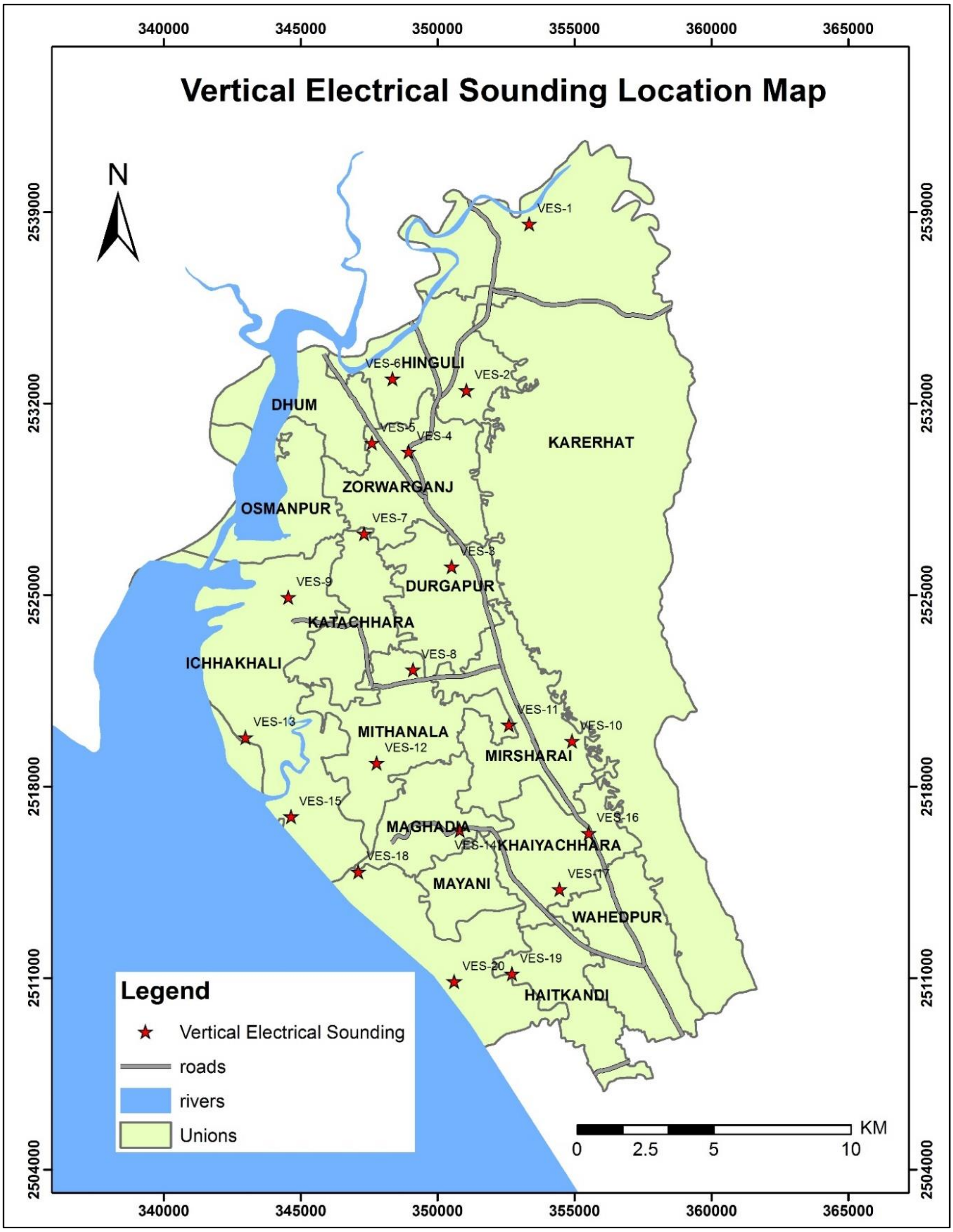

Figure 6: Vertical Electrical Sounding Locations in the project area.

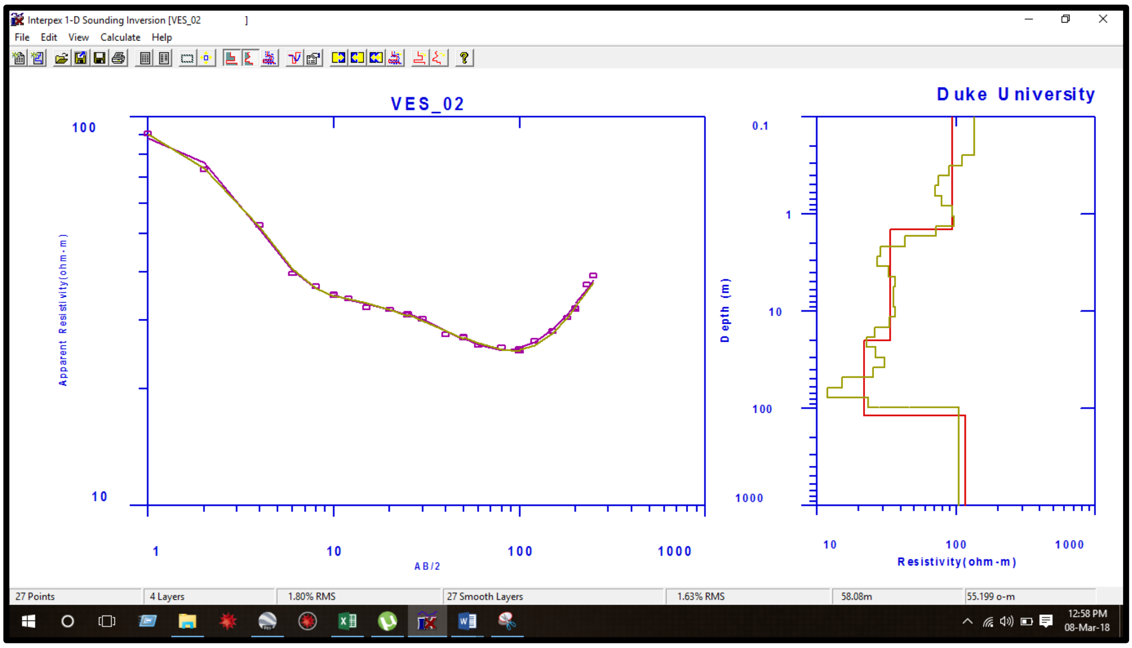

Figure 7: Sounding Curve VES 02 (Left) and the respective subsurface geo-electric model (Right)

VES-02					
Layers	**Resistivity (Ohm-m)**	**Thickness (m)**	**Depth (m)**	**Corresponding Type**	**Lithology of nearby Monitoring Well-01**
1	94.58	1.43	1.43	Top soil	Clayey sand
2	33.91	18.60	20.02	Fine to medium grained sand	Fine to medium grained sand
3	21.85	95.37	117.38	Silty clay	Fine to medium grained sand
4	116.45	Base not seen		Medium to coarse grained sand	Medium to coarse grained sand

Table 2: Interpreted result for VES-02 obtained from geo-electric model

Raw data from field for VES, Sounding Curves and subsurface geo-electrical model as well as interpretation from geo-electrical model of rest of the VES are given in Appendix-II.

Figure 8: Resistivity Survey (VES) in Presence of UDD personnel and Local Pouroshova Commissioner.

2.1.3. Water Quality Survey and Sampling

A number of field parameters were measured in the field using field kits and handheld filed instrument at more than 76 locations including shallow and deep wells in the study area (Figure-9). At every location, at least two wells, one at depth shallower than 100 m and the other at depth deeper than 100.0 m were surveyed.

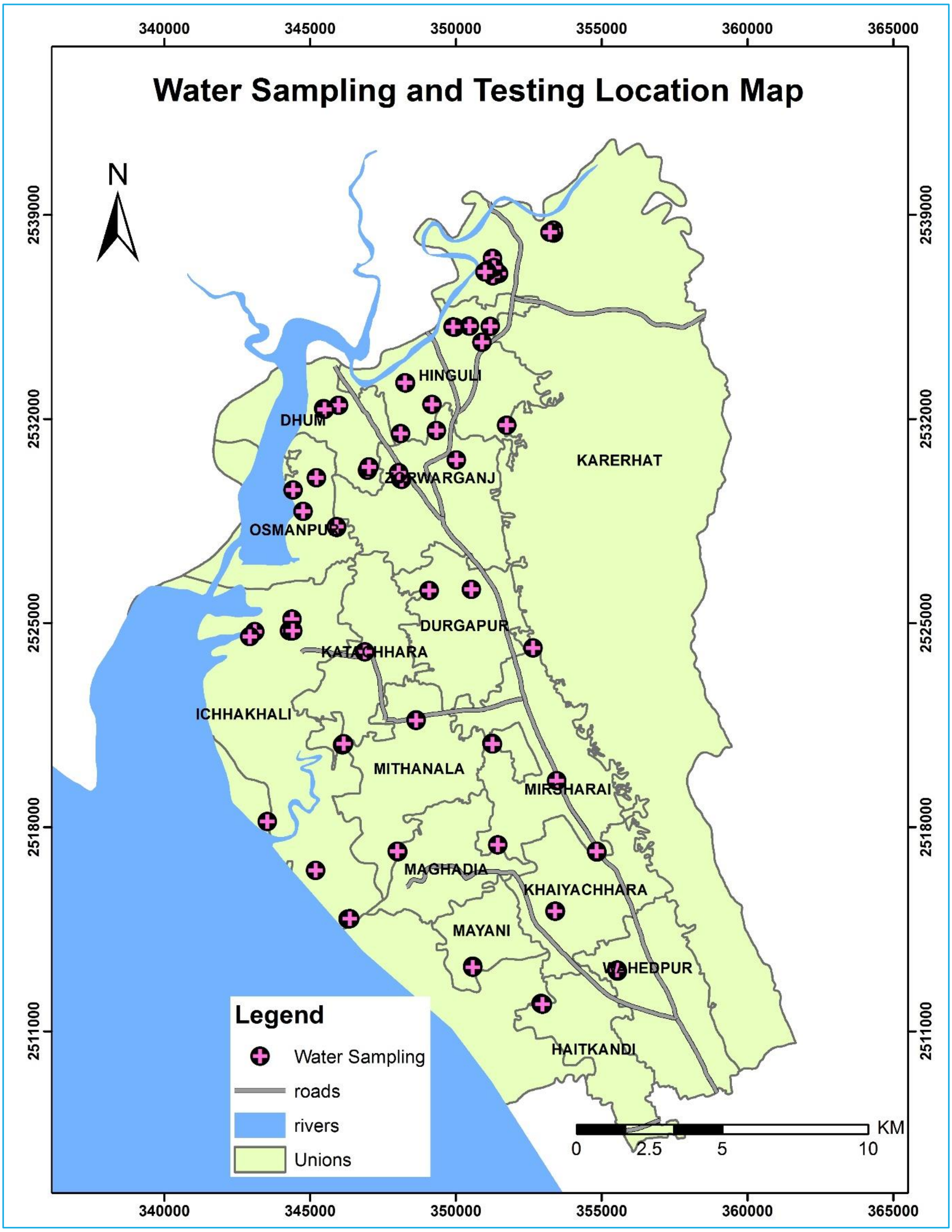

Figure 9: Water sampling and testing location map

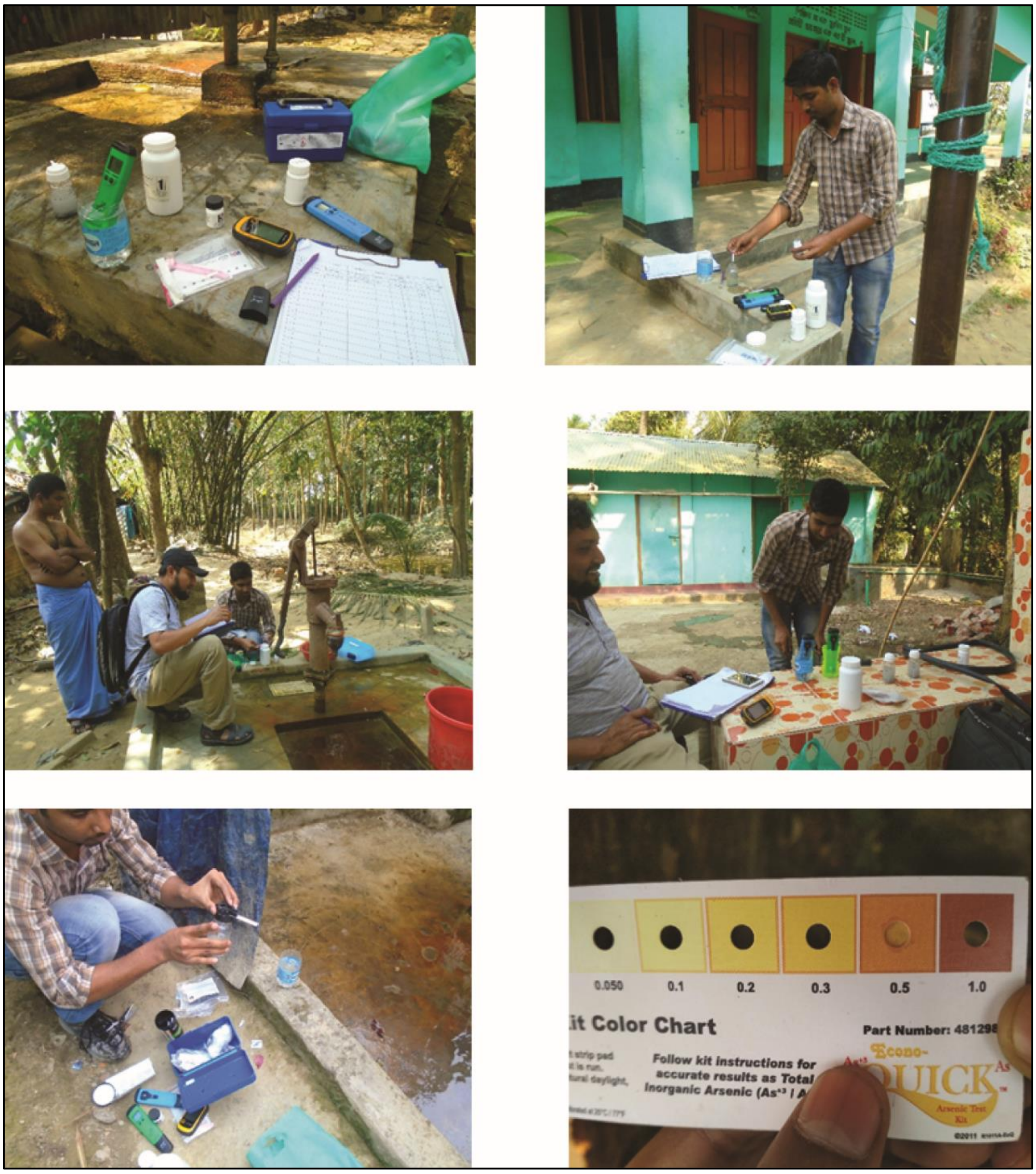

Figure 10: Water Sampling and Field Tests of Arsenic, EC, PH, EH, Temperature etc.

Water samples were also collected from these wells for detail chemical analysis in the laboratory. For each well, two samples each 125 ml and one acidified, was collected in plastic bottles. Each well was purged for at least 10 minutes before field measurements and sampling. The field parameters measured using handheld meters include- pH, Eh, EC, and Temperature. Arsenic was measured in the field using Econo-Quick™ Field kit. Details of the field data are given in Appendix-III.

2.1.4. Groundwater Level Survey

Depth to groundwater was measured in the filed using the Kaizen Imperial^{TM} level meter at each of the water sampling locations (Figure-9). Like the water sampling, water level was measured in both a shallow and a deep well at every location except when the pair was not available. The depth to water data collected from the field was later converted to groundwater level with the help of the DEM supplied by UDD.

Figure 11: Water Level data collection in various location in Field.

2.1.5. Slug Test

Slug test was carried out in 22 locations almost uniformly distributed within the Upazila (Figure-10). During the test procedure a slug (2.0 m long iron rod of 0.75 inches diameter) was rapidly lowered in the well (after removing well head) (Figure-11). The slug displaces water in the well equal to its volume and caused the water level in the well to rise almost instantaneously and decays to its original position with time. Time required for the water level to reach its original position provides estimates of hydraulic conductivity of the aquifer zone surrounding the screen. An automatic water level logger was kept in the well before the slug was lowered. The logger recorded the changes of water level in the well with time. (Figure-12 & 13). The interpretation of slug test is given in Appendix-IV.

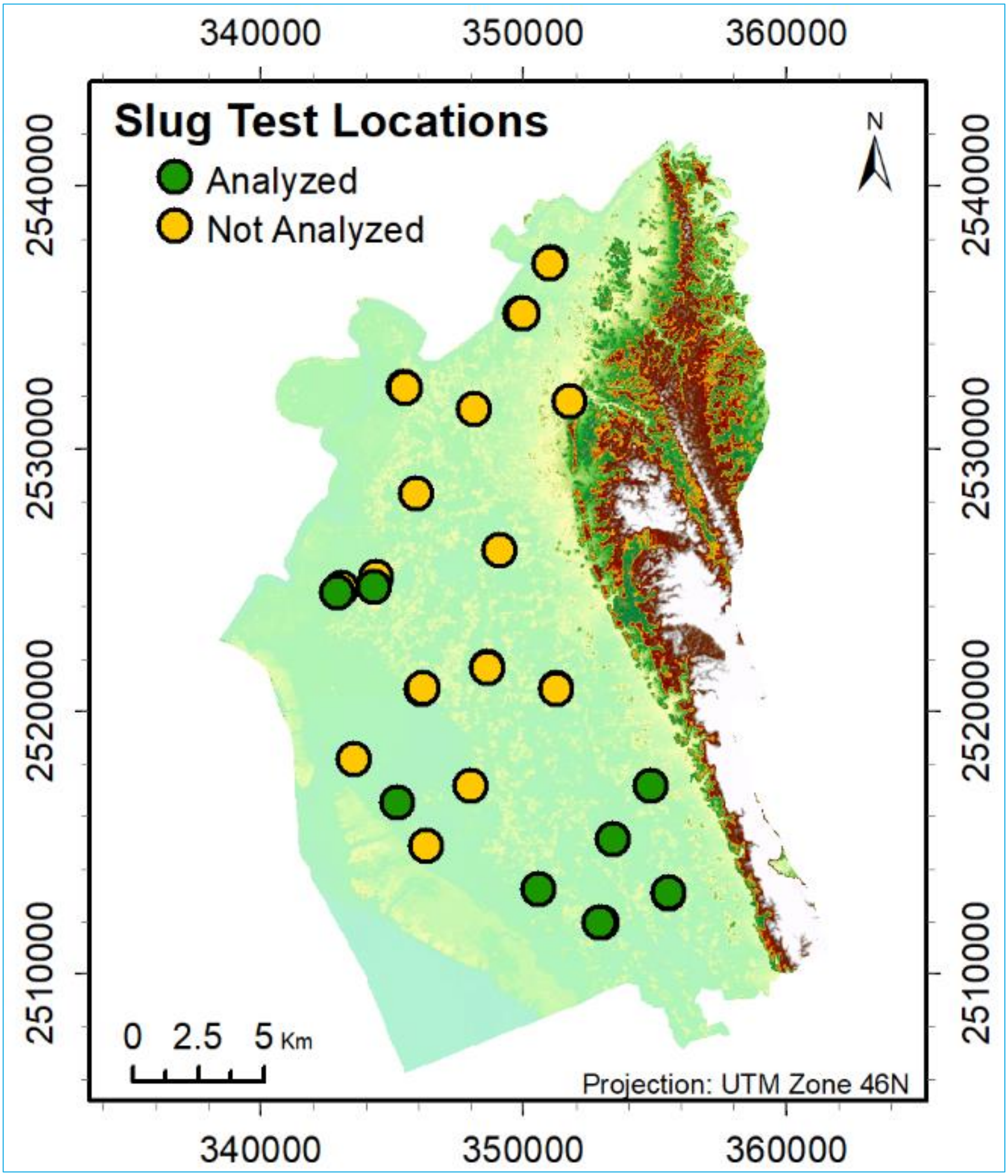

Figure 12: Map showing the locations where slug tests were carried out in the field. Most of the location has a pair of a deep and a shallow wells. Not all data have been analyzed yet, data points are highlighted for which hydraulic conductivity has been calculated from the field data.

Figure 13: Slug Test in field.

The Hvorslev equation (1) was used to analyze the slug test data for wells with overdamped response (Figure-14). A few wells showed underdamped response (Figure-15), slug test data for these wells were analyzed using Bouwer and Rice equation (2).

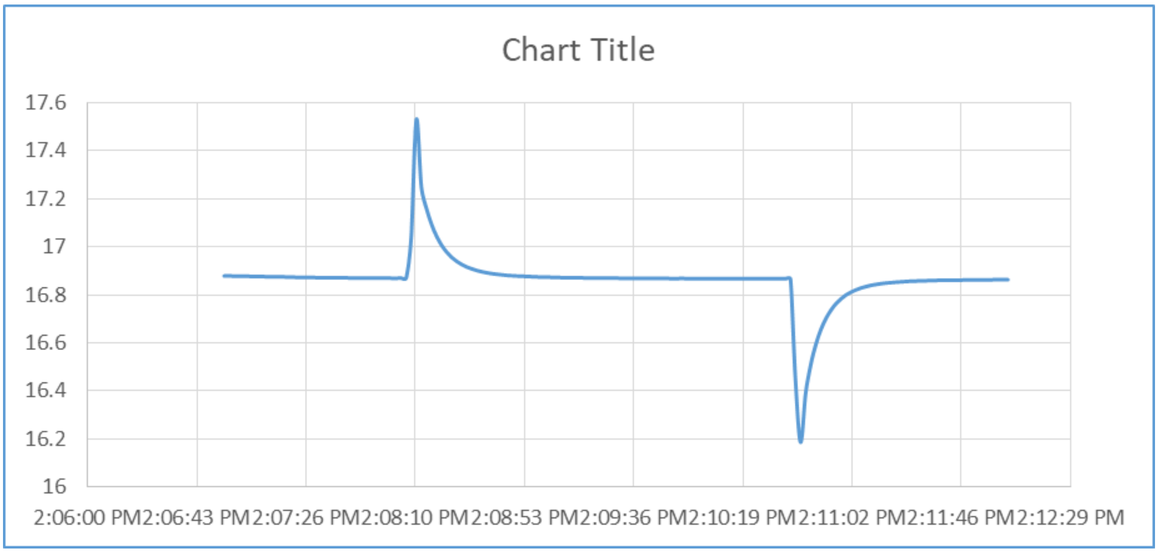

Figure 14: Overdamped Response.

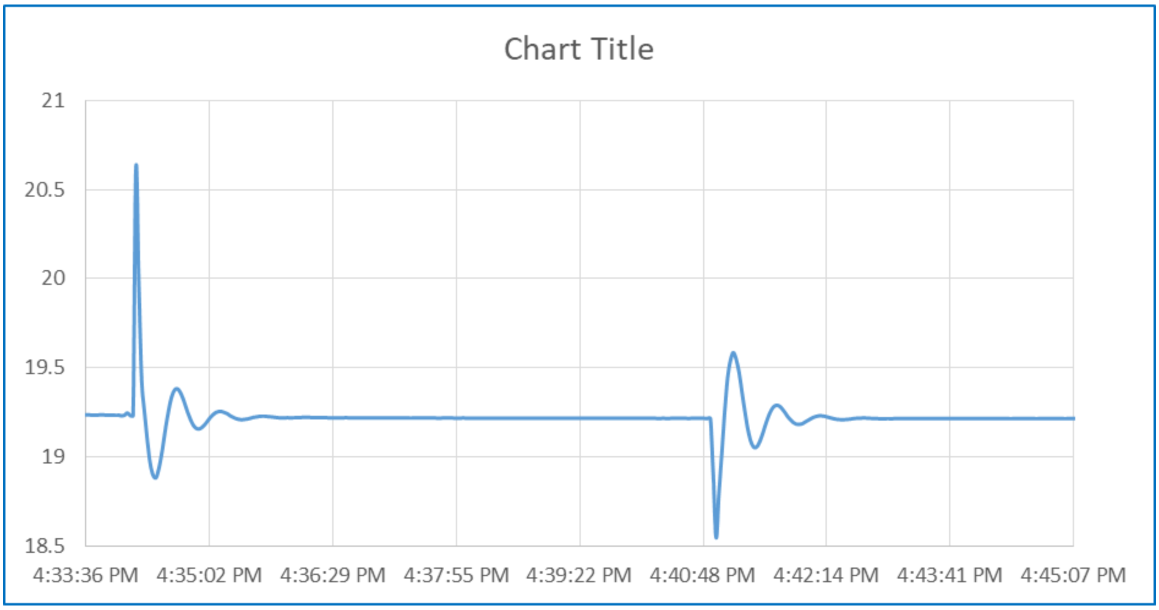

Figure 15: Underdamped Response.

Hvorslev Equation (1):

$$K = \frac{r_c^{\,2} \cdot \ln\left(\dfrac{L_e}{r_w}\right)}{2 \cdot L_e \cdot t_0}$$

where r_c is the radius of the well casing (m), L_e is the length of the well screen (m), r_w is the radius of the well screen (m), t_0 (s) is the basic time lag and the time value (t) is derived from a plot of field data. Generally, t_{37} (s) is used, which is the time when the water level rises or falls to 37% of the initial hydraulic head H_0 (m), the maximum difference respect the static level

Bouwer and Rice (1976) Equation (2):

$$K = \frac{r_c^{\,2} \cdot \ln\left(\frac{R_e}{r_w}\right)}{2L_e} \cdot \frac{1}{t} \cdot \ln\left(\frac{H_0}{H}\right)$$

where R_e is the radius of influence (m), and t is the time since $H=H_0$.
Using the results from an electric analog model, Bouwer and Rice obtained two empirical formulas relating $ln(R_e/r_w)$ to the geometry of an aquifer system, the first for $L_w>B$ and the second for $L_w<B$, where B is the formation thickness (m) and L_w is the static water column height (m).

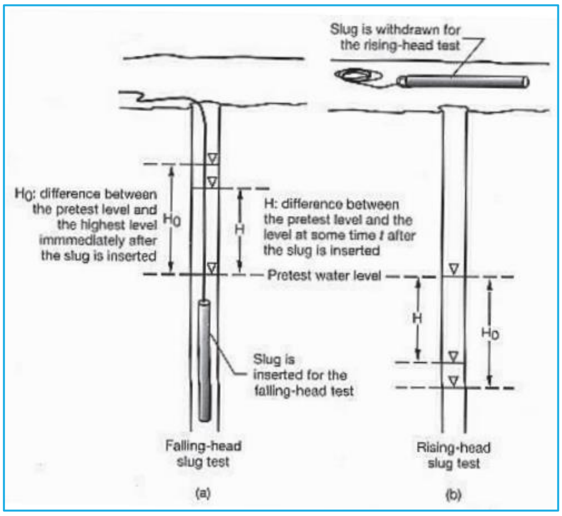

Figure 16: Slug Test Operative Method.

2.1.6. Identification of Surface Waterbody, Flash Flood zoning and mitigation approach

In Mirsharai Upazila Main River is Feni; Sandwip Channel is notable; Canal is about 30 nos, most noted of which are Feni Nadi, Isakhali, Mahamaya, Domkhali, Hinguli, Molisaish, Koila Govania and Mayani Khal. All the rivers and khals and canals are coming from eastern hilly region and falling in Bay of Bengal. In the high tide, sea water enter into the canal and go back into sea in low tide time.

At the monsoon season heavy rainfall occur. As the project area is bounded by hills at eastern side and west by sea, the rainwater influx affects the project area by flash flood. By discussing with local people it is very clear that flash flood effect is prominent in monsoon season. In this phase five (5) major basin/watershed were delineated which is shown in figure-17.

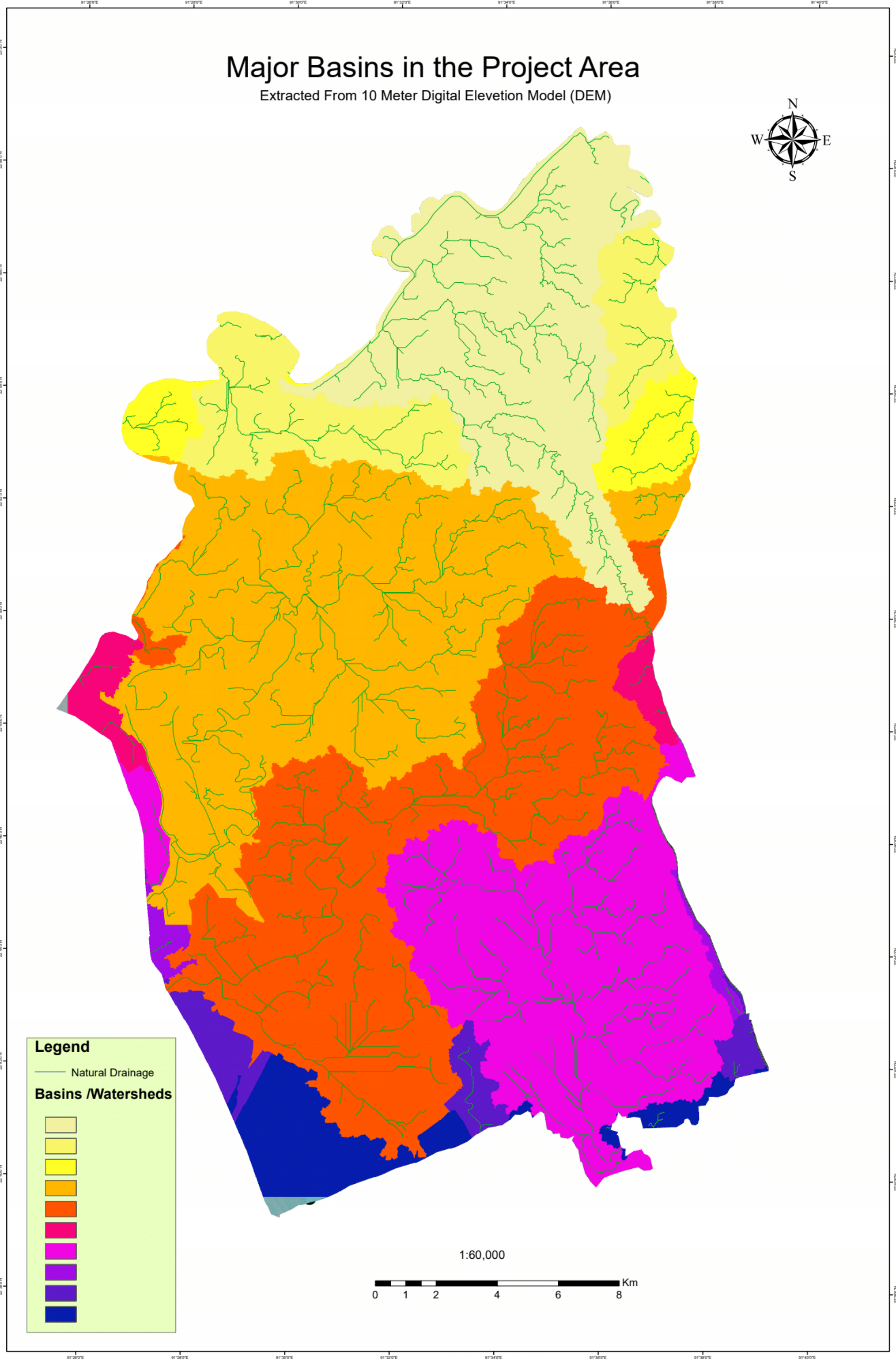

Figure 17: Major basin/watershed identified in the project area.

As the part of the study there was a scope beyond the ToR, to identify prospective artificial reservoirs for fresh water which can be the alternative source of water for irrigation as well as drinking and other uses. The prospective zones were identified (Figure-18) and labeled as prospect-1 to prospect-4. The existing Mohamaya Lake was also demarked to validate the prospect identified with the help of 10 m DEM supplied by the client.

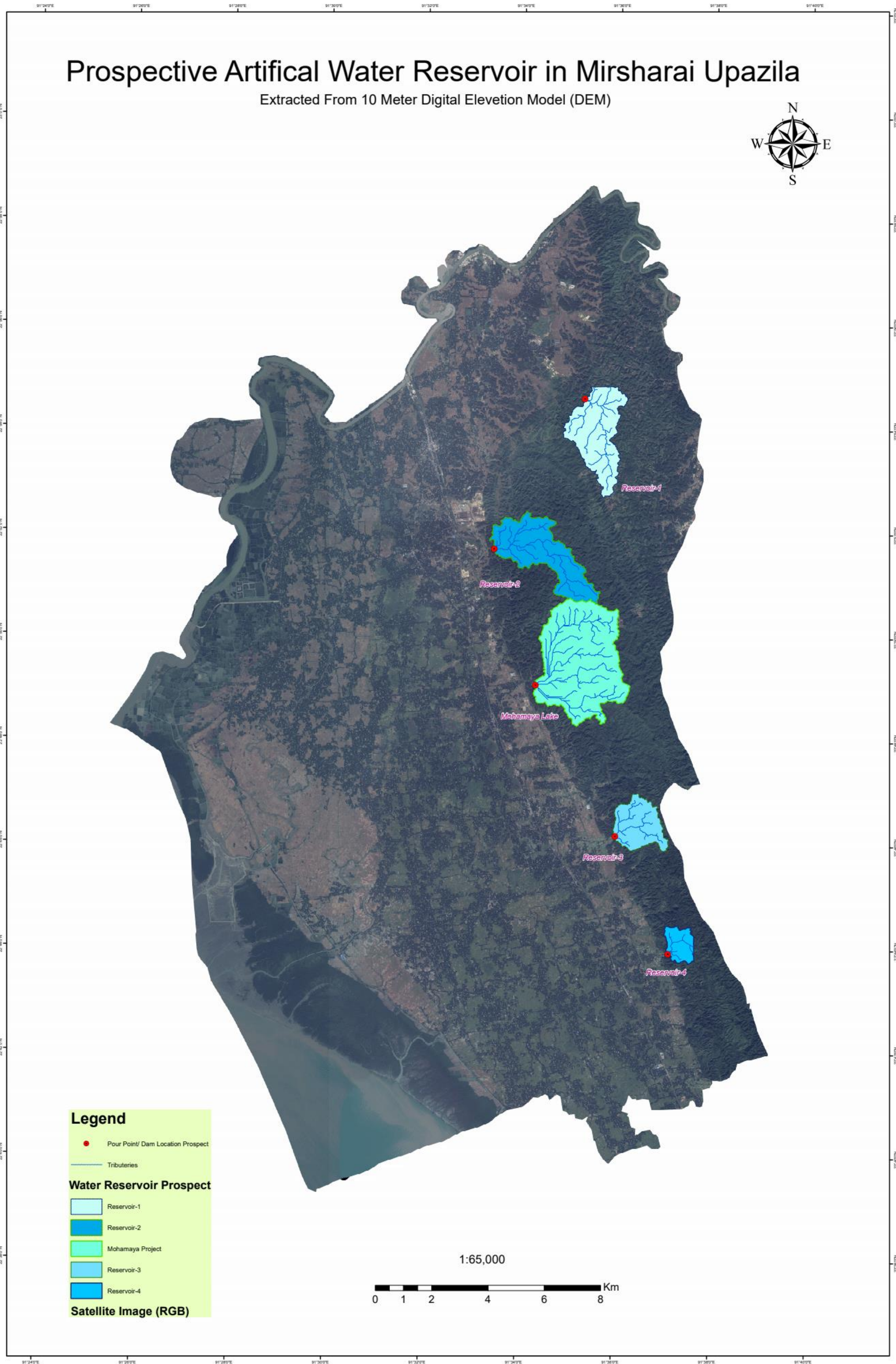

Figure 18: Prospective artificial reservoir locations

Surface waterbody maps, flash flood zoning and corresponding result of the project area will be provided after getting the Physical features survey data and verified DEM from UDD in the next phase of reporting.

2.2. Laboratory Analysis

2.2.1. Grain Size Analysis

Lithologic samples collected from the monitoring wells were sorted and depending on the lithological variability samples from each aquifer unit was selected for grain size analysis. Grain size analysis includes oven drying the samples and then sieving through various mesh sizes and calculation of weight percentage for different size fraction (Figure-19). Grain size data was later used in calculation of hydraulic conductivity of the aquifer unit using empirical formula.

In 1893, Hazen published his formula for estimating hydraulic conductivity:

$K = C_H \text{ x } d_{10}^2$

K = Hydraulic conductivity [m/s]

C_H = Empirical constant, in this study set to 0.01157 [-]

d_{10} = The particle size for which 10% of the material is finer [mm]

The graphs obtained from the grain size analysis of the samples from monitoring wells are attached in Appendix-V.

Figure 19: Grain size Analysis in Laboratory

2.2.2. Water Quality Analysis

Water samples collected from the field were brought to the laboratory for detail chemical analysis. Chemical analysis includes determination of the concentration of major ions and trace elements. All the samples are being tested in the laboratory and will take about one more month. List of chemical species and analytical methods are given in Table -3.

Serial no.	Chemical constituents	Methods and Instruments
1	Sodium (Na^+)	Atomic absorption spectrometer(GBC sens AAS)
2	Potassium (K^+)	Atomic absorption spectrometer(GBC sens AAS)
3	Calcium(Ca^{2+})	Atomic absorption spectrometer(GBC sens AAS)
4	Magnesium(Mg^{2+})	Atomic absorption spectrometer(GBC sens AAS)
5	Bicarbonate(HCO_3^-)	Titration method (standard H_2SO_4 for HCO_3^-)
6	Chloride(Cl^-)	Titration method (standard $AgNO_3$ for Cl^-)
7	Nitrate(NO_3^-)	UV visible spectro-photometer(wave length 410nm)
8	Iron (Fe)	Atomic absorption spectrometer(GBC sens AAS)
9	Manganese (Mn)	Atomic absorption spectrometer(GBC sens AAS)
10	Arsenic (As)	Atomic absorption spectrometer(GBC sens AAS)
11	Sulphate(SO_4^{2-})	UV visible spectro-photometer(wave length 410nm)

Table 3: List of chemical species and analytical methods

2.3. Groundwater Modeling

A three dimensional groundwater flow model will be developed after analyzing all the field data in the lab and detail assessment of the hydrogeological condition in the study area. Currently, the modeler is compiling and analyzing the the data as they become available.

3. Result

3.1. Groundwater Resources

3.1.1. Aquifer Framework

Preliminary examination of the drillers logs at the five monitoring well locations suggest that there are basically two aquifer zones present in the study area. The shallower of the two aquifers exists below a thin surficial clay/silty clay layer. This aquifer is about 100 to 120 m thick in the north and thins out to only about 50 m in the south. The hydraulic conductivity value of the aquifer as determined from slug test varies between 1.0 m/d to 11.0 m/d and that from grain size analysis varies between 1.6 m/d to 14.4 m/d. This aquifer is mostly unconfined to semi-confined at places where the surficial clay is present.

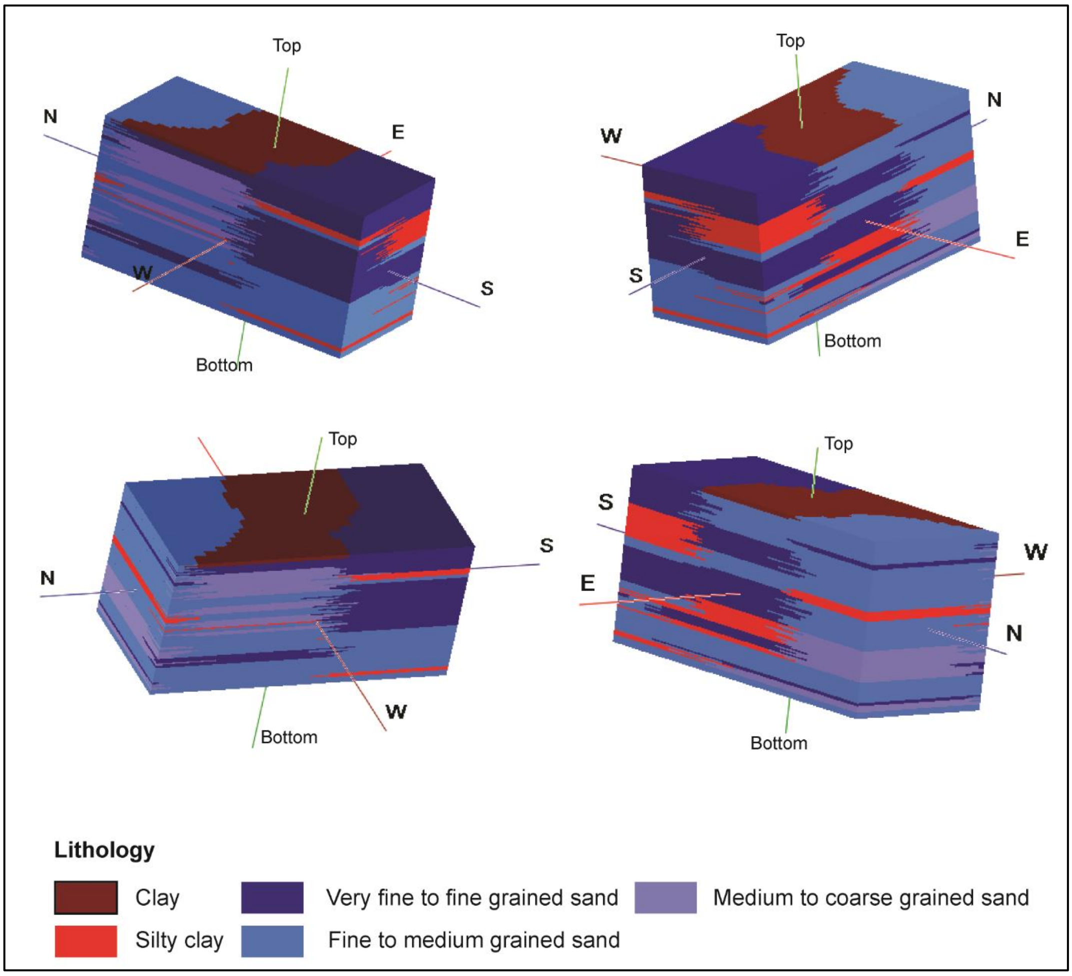

Figure 20: Lithological models

The deeper aquifer exist below a depth of more than 100 meter in all locations and separated from the shallow aquifer by the presence of an aquitard. This aquifer is 50.0 to more than 100.0 m thick. Again the thickness of this aquifer is greater in the north and lesser in the south. The aquifer is confined in nature. The hydraulic conductivity value of the aquifer as determined from slug test varies between 1.0 m/d to 11.0 m/d and that from grain size analysis

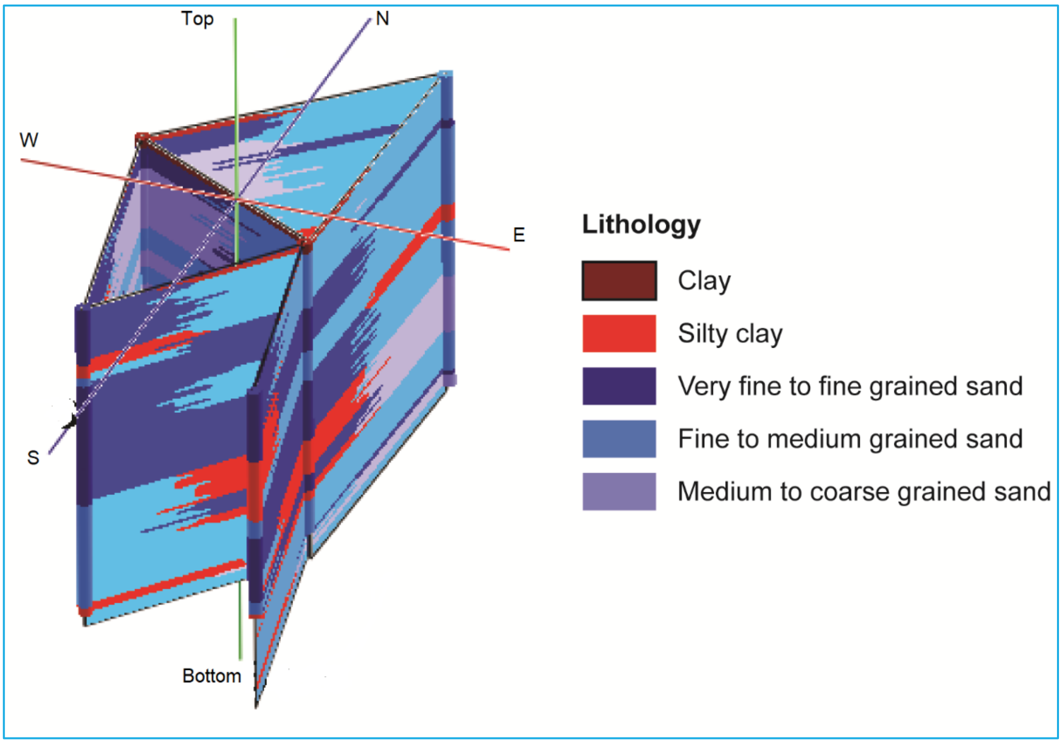

Figure-21: Fence Diagram for the project area.

varies between 1.6 m/d to 14.4 m/d. From the limited number of analyzed data points it appears that the deep aquifer has higher hydraulic conductivity in the east than in the west.

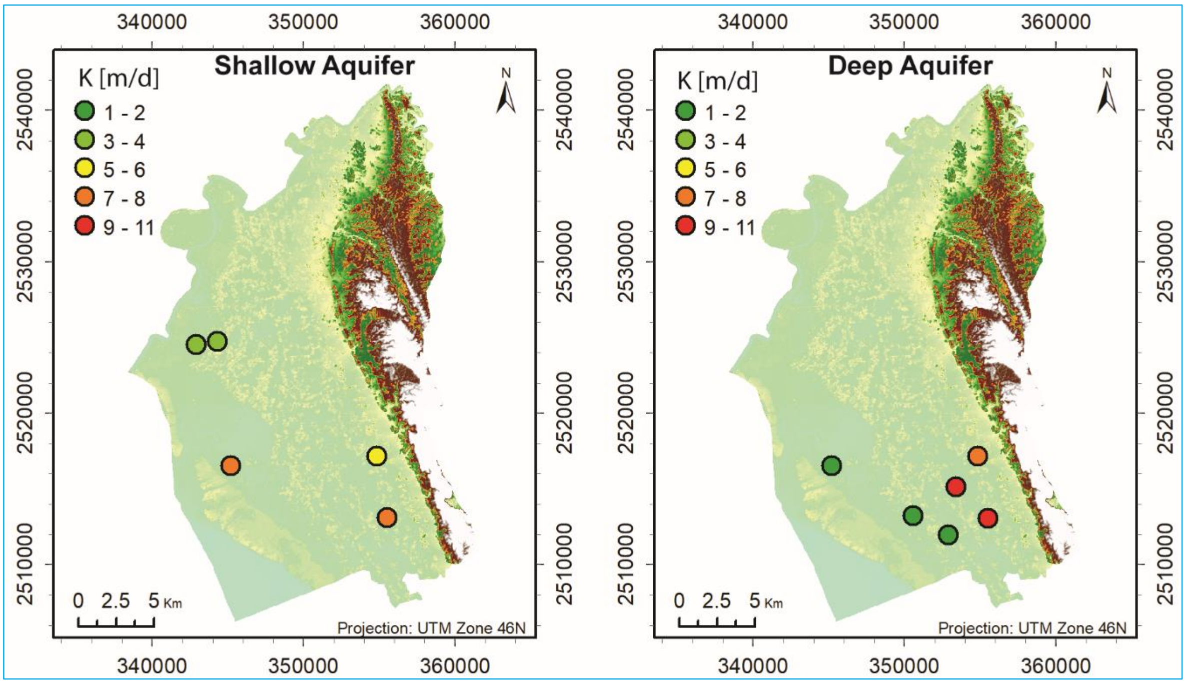

Figure 212: Hydraulic conductivity value of the shallow and deep aquifer at various locations determined from slug test.

The aquitard separating the two aquifers is about 5 to 10 m thick in the north and more than 50 m thick in the south. It is also possible that the thin aquitard encountered in the north is not spatially continuous and the shallow and deep aquifers are actually connected. However, this cannot be confirmed right now as the monitoring wells are widely distributed and interpretation of the aquifer system based on only these 5 wells may not be reliable. Incorporation of the VES data in the interpretation would immensely increase the accuracy of the interpretation. The VES data are still being analyzed and should be ready within a week or two.

Well	Aquifer Type	Hydraulic Conductivity (m/d)
MW-01	Shallow AQ	15.5
	Deep AQ	2.5
MW-02	Shallow AQ	6.4
	Deep AQ	14.4
MW-03	Shallow AQ	10
	Deep AQ	3
MW-04	Shallow AQ	1
	Deep AQ	3
MW-05	Shallow AQ	6.4
	Deep AQ	1.6

Table 4: Hydraulic properties derived from Grain Size analysis.

3.1.2. Groundwater Flow Direction

Groundwater flow direction was determined based on the field measurement of depth to groundwater level. The depth data was later converted to groundwater elevation based on the DSM supplied by UDD.

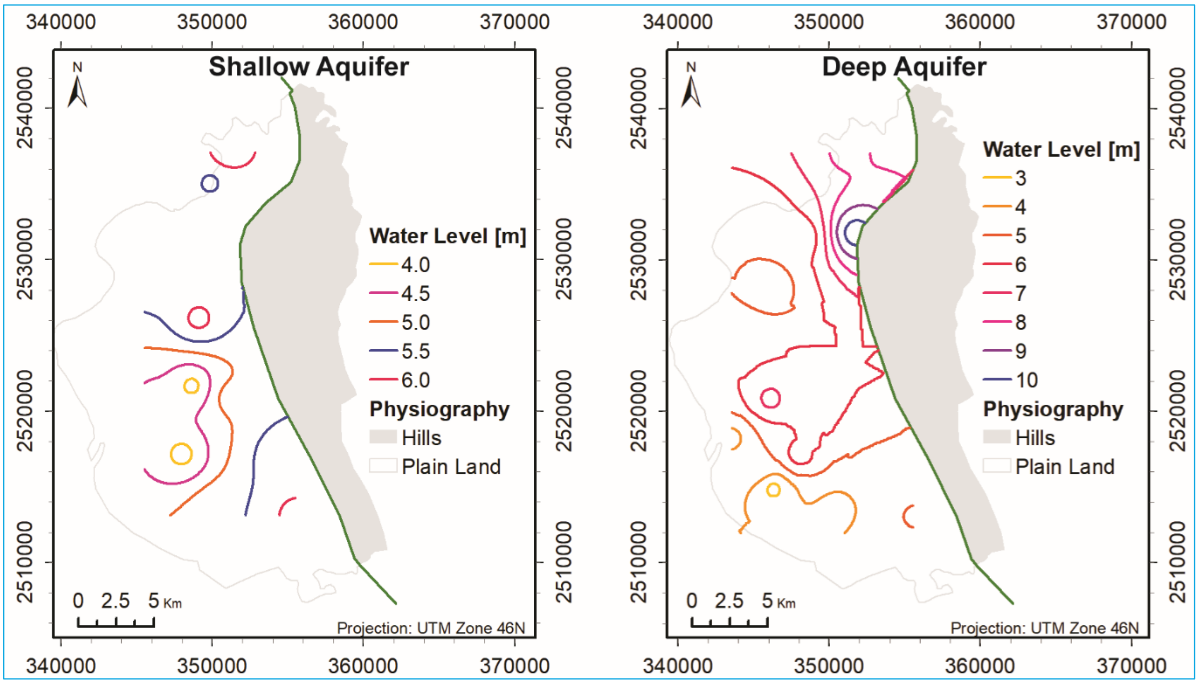

Figure 223: Groundwater level contour in the study area of the shallow aquifer and deep aquifer.

Figure-23 shows the groundwater level for both the shallow and deep aquifer. Groundwater level in the shallow aquifer varies between 4 m and 6 m. Spatially there seems to be no definite trend in the groundwater level data. This is either due to inaccurate topography data or the flow direction in the shallow aquifer is erratic. Nevertheless, a trend is apparent in the central part of the study area where the shallow groundwater flow direction is from east to west. Groundwater level data for the deep aquifer is in contrast more coherent than the shallow data. There is a strong trend in groundwater level, groundwater flows from NNE to SSW direction. The range of water level is also higher in the deep aquifer than in the shallow aquifer (3.0 m to 10.0 m).

It is worth noting that artesian flow has been observed in the field in the extreme north corner of the study area (Figure-24). Only the deep (>200 m deep) aquifer in that location flows automatically with an approximate head of 5 m above the land surface.

Figure 234: Artesian well the north-eastern part of the Project area.

3.1.3. Groundwater Quality

3.1.3.1. Electrical Conductivity

Electrical conductivity (EC) in groundwater is a measure of salinity and can indicate seawater intrusion or similar phenomenon. The EC in the shallow aquifer varies between 500 µS in the north to more than 8000 µS in the south and south west near the Sandwip Chanel. While, the groundwater in the deep aquifer is very fresh throughout the region with maximum EC value of 900 µS encountered in the extreme south. The EC value is exceptionally low (<200 µS) for both the shallow and deep aquifers in the northern tip of the study area.

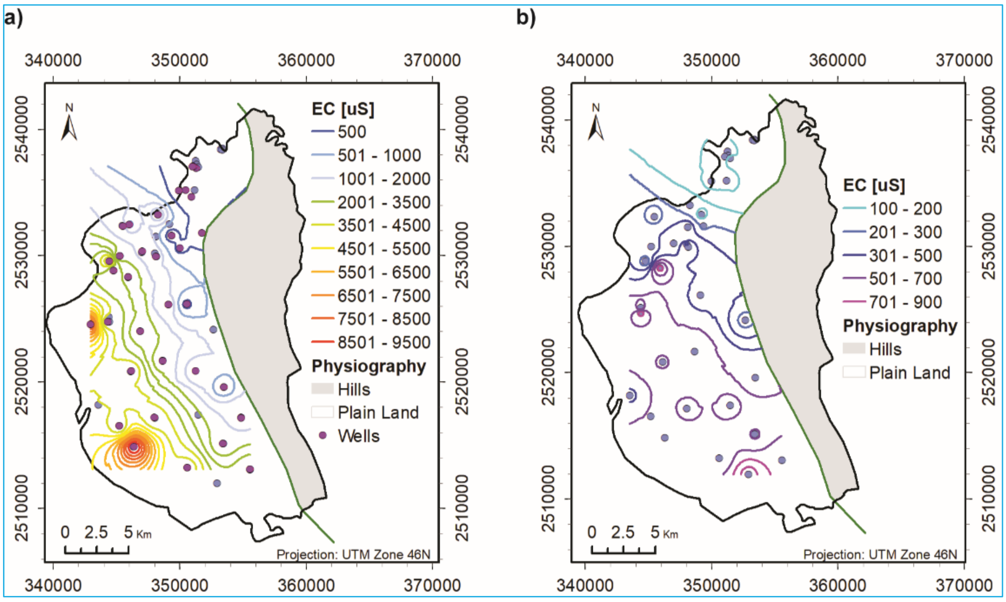

Figure 245: Map showing the spatial variability of electrical conductivity in the (a) shallow and (b) deep aquifer, respectively.

3.1.3.2. Arsenic

Field kit measured arsenic concentration in a number of wells distributed within the study area are shown in Figure-26. Field kit data suggest that the shallow aquifer is heavily contaminated with elevated arsenic concentration throughout the Upazila except in the extreme northern corner. However, the deep aquifer is largely low in arsenic concentration except one or two locations. In these locations it is highly likely that the sampled wells are actually shallower than reported, depth verification is required before making any conclusion on the arsenic contamination of the deep aquifer in the study area. Moreover, field kits only provides indication of the likelihood of contaminated wells. Without laboratory analysis confirmation about the arsenic status for the deep aquifer where only a few samples show marginally high concentration would not be accurate.

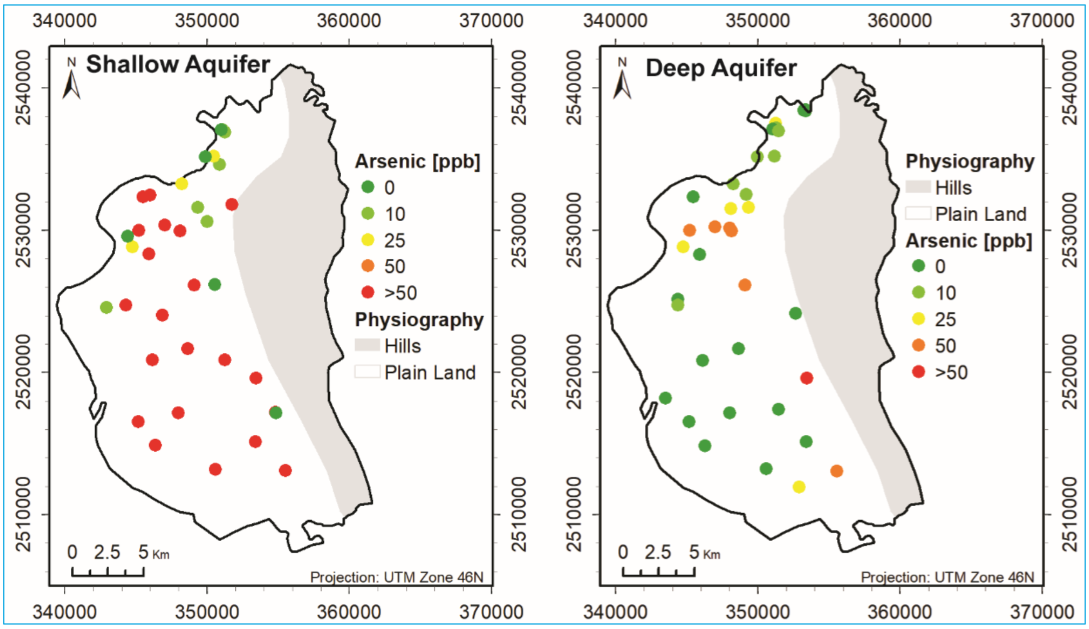

Figure 256: Arsenic distribution of Shallow and Deep Aquifer of the project area.

3.1.1. Groundwater Recharge Areas

Some preliminary assumptions about the groundwater recharge locations in the study area can be made based on the field observations. Groundwater level is the most important dataset delineating recharge zone, however, because of the erratic nature of the groundwater level data of the shallow aquifer it is really difficult to conclude anything based on groundwater level data for the shallow aquifer. However, the EC map provides a nice indication of the groundwater recharge areas as well as groundwater flow direction for the shallow aquifer. In recharge areas, the EC values are expected to be exceptionally low, and an increasing trend in EC from recharge areas towards discharge area is expected. Figure-23 (EC map) clearly suggest that the shallow aquifer receives most of its recharge in the northern part of the study area. This assumption is also supported by the arsenic concentration data. High arsenic is expected in old reduced water while there should be little or no arsenic in newly recharged oxidized water. The arsenic map of the shallow aquifer suggest that the norther part of the study area have very low arsenic concentration.

The groundwater level map of the deep aquifer readily indicates the location of the recharge area. It is also located in the north. Presence of artesian flow in some areas also indicates that some part of the deep aquifer must be exposed in the hills in the north where they receives bulk of the recharge.

3.2. Surface Water Resources and Flash Flood zoning and mitigation approach

This part will be summarized after getting the physical feature survey data and verified DEM provided by UDD in the next phase of reporting.

4. Discussion

Only a limited number of data has been analyzed so far and the following discussion is based on these small number of data and is subject to change/modification after the analysis of full dataset.

From the field data it appears that there are two aquifers present in Mirsharai Upazila. The shallower one is at a depth less than 100.0 m and the deeper one is at a depth greater than 100.0 m. The hydraulic separation between these two aquifers are greater in the south. In the north, it is possible that these two aquifers are joined together to form a single unconfined aquifer. Both aquifers are likely to receive recharge in the north and flow in a NNE-SSW direction, i.e. from hilly areas to the Sandwip Chanel.

Presence of high EC in the shallow aquifer only and not in the deep aquifer indicates that the source of high EC in the shallow aquifer might be due flooding of the area with sea water during the past. Perhaps this happened during storm surges in near past (100 years scale) or during the high sea level stand 5000 years before present.

The shallow aquifer contains very high arsenic concentration and is unfit for drinking purpose, while the deep aquifer is fresh and can be a good option for drinking water supply. Presence of artesian condition in the northern part of the study area indicates that the recharge potential of the deep aquifer is very high. Development of the artesian aquifer in the north could be good option for drinking water supply throughout the Upazila, however, this need detail field and modeling investigation.

There is one important concern about deep pumping in the southern part of the study area, where the aquitard between the shallow and the deep aquifer is thicker than 50 m. Heavy pumping from below that aquitard would cause a drop in pressure in the aquifer, and would initiate draining the overlying aquitard. The aquitard is composed of very soft marine clay. Upon drainage such clay layers have potential to lose more than 50% of its thickness causing subsidence. On the other hand, this thick aquitard can provide protection against downward migration of brackish water in the deep aquifer if the pumping in the deep aquifer in this part of the study area kept low.