Final Report

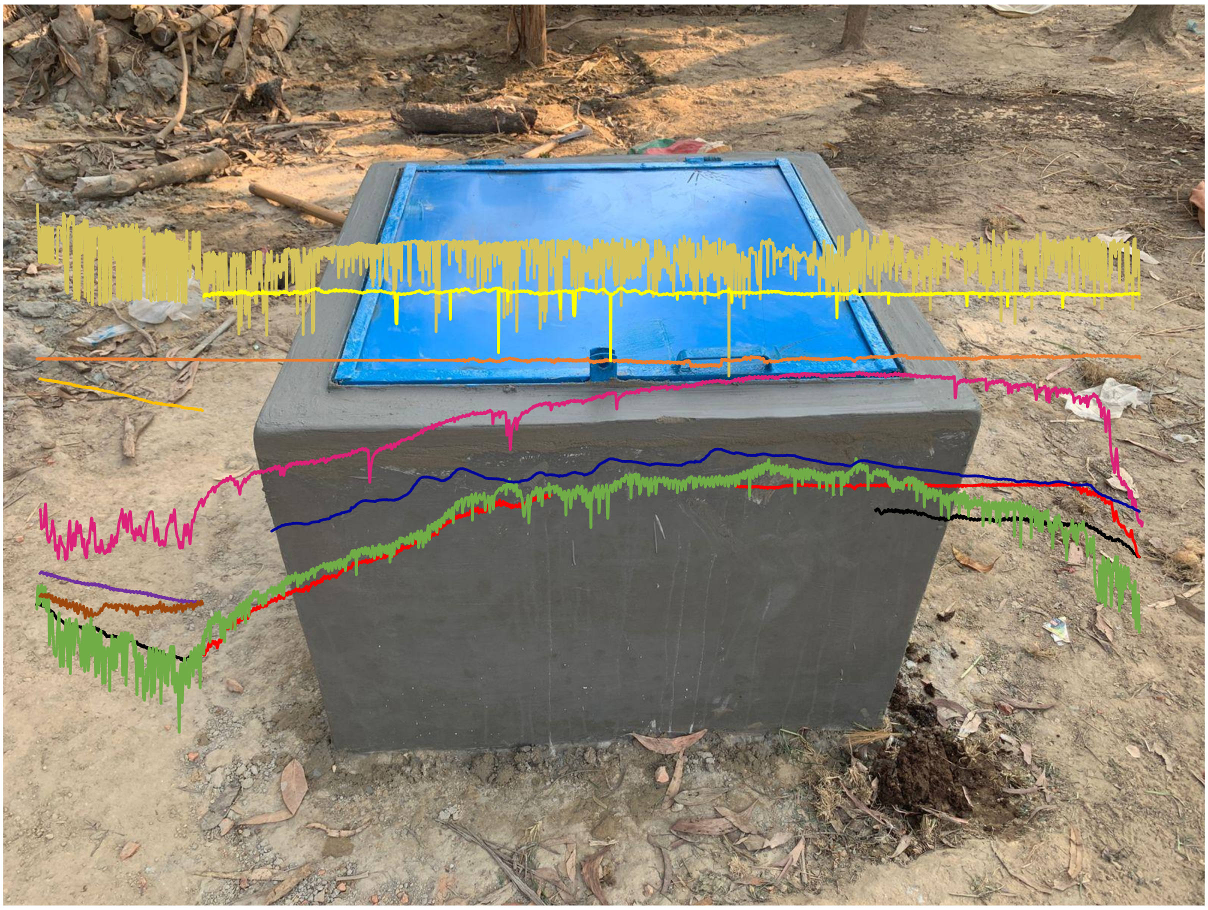
on

Groundwater Monitoring in Whykhong and Hnila Union, Teknaf Upazila, Cox's Bazar

Under

Groundwater Based Potable Water Supply for Host Communities and Refugees

JANUARY 2023



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EXECUTIVE SUMMARY

Teknaf municipality has a long history of water scarcity. UNHCR has received funding from the Japanese Government to develop a well field and piped network system to improve water supply in Teknaf. UNHCR commissioned, through Oxfam, Department of Geology, Dhaka University (DoG-DU) to monitor groundwater level and water quality to identify potential risks and concerns for the proposed project. Dhaka university monitored groundwater levels and EC using automated data loggers, conducted laboratory analysis of major water quality parameters for pre-monsoon and post-monsoon season, and conducted a blanket microbiological testing of 100 wells in the area through DPHE.

Groundwater monitoring data suggests that there are two different aquifer systems in the area, (1) artesian, and (2) non-artesian. The artesian system exists mostly in the west of Cox-Teknaf highway and does not show any seasonality in the groundwater level, while the non-artesian system shows about 6 m of seasonality. In the non-artesian aquifers, the lowest water level is found in mid-April while the highest occurs in late October. Groundwater level is higher in the west and lower in the east, suggesting groundwater recharge in the hills and discharge in the Naf River.

The most significant findings for this particular project is the evidence of lack of hydraulic connection between shallow and deep aquifer in Palongkhali area, a potential area for well field. The implication is that high rate of proposed pumping from the deep aquifer in this area is unlikely to impact the water level of the shallow aquifer and consequently less impacts on the existing water wells of the local community.

The water quality analysis of both microbiological contamination and groundwater chemistry reveals that the majority of water is in excellent condition for drinking purposes. More than 70% of the sampled wells show no microbiological contamination. The remaining wells that show contamination is most likely sourced from the well head, rather than the aquifer. This is because no spatial or depth trend was observed in the data. In terms of the total dissolved solids and major ion chemistry all but one wells have excellent quality of water for drinking purposes. The one well showing sea water contamination is located near Naf river and probably has some construction issue. However, there is some concerns about the aesthetics of the water as many of the samples show higher bi-carbonate, iron, and manganese concentration. Water with high bicarbonate and iron may not appealing to the consumers, while both iron and manganese can be an issue for the proposed pipeline.

Since the well field has yet to be operational, it is recommended that the monitoring be continued in 8 of the 11 DU wells, 3-4 of the new wells installed by GWR in camp 21 for the period of 2023 and then based on the observation of 2023 selective monitoring can be continued from 2024 onward.

Contents

Chapter 1 : Introduction and Background

Due to the influx of more than a million Rohingyas, Cox's Bazar district has become one of the most vulnerable districts of the country in terms of food, shelter, livelihood, water, sanitation, health, and environment. With support from donor communities, such as the United Nations and various national and international NGOs, the Government of Bangladesh is providing basic support to the forcefully displaced Myanmar Nationals (FDMN).

Water resources in Cox's Bazar district are very limited in scope and very challenging in terms of exploration. Water supply in this area heavily depends on groundwater throughout the year. The study area Teknaf Upazila is one of the most Hydrogeologically complicated areas in Bangladesh, where significant groundwater sources are yet to be found for providing enough water for the local inhabitants. People are living below the standard of having safe drinking water supply per day for very long. Moreover, recently the Rohingya community added more stress on it. Local stream (known as Chhara) and some shallow tube well (often brackish in quality) commonly used for water supply in this area, where often health issues arise for water quality and its scarcity.

Teknaf Upazila has a population size estimated to be currently 423,750. This population is made up of approximately 111,250 refugees and 312,500 host community. UNHCR has received funding from the Japanese Government to improve water security in the Upazila through maximizing the exploitation of ground water resources. They are therefore looking to develop a well field and piped network system to create a unified water supply system for the entire host community, which will be socially, economically and environmentally sustainable in the medium to long-term. The well field would focus on the supply of the host community and would initially look to supply priority communities with an estimated 2.0 Megalitres per day (MLD). A groundwater feasibility study has been conducted and work is being carried out to find the best location for the well field and determine its design.

Any groundwater intervention requires a follow-up monitoring plan. Department of Geology, University of Dhaka formed a partnership with OXFAM and took the responsibility of groundwater monitoring for the year of 2022 in this area. The plan was to carryout automated water and electrical conductivity in a number of piezometers strategically located and installed by Dhaka University in the previous phase (Sep-Dec 2021) of the study.

During the first phase of the study, based on geophysical exploration, exploratory boreholes, existing water point mapping a total of three zones (Figure-1.1) were selected as potential well field sites. Groundwater modelling results suggested that Zone-B and C are favourable over zone A. Further assessment of site logistics Zone-C (camp-21) was chosen to be investigated more and to be selected as the final site for well field and the subsequent monitoring plan was heavily influenced by this decision. The planned activities, deliverables and time line under this study is summarized in a table 1.1.

This report is organized as per the activities listed in table-1.1.

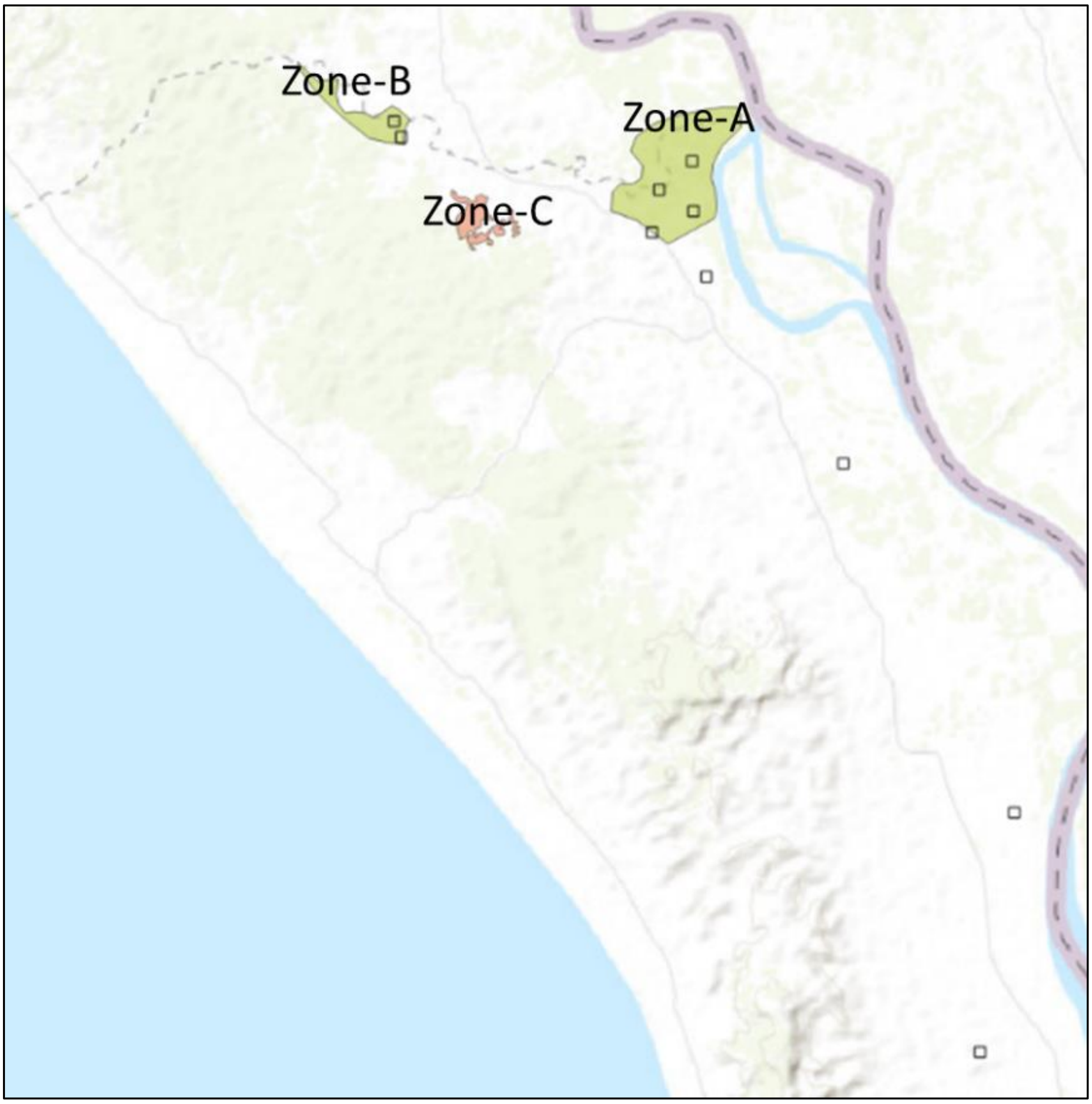

Figure-1.1: Potential zones for well filed installation. The squares show the location of the piezometers.

Table-1.1: Activities, deliverables and time line

Sl	Activity	Q1	Q2	Q3	Q4
1.	Installation of 3 shallow monitoring wells clustered with three of the existing deep monitoring wells with RTK elevation survey				
2.	Procurement and installation of water level and CTD loggers and relevant accessories				
3.	Groundwater level data download and analysis				
4.	Groundwater Sampling in Pre-monsoon and post-monsoon seasons and laboratory analysis for major ion chemistry and microbiological analysis				
5.	Project completion workshop and reporting				

Chapter 2 : Installation of Monitoring Wells

Installation of Additional Monitoring Wells:

During the previous phase of the study, Dhaka University has installed 9 monitoring wells covering the southern part of Palongkhali Union, Ukhia Upazila, eastern part of Whykhong union and the Hnila union of Teknaf upazila (Figure-2.1). Under the current phase, it was originally proposed to install three additional shallow monitoring wells in Zone-A. Later, it was decided to install one deep and one shallow monitoring well near zone B and C instead of three shallow wells in Zone A as the focus was shifted from Zone A to Zone B and C. Therefore, a shallow monitoring well (ID MW3.1) was installed using direct circulation drilling method (Figure 2.2) next to previously installed deep monitoring well (MW-1.1), and a deep monitoring well (ID 3.2) was installed about half a kilometre south of MW 1.1. The well logs and fixtures are given in Figure 2.3 and 2.4.

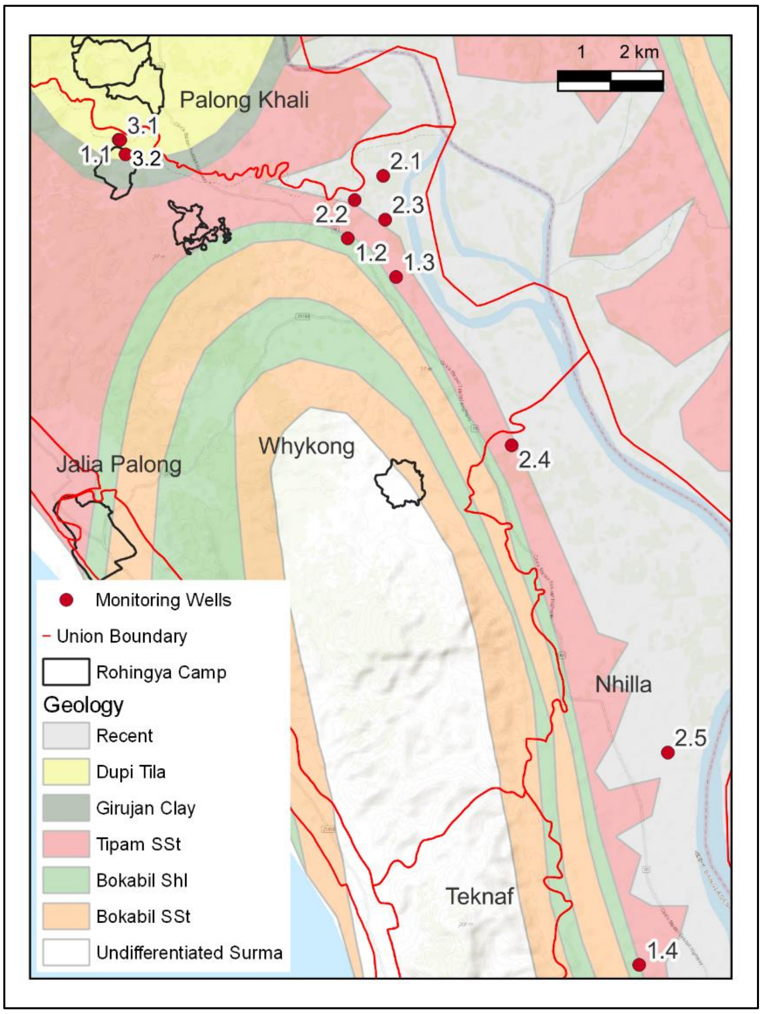

Figure-2.1: Map showing the locations of the monitoring wells

Figure 2.2: Photograph showing drilling technology for the deep monitoring wells

Depth Top [m]	Depth Bottom [m]	Color of Sediments	Lithology	Graphic Log
0.0	6.1	Yellowish Browm	Clay	
6.1	15.2	Brown	Fine sand	
15.2	18.3	Grey	Clay	
18.3	21.3	Grey	Fine sand	
21.3	27.4	Grey	Clay	
27.4	30.5	Grey	Fine sand	
30.5	36.6	Grey	Clay	
36.6	42.7	Grey	Fine sand	
42.7	48.8	Grey	Medium Sand	
48.8	51.8	Dark Grey	Very Fine Sand	
51.8	57.9	Dark Grey	Fine sand	
57.9	64.0	Dark Grey	Medium Sand	
64.0	67.1	Dark Grey	Fine sand	
67.1	70.1	Grey	Medium Sand	
70.1	76.2	Dark Grey	Clay	
76.2	91.5	Dark Grey	Fine sand	

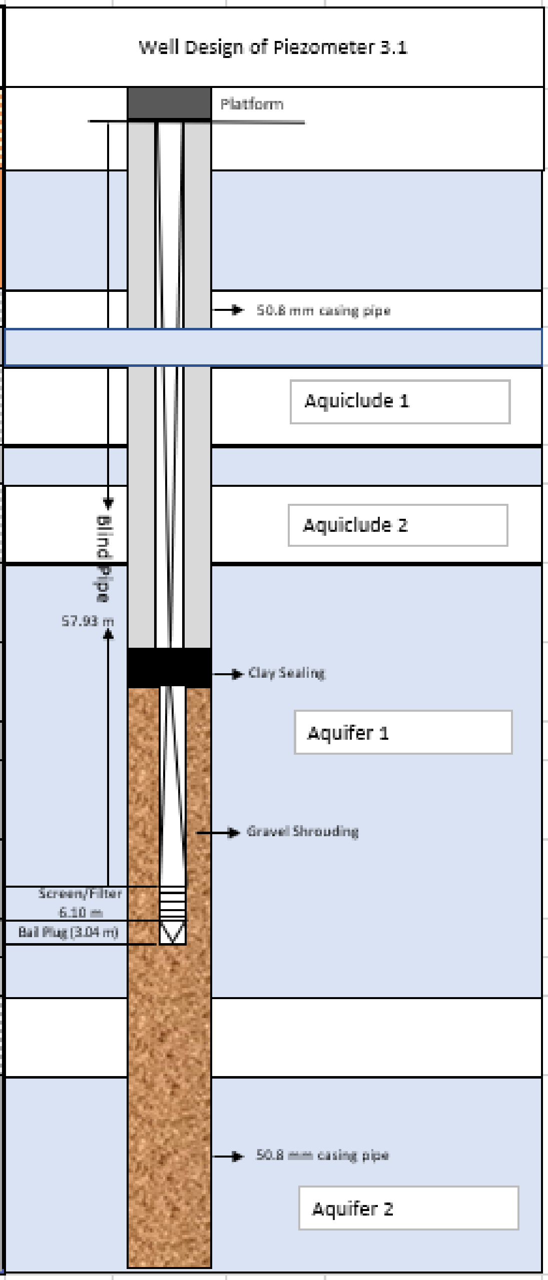

Figure 2.3: Borehole log and well fixture for MW-3.1.

Depth Top [m]	Depth Bottom [m]	Color of Sediments	Lithology
0.0	6.1	Brown	Clay
6.1	18.3	Grey	Clay
18.3	33.5	Grey	Very fine sand
33.5	48.8	Grey	Medium to fine sand
48.8	67.1	Grey	Very fine to fine sand
67.1	82.3	Grey	Fine to medium sand
82.3	91.5	Grey	Very fine to fine sand
91.5	155.5	Dark Grey	Clay
155.5	173.8	Grey	Fine to medium sand
173.8	198.2	Grey	Very fine to fine sand
198.2	259.1	Grey	Fine sand
259.1	274.4	Grey	Fine to medium sand
274.4	286.6	Grey	Clay
286.6	304.9	Grey	Fine to medium sand

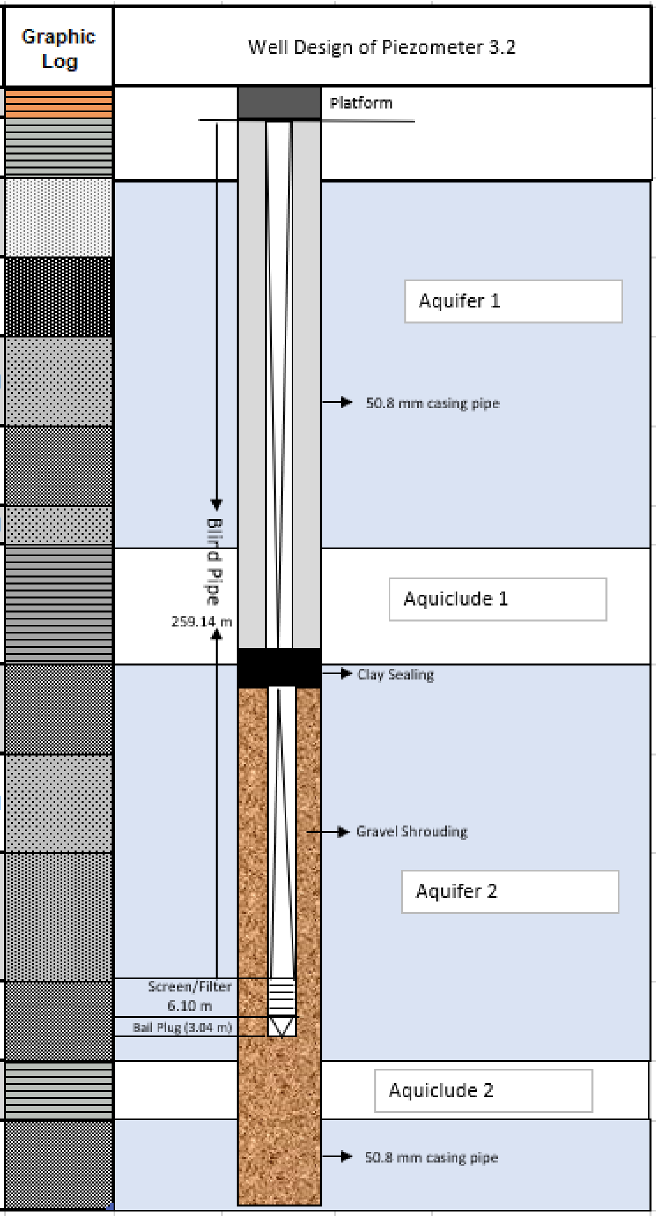

Figure 2.4: Borehole log and well fixture for MW-3.2.

Elevation Survey of the Monitoring Wells

Elevation of the monitoring well is essential in any groundwater study. Without elevation correction the observed groundwater level data cannot be compared among wells and no conclusion can be made on groundwater flow direction. Therefore, all 11 (9 previous and 2 new) monitoring wells installed by Dhaka University and three additional monitoring wells installed by Groundwater Relief in Camp-21 were surveyed using Real Time Kinematics (RTK) and the elevation of these wells were measured (Figure 2.5). The elevation of the monitoring well varies between 10 and 2 meters. Monitoring wells located near the Naf river have relatively low elevation than those located in the west, i.e. in the hilly areas (Table 2.1).

Table-2.1: Summary data of the monitoring wells

Well ID	**Northing**	**Easting**	**Well Screen Center Depth [m]**	**Elevation Top of Casing (TOC)[msl]**
DU 1.1	2338695.6	411200.4	231.7	6.99
DU 1.2	2336818.2	415556.0	225.61	4.96
DU 1.3	2336081.8	416474.8	219.56	5.15
DU 1.4	2322987.6	421096.4	189.02	10.16
DU 2.1	2338006.9	416229.1	225.61	2.29
DU 2.2	2337546.3	415687.6	170.73	1.97
DU 2.3	2337172.3	416267.1	201.22	4.64
DU 2.4	2332878.3	418672.3	198.17	2.32
DU 2.5	2327028.9	421642.9	228.66	2.53
DU 3.1	2338689.39	411228.27	60.96	6.65
DU 3.2	2338416.77	411329.5	262.128	6.50
GWR 01	2337378.67	412490.69	?	8.39
GWR 02	2336784.58	412798.28	?	6.45
GWR 03	2337019.56	412956.63	?	6.85

Figure 2.5: Elevation survey of the monitoring well platform.

Chapter 3 : Procurement of Data Loggers

Oxfam has procured a total of telemetric data loggers during the first phase of the study. During the current phase Dhaka University has procured three level loggers of the same configuration as of those procured previously by OXFAM. All data loggers are manufactured by In-Situ™. These three loggers have been handed over to Groundwater Relief through OXFAM so that the three monitoring wells of GWR in camp 21 can be equipped with these loggers. Each of the data loggers have the following specifications (Figure 3.1).

GENERAL	RUGGED TROLL 100 & 200	RUGGED BAROTROLL
TEMPERATURE RANGES[1]	Operational: 0-50° C (32-122° F) Storage: -40-80° C (-40-176° F) Calibrated: 0-50° C (32-122° F)	Operational: 0-50° C (32-122° F) Storage: -40-80° C (-40-176° F) Calibrated: 0-50° C (32-122° F)
DIAMETER	2.62 cm (1.03 in.)	2.62 cm (1.03 in.)
LENGTH	14.43 cm (5.68 in.)	14.43 cm (5.68 in.)
WEIGHT	137 g (0.30 lb)	137 g (0.30 lb)
MATERIALS	Titanium body; Delrin® nose cone, hanger, backend	Titanium body; Delrin nose cone, hanger, backend
OUTPUT OPTIONS	Rugged TROLL 100: USB via docking station; Wireless Rugged TROLL Com Rugged TROLL 200: USB via docking station; Wireless Rugged TROLL Com; Modbus/RS485 or SDI-12 via Rugged TROLL 200 Cable	USB or RS232 via docking station; Modbus/RS485 or SDI-12 via Rugged TROLL 200 Cable; Wireless Rugged TROLL Com Device
BATTERY TYPE & LIFE[2]	3.6V lithium; 10 years or 2M readings	3.6V lithium; 10 years or 2M readings
EXTERNAL POWER	Rugged TROLL 100: NA Rugged TROLL 200: 8-36 VDC	8-36 VDC
MEMORY Data records[3] Data logs	2.0 MB 120,000 Rugged TROLL 100: 1 log Rugged TROLL 200: 2 logs	2.0 MB 120,000 1 log
FASTEST LOGGING RATE	1 per second	1 per minute
FASTEST OUTPUT RATE	Rugged TROLL 200 only Modbus & SDI-12: 1 per second	Modbus & SDI-12: 1 per second
LOG TYPES	Linear, Fast Linear, and Event	Linear
SENSOR TYPE/ MATERIAL	**PIEZORESISTIVE; CERAMIC**	**PIEZORESISTIVE; CERAMIC**
RANGE	9 m (30 ft) (Burst: 18 m; 60 ft) 30 m (100 ft) (Burst: 40 m; 134 ft) 76 m (250 ft) (Burst: 112 m; 368 ft)	7 to 30 psi; 0.5 to 2 bar
ACCURACY	±0.05% FS from 0 to 50 °C	±0.05% FS from 0 to 50 °C
RESOLUTION	±0.01% FS or better	±0.01% FS or better
UNITS OF MEASURE	Pressure: psi, kPa, bar, mbar, mmHg Level: in., ft, mm, cm, m	Pressure: psi, kPa, bar, mbar, mmHg, inHg
TEMPERATURE SENSOR	**SILICON**	**SILICON**
ACCURACY	±0.3° C	±0.3° C
RESOLUTION	0.01° C or better	0.01° C or better
UNITS OF MEASURE	Celsius or Fahrenheit	Celsius or Fahrenheit
WARRANTY	**2 YEARS**	**2 YEARS**

Figure-3.1: Specifications of data loggers

Chapter 4 : Results of Groundwater Monitoring Using Automated Data Loggers

Analytical Method for Groundwater Level Data:

Loggers were setup to measure depth to water in meter and electrical conductivity in uS/cm. Measurement intervals were selected to be 4 hours in order to ensure both data density and maximize the battery life of the instrument. During logger installation depth to groundwater was measured manually at each location. The manually measured data was used later to correct the logger measured depth to water. Barometric correction was performed automatically in wells equipped with VuSitu telemetry system (Figure 4.1). In the remaining piezometers where the VuSitu could not be installed due to site issues, barometric correction was performed during the data processing. The elevation of the top of casing of each of the 11 monitoring wells (Table 2.1) were surveyed using Realtime Kinematic (RTK). Out of the 11 wells, there was no data recorded in one well (Well ID: 2.2) till April, the probe was found to be faulty. Further, monitoring was discontinued in MW1.4, 2.4 and 2.5 as those monitoring wells are located in Hnila and far away from the current area of interest. The loggers have been removed from the 03 monitoring wells (well ID 1.4, 2.4 and 2.5) of Hnila and Unchiprang and placed in the 2.2, 3.1 and 3.2 monitoring wells in Ulubunia and Palongkhali.

Figure: 4.1: Photographs showing (left) installation of telemetric unit, (right) downloading of data from non-telemetric unit.

Insights from Groundwater level data:

Based on the observed groundwater levels, the monitoring wells can be grouped into artesian, seasonally artesian, and non-artesian. The artesian wells (1.1, 1.2 and 3.2) do not show any pronounced seasonality. Also, the groundwater level in these wells are the highest (Figure 4.1). Among these three artesian wells, the one located in Palongkhali (ID-1.1) shows some daily fluctuations in the range of about 2 meters.

This monitoring well is located within a kilometre of the Jamtali camp in the north and the Chaukhali camp in the south. The daily fluctuations may be due to camp pumping. Apart from these erratic fluctuations, the groundwater level in these artesian wells remains the same.

All the non-artesian and seasonally artesian wells show a seasonal fluctuation in the range of about 6 m (Figure 4.2). The lowest groundwater level is found in mid-April and the highest in late October. The shape of the groundwater level curve of monitoring wells 1.3, 2.1, 2.2, and 2.3 are more or less similar with the exception that the water level during the end of December falls rather sharply in 1.3 and 2.2 compared to the other two. This could be due to irrigation withdrawal in the area close to MW 1.3 and 2.2.

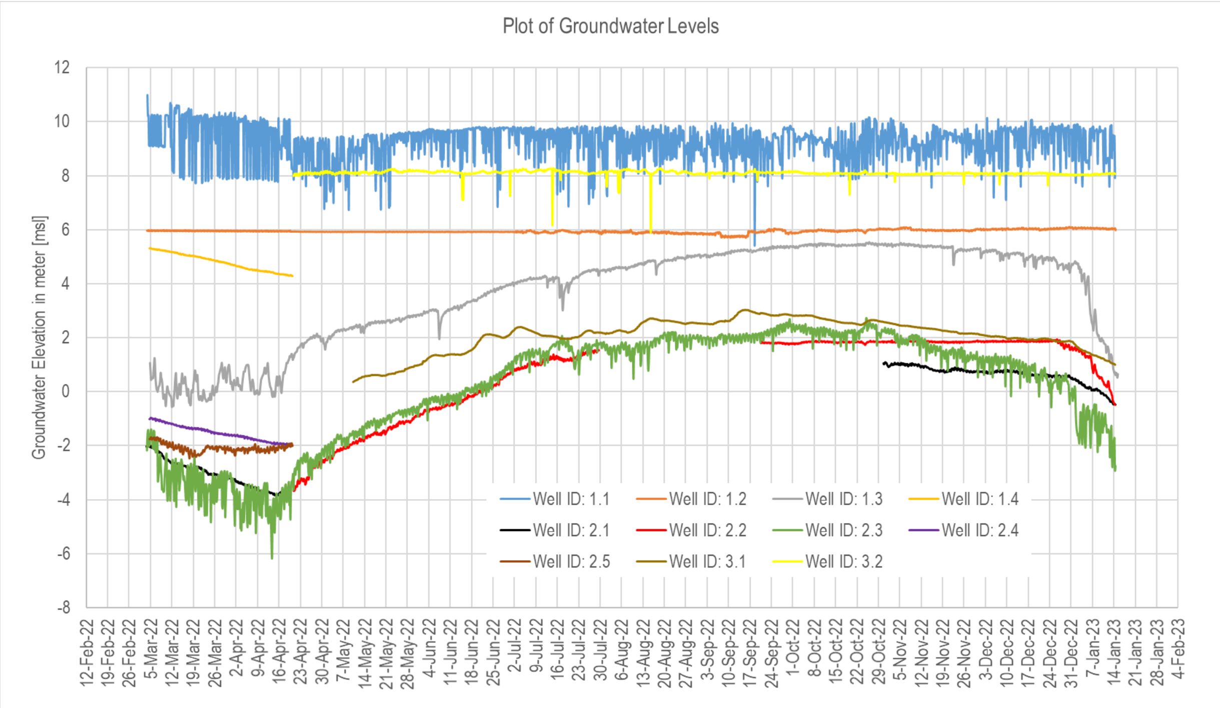

Figure-4.2: Plot of groundwater levels. Measurement intervals were 4 hours.

Overall, it is apparent that the wells located in the western side of the Cox's Bazar-Teknaf highway (ID 1.1, 1.2, 1.4 and 3.2) has higher groundwater level (hydraulic head) than those located in the east. Data is available for the six monitoring wells located on the east side of the highway. Among these six, one well (ID-1.3) is located close to the road and in exposed area of the Tipam sandstone aquifer (Figure 2.1). The rest (ID-2.1, 2.2, 2.3, 2.4 and 2.5) are located in the Naf river valley and in a close proximity to the river (Figure 2.1). Well 1.3 exhibits some erratic daily to weekly fluctuations (Figure 4.2). This well is located in a mosque just besides a pumping well in the mosque and an irrigation well nearby; besides the neighbouring community has a large number of domestic wells equipped with submersible pumps. The erratic fluctuation could be due to mosque pumping (Friday water uses is high) and local pumping. Besides, the short-term fluctuations there is pronounced seasonality of about 6 m in groundwater level. Groundwater levels in all five wells in the Naf River valley remain below sea level for approximately half of the year (Jan-Jun, Figure 4.2), indicating potential for seawater intrusion from Naf. This range of seasonality in these wells is similar to that of well 1.3.

One particularly important result is shown by the data of MW1.1 and 3.1. These are collocated wells with different screen depth. Well 3.1 is shallow and 1.1 in deep. Data suggests that there is about 8 meter of head (water level) difference between the shallow and deep aquifer in Palongkhali. The head in the shallow aquifer is lower with pronounced seasonality while the head in the deep aquifer remains above groundwater surface throughout the year. This indicates that the deep and shallow aquifer in this area are not connected and pumping from the deep aquifer is unlikely to impact the water level in the shallow aquifer, which is the primary screened interval of the local community.

Insights from loggers EC data:

Except one well (MW 2.3) all monitoring wells show groundwater EC in the range of 300 to 700 µS/cm and remains relatively stable throughout the year. The wells located west side of Cox-Teknaf highway are the freshest with groundwater EC values within 300-400 µS/cm and remain more or less the similar during the period of record (Figure 4.3). Groundwater EC in MW 1.3 seems to vary between <400 to little over 500 µS/cm range. This could be due to instrumental calibration issue. The EC data of MW 2.3 is erratic and the logger recorded value has no correlation with lab data, it is likely that the logger is faulty or need calibration. However, EC measurement using field meter shows an EC value of 4.28 mS/cm, which although high is much less than that measured by the data logger (>30 mS/cm), this is an indication of poor logger calibration or faulty logger. Nevertheless, during installation of this well in December 2021, it was found to contain fresh water (EC <1000 uS/cm). Therefore, even if the logger's data is unrealistic there is certainly an increase in EC. This could be due to well failure and water exchange with shallow depth.

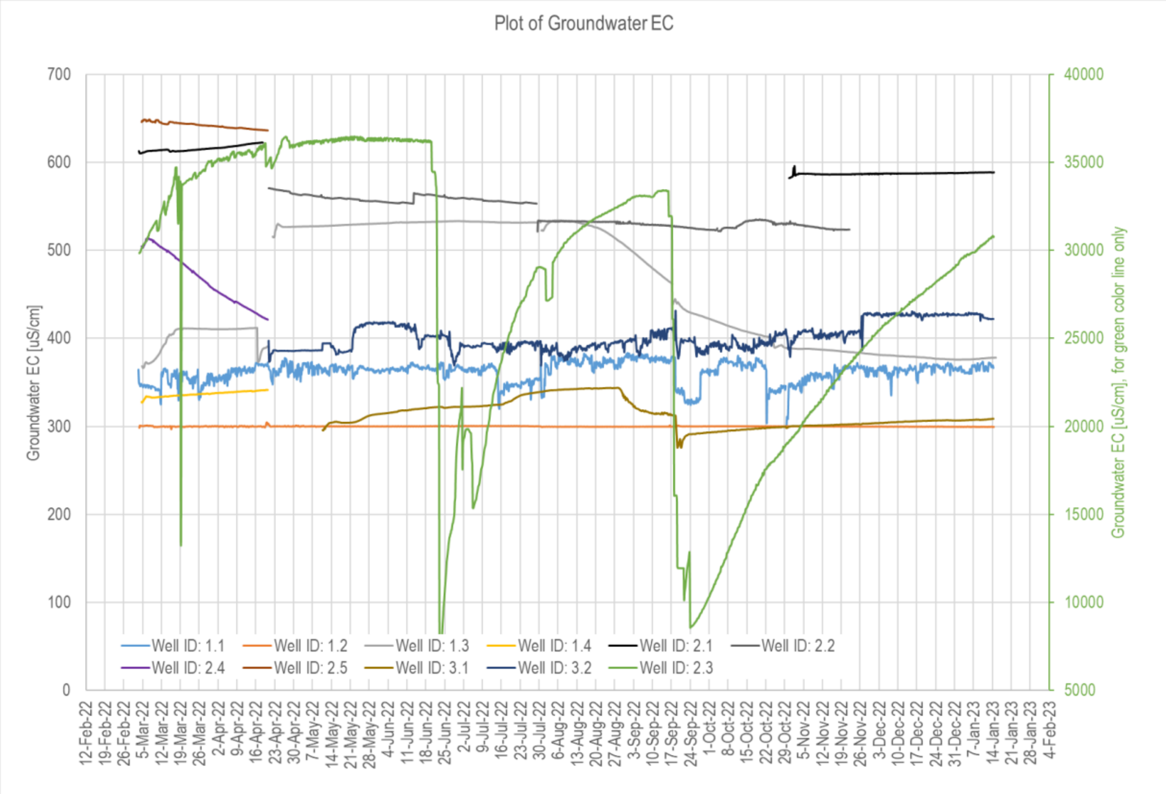

Figure-4.3: Plots of groundwater electrical conductivity (Measurement intervals were 4 hours). Because one well (green color) has very high EC value it is plotted in the right-hand axis, all other wells are plotted against the left-hand axis.

Chapter 5 : Laboratory Analysis of Groundwater for Chemical and Microbiological Parameters

Groundwater quality can vary seasonally. Therefore, it was decided that all these monitoring wells would be sampled for major ion and trace elements (iron and manganese) analysis twice a year- pre-monsoon and post-monsoon periods. Additionally, in order to assess the potential for microbiological contamination of groundwater sources a random sampling was planned for 100 existing wells (Figure-5.1) including the 13 piezometers for the analysis of faecal coliform. During sampling water from these wells were measured for TDS using a field meter.

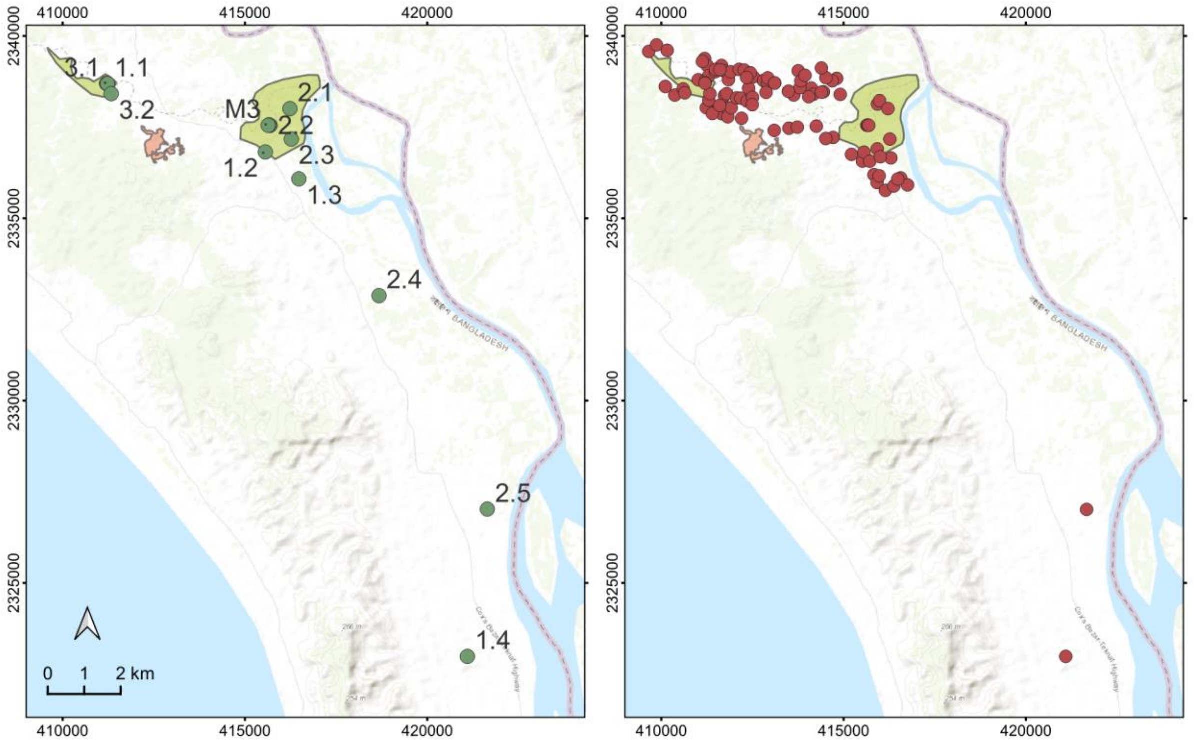

Figure 5.1: Map showing the locations of the monitoring wells (left) and the locations of 100 wells sampled for microbiological analysis in Palongkhali, Whykong, and Hnila Unions of Teknaf Upazila, Cox's Bazar District.

Sampling and analysis for fecal coliform

Samples were collected directly from the outlet of the existing well heads equipped with either handpumps or submersible pumps (Figure 5.2). Before sample collection each well were purged for 5-10 minutes. During sample collection the sampler sterilized his hands and used hand gloves. Samples were collected in sterile ziplock bags and immediately stored in a cooler.

Collected samples were then carried to the DPHE Cox's Bazar lab for analysis. Samples were analysed for fecal coliform using the membrane filter method. In this method 100 ml of water was filtered through 0.45 µm membrane filter, the filter was then transferred to the culture medium in a Petri dish. The petri dish was incubated for 24 hours at 44.5^{0}C temperature and the blue colony was counted, if any.

Figure 5.2: Photographs showing (left) sampling for laboratory analysis of water chemistry, (middle) field kit test of arsenic in the field and in-situ field parameter measurements, and (right) sampling for microbiology (hand was sterilized before sampling).

Water quality sampling for chemical analysis:

Before sampling at least three-well volume of water was pumped in each well and the samples were filtered through 0.45 µm membrane filter for removing colloidal materials and unwanted particles. Samples were collected in 125 ml plastic bottles. Two samples were collected from each well, one sample was acidified and the another one was non-acidified. Concentrated HNO3¯ was used to acidify the sample in order to lower the pH value to less than 3 to avoid the precipitation of the dissolved constituents from the samples. Each sample was given a sampling ID and sample bottle was labelled accurately with ID. Collected water samples were then transported to the lab and preserved in refrigetor for avoiding any chemical changes.

Analytical mathods used in the laboratory study is given in Table 5.1, whereas Figure 5.3 shows various analytical equipment used.

Table:5.1 Methods and Instruments used for different chemical constituents

Serial No	Chemical Constituents	Methods & Instruments
1	Calcium (Ca^{2+})	Atomic Absorption Spectrometer (GBC Sens AA)
2	Magnesium (Mg^{2+})	Atomic Absorption Spectrometer (GBC Sens AA)
3	Sodium (Na^{+})	Atomic Absorption Spectrometer (GBC Sens AA)
4	Potassium (K^{+})	Atomic Absorption Spectrometer (GBC Sens AA)
5	Bicarbonate (HCO_3^{-})	Titration Method (Standard H_2SO_4)
6	Chloride (Cl^{-})	Ion Chromatography (Dionex ICS 1100)
7	Sulphate (SO_4^{2-})	Ion Chromatography (Dionex ICS 1100)
8	Nitrate (NO_3^{-})	Ion Chromatography (Dionex ICS 1100)
9	Iron (Fe^{2+})	Atomic Absorption Spectrometer (GBC Sens AA)
10	Manganese (Mn^{2+})	Atomic Absorption Spectrometer (GBC Sens AA)

Figure 5.3: Equipment and methods used for the chemical analysis. From left to right - Atomic Absorption Spectrometry (AAS), Ion Chromatography (IC), and Acid based titration

Results of Fecal Coliform Analysis

Among the 100 sampled wells, 74% and 72% showed no microbial growth in pre-monsoon and post-monsoon seasons, respectively. There were various levels of fecal coliform growth in the remaining 26% and 28% of the pre and post-monsoon samples, respectively (Figure-5.4). Count of fecal coliform in the contaminated samples varies from 1 to more than 200. However, there is no spatial or depth pattern. Figure-5.5 and 5.6 shows that there is no correlation of bacterial contamination with depth or area. The contamination seems to be random. This is perhaps due to the fact that the source of contamination is not the aquifer, rather it is the well head, similar findings were also made in the MICS 2019 survey report[1].

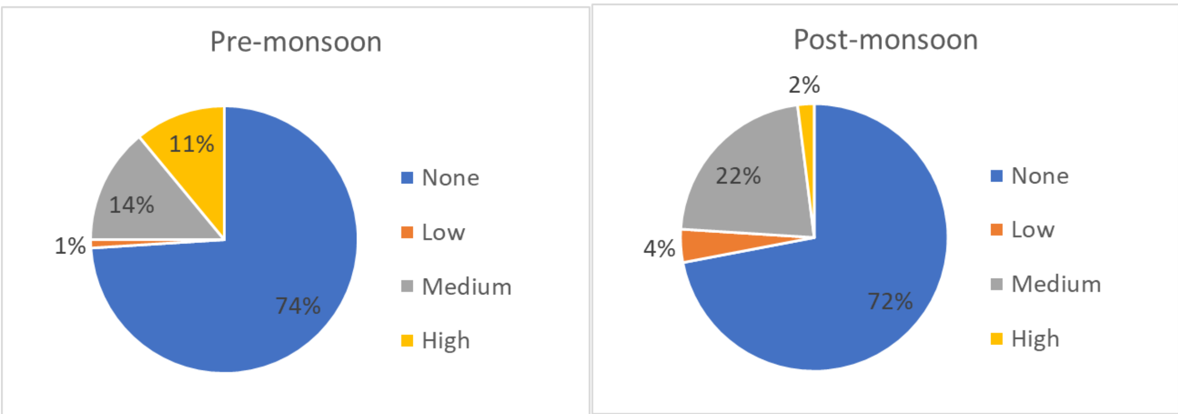

Figure 5.4: Summary results of microbiological analysis

[1] Bangladesh MICS 2019: Water Quality Thematic Report

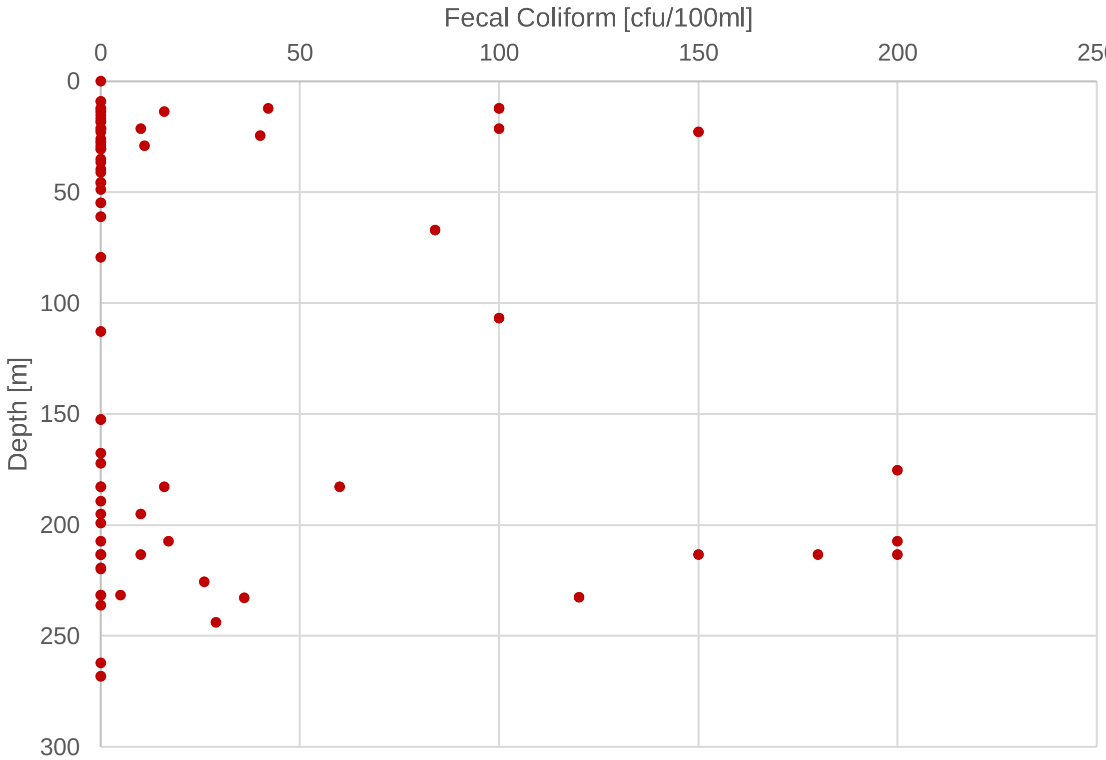

Figure-5.5: Depth distribution of water samples with their fecal coliform count

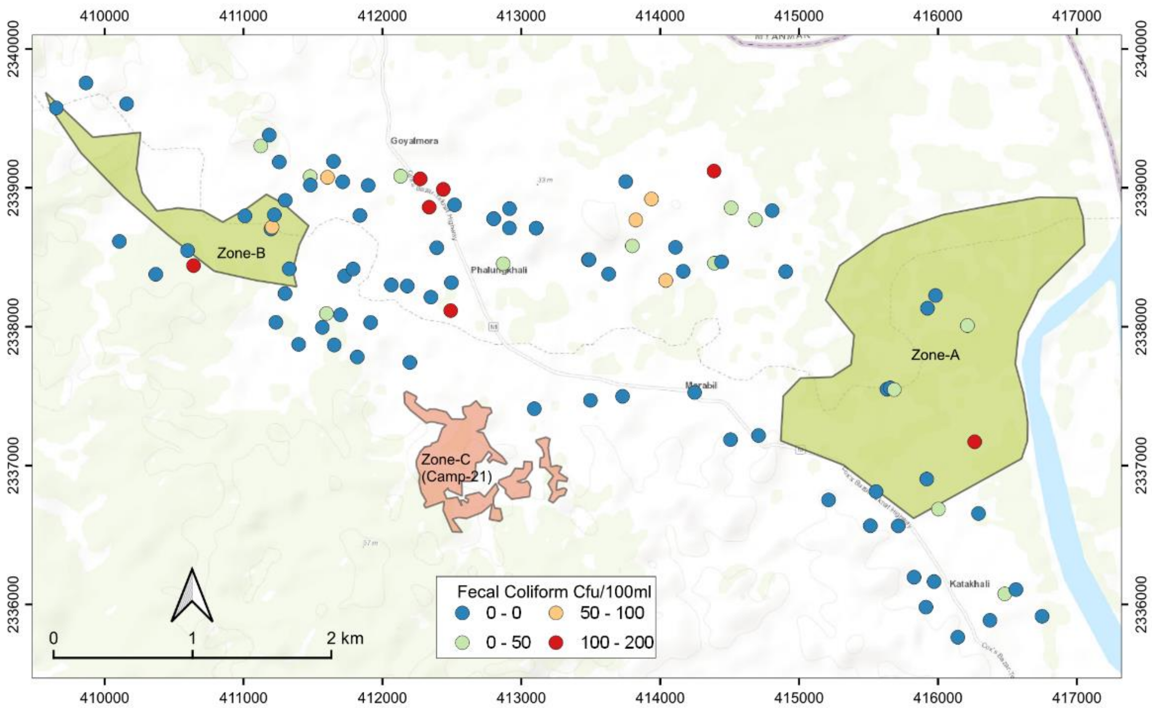

Figure-5.6: Spatial distribution of wells that were sampled for microbiological analysis. Wells are color coded according to the count of fecal coliform in the samples.

Groundwater Quality

The total dissolved solids in groundwater reflects the overall ionic concentration in water and provide a quick assessment of water quality. An opportunistic sampling was performed during the microbiological sampling. TDS in all wells sampled for microbiological analysis were measured in-situ using a pocket meter. Figure-5.7 shows the distribution and concentration of TDS in all those wells. With the exception of MW-2.3, all wells have excellent quality of water in terms of TDS. TDS calculated from the detail chemical analysis in the lab is in conformity with the filed data (Figure-5.8)

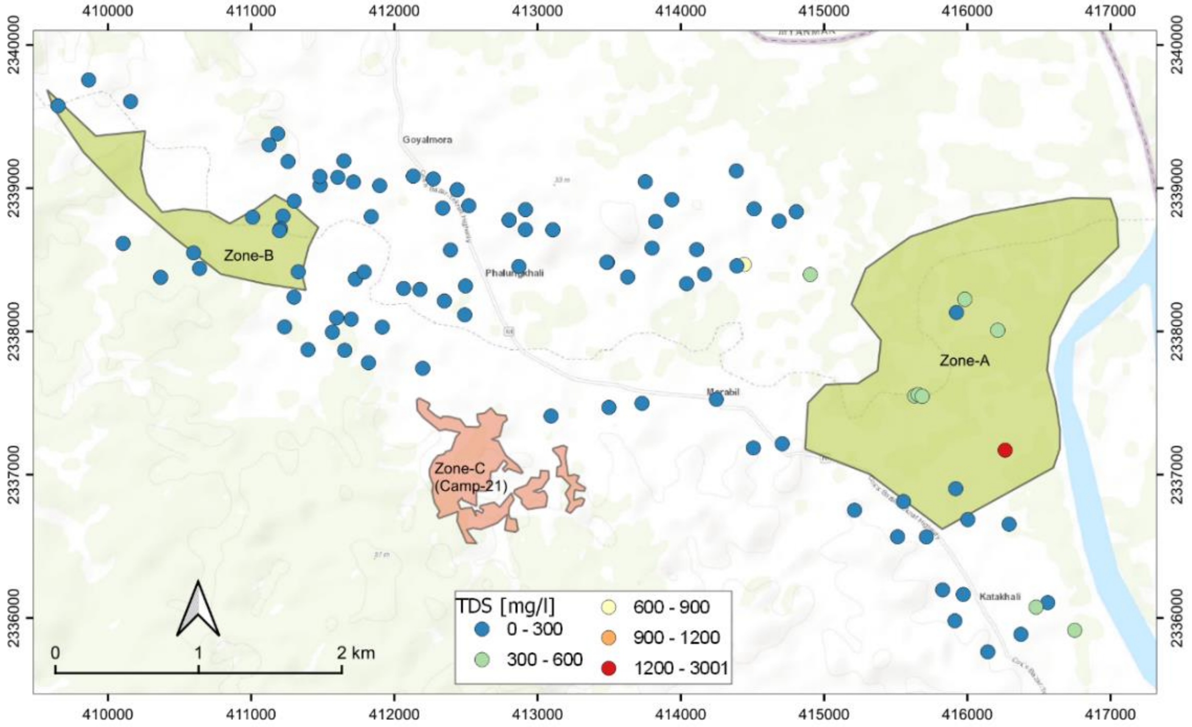

Figure-5.7: Spatial distribution of TDS in existing wells sampled for microbiological analysis.

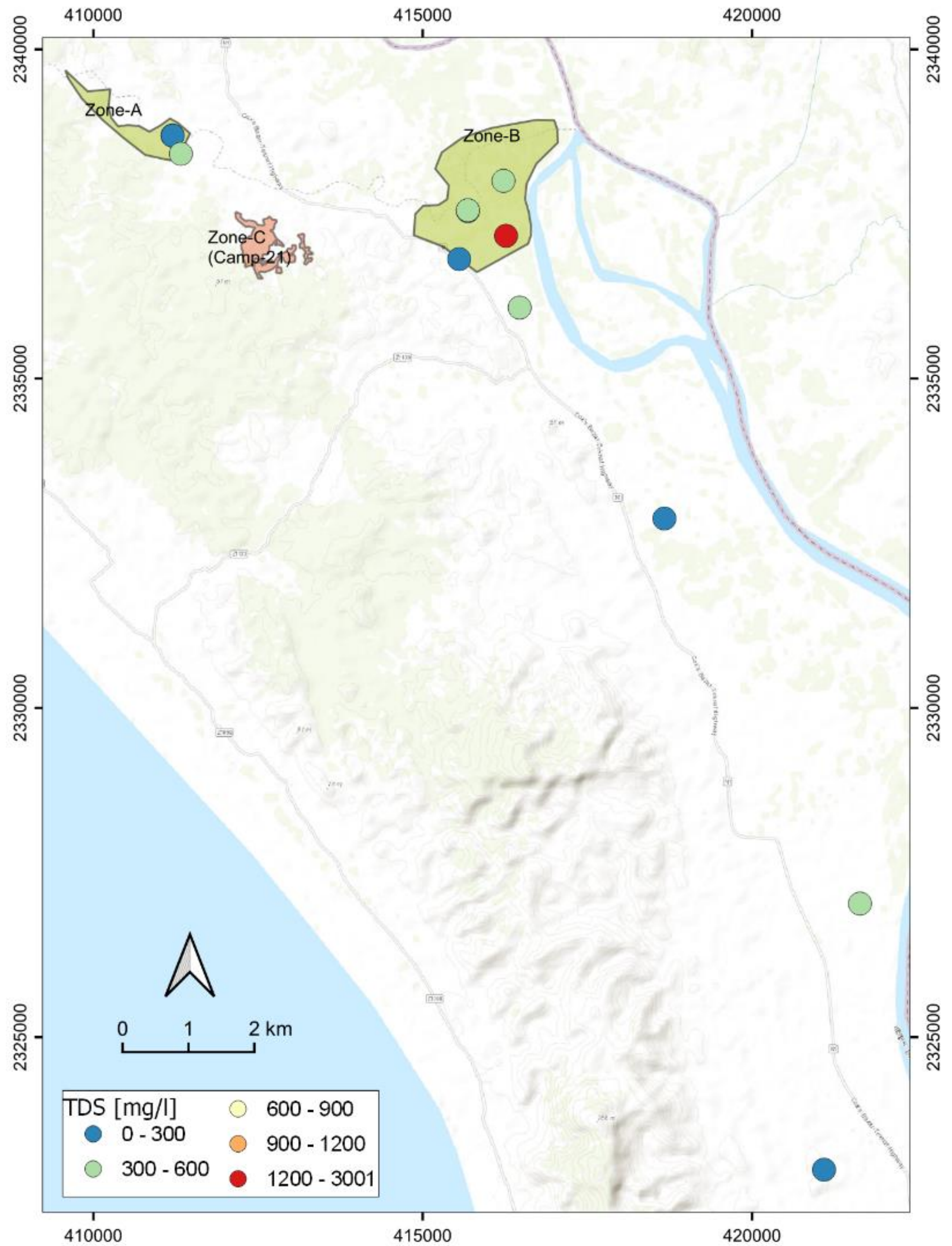

Figure-5.8: Spatial distribution of TDS in monitoring wells.

Major Ion Chemistry

Major ion chemistry (Table-5.2) reveals four different types of water, 1) Ca-HCO_3 type, 2) Na-HCO_3 type, 3) Na-Ca-HCO_3 type and 4) Na-Cl-SO_4 type (Figure 5.9 and 5.10). Different water types are either in different aquifer layers and or in different areas. All of the 6 piezometers located on the western side of the Cox's Bazar Teknaf highway shows Ca-HCO_3 type water indicating recharge followed by calcite dissolution in the aquifer. As this water flows eastward, cation exchange occurs with clay mineral along its flow paths and the water transform from Ca-HCO_3 to Na-HCO_3 type. Most of the samples located on the eastern side of the highway contains either Na-HCO_3 type or Na-Ca-HCO_3 type water, this is consistent with expected geochemical evolution path of this water. Sea water mixing is apparent in only one piezometer, MW-2.3. The proposed well field area in camp-21 or in Palongkhali is located in an elevated recharge area and there should be no risk of salinity. There is also no major seasonal variation in water quality as can be seen in lab calculated values of TSD (Figure 5.11).

Table-5.2: Concertation of various ions in groundwater samples measured in laboratory

Pre-monsoon Data											
Sample ID	***Ca^{2+} [mg/l]***	***Mg^{2+} [mg/l]***	***Na^{+} [mg/l]***	***K^{+} [mg/l]***	**HCO_3^- [mg/l]**	***Cl^- [mg/l]***	***SO_4^{2-} [mg/l]***	***NO_3^- [mg/l]***	***Fe^{2+} [mg/l]***	***Mn^{2+} [mg/l]***	***TDS [mg/l]***
1.1	50.85	1.23	39.02	1.79	228.75	2.14	12.49	0.00	0.01	0.09	336.37
1.2	43.35	2.37	15.23	2.01	198.25	3.05	4.27	0.00	0.06	0.32	268.91
1.3	51.05	1.31	39.35	1.81	343.13	2.75	6.57	0.00	0.01	0.09	446.06
1.4	47.50	1.86	18.77	2.40	213.50	4.59	0.00	0.00	2.54	0.53	291.69
2.1	15.65	0.54	134.10	2.42	388.88	7.15	0.00	0.00	0.11	0.08	548.92
2.2	13.90	0.47	122.15	0.09	305.00	7.61	5.33	24.69	0.07	0.05	479.35
2.3	81.35	21.31	958.50	3.70	373.63	2347.00	0.00	0.00	2.87	0.19	3788.55
2.4	21.55	2.28	27.02	1.56	167.75	5.23	0.00	0.00	1.78	0.19	227.36
2.5	33.95	0.49	104.33	3.46	251.63	68.52	6.05	0.00	0.02	0.08	468.52
3.1	31.05	2.05	26.95	1.82	152.50	2.40	12.95	0.00	0.35	0.49	230.56
3.2	62.80	1.13	44.72	3.78	198.25	1.62	45.12	0.35	0.09	0.15	358.01
M2	19.85	0.92	130.83	4.04	366.00	22.28	2.25	0.00	0.00	0.00	546.17
M3	15.65	0.69	116.83	3.95	327.88	16.13	2.37	0.00	0.00	0.00	483.50
Post-monsoon Data											
1.1	33.7	7.15	40.87	2.41	228.75	1.87	10.85	0	0.067	0.01	325.677
1.2	28.6	12.55	16.46	2.27	186.05	4.75	4.27	0	0.42	1.2	256.57
1.3	22.2	11.55	65.12	1.5	274.5	1.45	4.56	1.25	0.16	0.98	383.27
1.4	33.3	11.5	19.89	9.17	201.3	2.79	2.78	10.78	0.48	2.8	294.79
2.1	7.35	2.8	129.83	1.11	375.15	8.45	0	0	0.12	0.96	525.77
2.2	4.65	2.3	117.73	2.19	335.5	7.89	2.33	20.47	0.07	1.56	494.69
2.3	192.1	148	2460	4.72	289.75	3117	177	0	7.66	0.78	6397.01
2.4	19.65	12.15	30.37	3.91	170.8	7.85	0	0	2.006	0.09	246.826
2.5	30.2	3	109.9	3.17	247.05	48.58	3.45	2.68	0.65	1.25	449.93
3.1	18.75	9.25	28.82	2.48	149.45	2.1	10.85	1.08	0.41	1.85	225.04
3.2	41.45	8.8	46.86	1.28	198.25	1.62	45.12	0.35	0.09	0.09	343.91
M2	8.25	4.85	129.05	3.03	359.9	28.78	1.25	0	0.11	0.01	535.23
M3	6.15	3.7	114.14	3.11	326.35	20.14	4.85	0	0.1	0.01	478.55

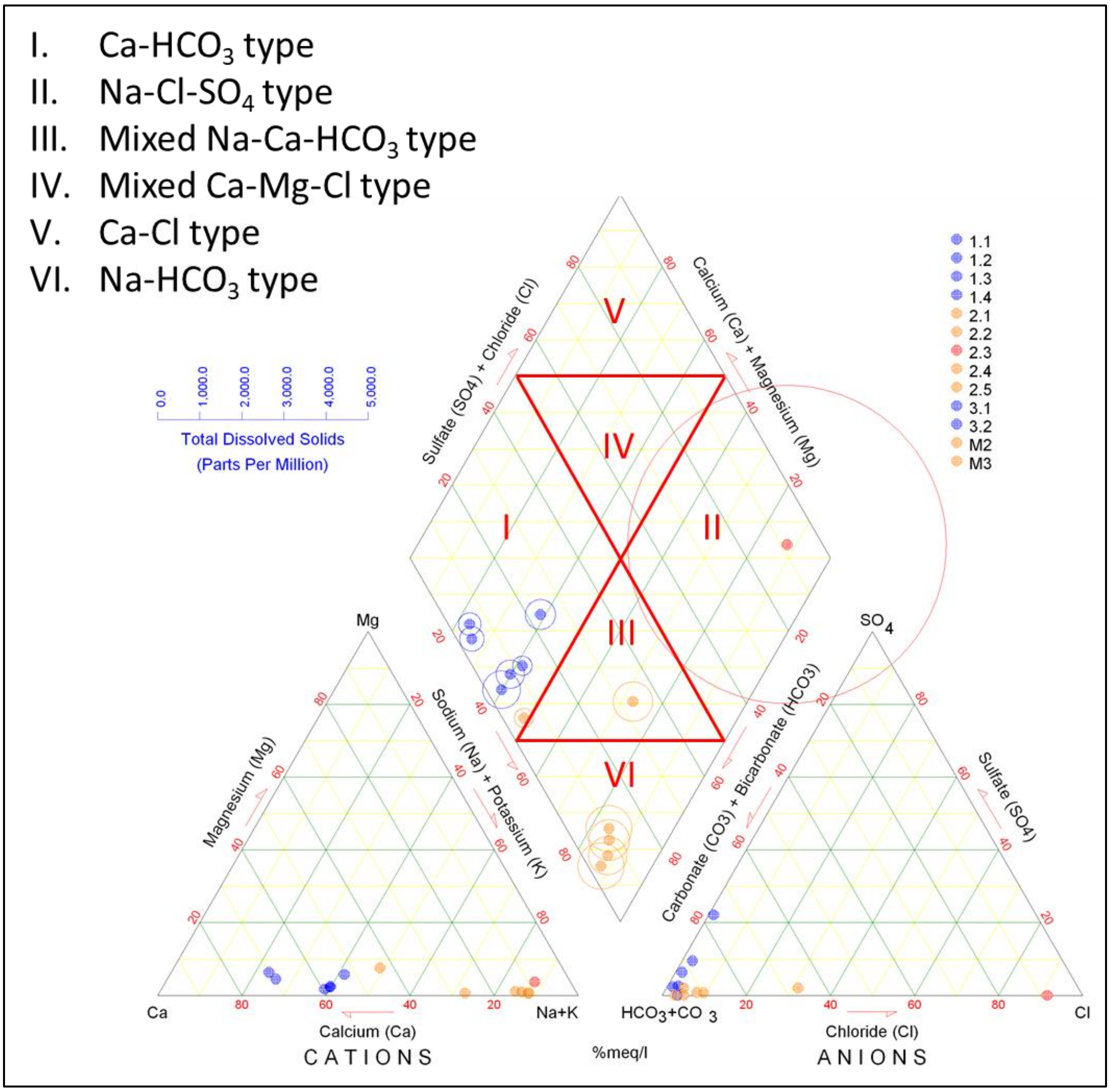

Figure-5.9: Piper diagram showing major water types.

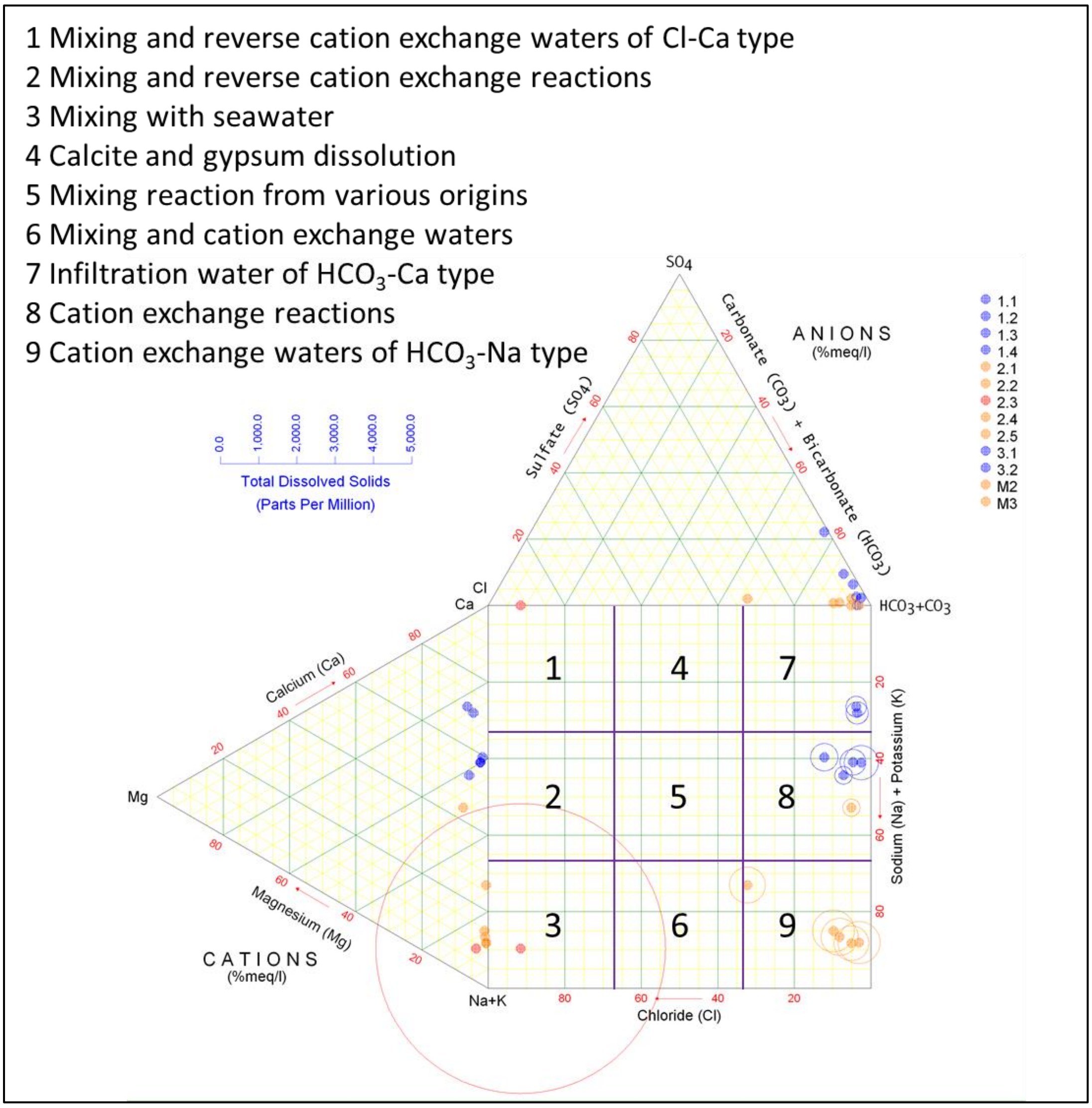

Figure-5.10: Durov plot showing samples locations in major geochemical process fields

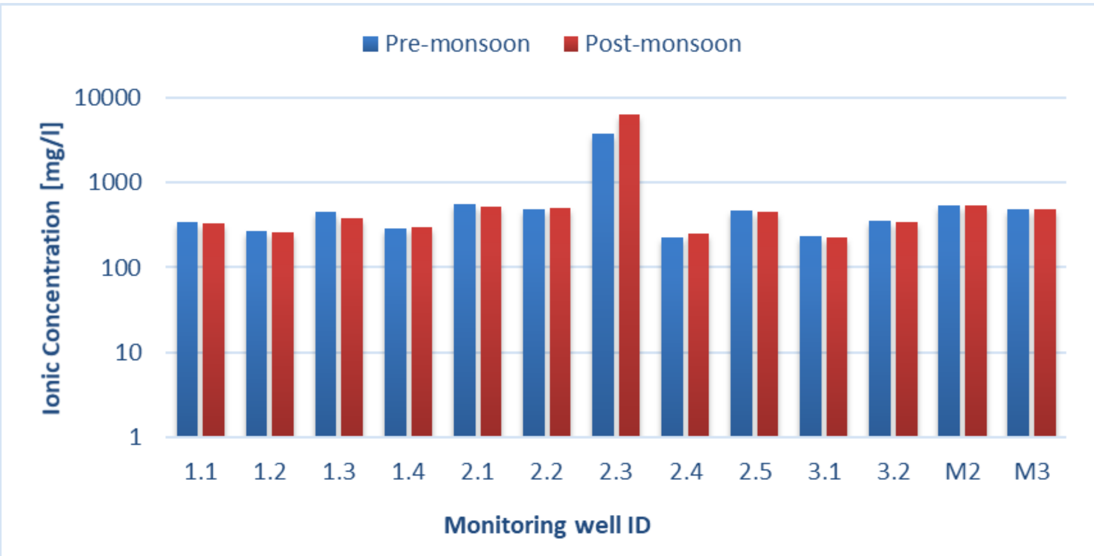

Figure 5.11: Comparison of lab calculated TDS of pre and post-monsoon samples

Trace Elements (Iron and Manganese)

Iron in water does not possess any health threat but it is of concern for aesthetics. There are 3 and 4 wells that exceed the upper limit Bangladesh drinking water standard (0.3-1.0 mg/l) during the pre and post-monsoon season, respectively.

A relatively higher proportion of wells (8) containing manganese exceeding the WHO guideline value for manganese of 0.4mg/l was found during the post-monsoon season compared to the pre-monsoon season (02). WHO has recently added manganese to its drinking water guideline and the implications is still not clear.

Suitability of Groundwater for Drinking

Table (5.3) summarizes the number of wells exceeding various drinking water quality parameters of Bangladesh. It is apparent that all but one wells has water suitable for drinking. Some wells exceed water quality parameters such as bi-carbonate, iron, and manganese. These parameters do not have serious health implications, they mostly affect the aesthetics of the water. However, high iron and manganese content may be an issue for pipeline.

Table 5.3: Suitability of groundwater for drinking purposes based on major water quality parameters

Parameter	Bangladesh Drinking water Standard [mg/l]	No of samples exceeding the drinking water standard	
		Pre-monsoon	Post-monsoon
TDS	1000	1	1
SO4	400	0	0
Cl	600	1	1
NO3	10	1	2
Ca	75	1	1
Mg	35	0	1
Na	200	1	1
K	12	0	0
HCO3	200	9	9
Fe	1	3	2
Mn	0.4	2	7
As	50	0	0

Chapter 6 : Annual Progress Review Meeting/Project Ending Workshop

Annual Progress Review Meeting on Groundwater Based Potable Water Supply for Host and FDMN Communities in Teknaf **28th December 2022** Beach Garden Conference Hall, Hotel Jol Torongo, Cox's Bazar		
Participants		
DPHE	**UNHCR, OXFAM and Others**	**Dhaka University**
1. Mr. Eng. Md. Mostafizur Rahman, Executive Engineer, DPHE Cox's Bazar	1. Helen Salvestrin, Sr.Water Officer, UNHCR 2. Mr. Mahfuzur Rahman, WASH Associate, UNHCR	**1. Prof. Dr. Kazi Matin Ahmaed, Team Leader , DU** **2. Prof. Dr. Subrota Kumar Saha, Chairman, Department of Geology, DU** **3. Dr. Mahfuzur Rahman Khan. GW Modeler, DU**

2. Ms. Rifat Sharmin, Sr. Hydrogeologist, GWC,DPHE,Dhaka **3. Mr. Abul Monjur, AE, DPHE Cox's Bazar** **4. Mr.Md. Sharif Imtiaj, SAE, DPHE, Ukhiya, Cox's Bazar** **5. Mr. Shanjit Kumar Mitro, SAE, DPHE, Teknaf** **6.Mr. Md. Al-Amin Biswas, Draftsman, DPHE, Cox's Bazar** **7. Md. Shajedur Rahman Sumon, National Hydrogeologist, DPHE/DU/UNICEF project**	3. Ashish Damle, Country Director, Oxfam in Bangladesh 4. Atwar Rahman, Head of HADR, Oxfam in Bangladesh 4. Ashutosh Dey, Head of Sub Office, Oxfam Cox's Bazar 5. Mr. Enamul Hoque, Head of WASH, Oxfam Cox's Bazar 6. Mr. Safwatul Haque Niloy, WASH Co, Oxfam Cox's Bazar 7. Abdus Sobhan, PM, UNHCR Project, Oxfam Cox's Bazar 8. Md. Al Rahat, PHE-Officer, Oxfam Cox's Bazar 9. Araf Al Saad, PHE-Officer, Oxfam Cox's Bazar 10. Shihab Uddin Shihab, Project liaison, Oxfam Cox's Bazar 11. Glen Ainsworth, Hydrogeologist, GWR	**4. Md. Tareq Chowdury, WRM Expert, DU**

Agenda	Discussion
Welcome and Introduction	- A quick welcome note was shared Mr. Safwatul Haque Niloy, WASH Coordinator, Oxfam Cox's Bazar followed by introduction of the participants.
Speech from CD Oxfam in Bangladesh	- Mr. Ashish Damle provided the inaugural speech by mentioning DU is an integral part of Bangladesh history. Water is not only a commodity but also connected to life and culture. Inspite of one of the biggest deltas, water scarcity is there. - Mr. Damle added that DU investigation is very important to understand the local condition for water availability and supply.
Speech from Chairman, Department of Geology. DU	- Prof. Dr. Subrota Kumar Saha provided the special guest speech mentioning Department of Geology, DU has the capacity to explore, provide consultancy and advocacy for various needs of Groundwater and are working in different part of the country. - Dr. Saha thanked OXFAM and UNHCR for the opportunity to engage in this very important project as Teknaf have water scarcity for long.
Speech from Executive Engineer, DPHE Cox's Bazar	- Eng. Md. Mostafizur Rahman reminded the water scarcity in Teknaf in the beginning of his all-important speech. He mentioned due to FDMN influx lots of project is ongoing in this area and a balance of surface water and groundwater for water supply is required for sustainable water supply. - Executive Engineer assures that DPHE is ready to cooperate and coordinate any project designed for sustainability.
Presentation on progress and findings for Ground water investigation project by DU.	- Prof. Dr. Kazi Matin Ahmed thanked UNHCR and OXFAM for the initiatives for Teknaf people and to engage DPHE as DPHE is the mandated organization for Water Supply by Bangladesh Government. - Dr. Marin presented the annual progress by the project which included the water point survey, water quality lab analysis, suitable site selection and installation of 11 monitoring wells and continuous monitoring of water level and water quality through automated data loggers. - Dr. mahfuzur Rahman Khan presented the key findings for the projects which includes the water level and water quality trends and changes found during the course of the time. - Dr. Khan also provided a quick update of the previous ground water model signifying the importance of long-term

	monitoring and modeling updates for sustainable water supply for the project area.
QNA and Open Discussion	- An open discussion round along with QNA was performed where Glen Ainsworth from GWR, SAE DPHE Teknaf, Helen Salvestrin from UNHCR and other participants share their experiences and challenges working in the project area. - Executive Engineer, DPHE asked about the abstraction rate calculated in the model and what if we withdraw more? - Dr. Mahfuz replied that the current design is to abstract 2 million liter per day and the model can predict the possible impact if we want to withdraw more. - Mr. Sobhan from Oxfam asked how to advocate the local community regarding the possible impact? - Prof. Matin replied that we can guide or provide scientific evidence and need local communication expert to convince local people and some social investigation required before going for the final production. - Mr. Sanjit from DPHE Teknaf was pointing on getting feedback from the community regarding Arsenic, water level drop and salinity from camp-21, Teknaf Pourosova and Sabrang. - Dr. Mahfuz mention there was no survey done on Sabrang and Teknaf pourosova yet under this project and continuous monitoring is being carried out to understand these issues and hopefully we can come out with some solutions.
Way Forward	- Executive Engineer DPHE emphasize to conduct study on Sabrang and other areas which were not included in the previous phase as these areas are being planned to developed by the government in the near future. - Mr. Mostafizur Rahman was pleased as there is no big quality issue so far but need quantities analysis to ensure sustainability. - Fruitful discussions among the participants went through on new potential zone and need further investigation.
Vote of Thanks	- Helen Salvestrin from UNHCR provided the vote of thanks.

Chapter 7 Summary, Conclusion and Recommendation

Water scarcity is a major issue in Teknaf, Cox's Bazar, Bangladesh. In order to improve the limited access to safe drinking water a pipeline water supply system has been conceptualized. The water supply system would be sourced by both surface water (80%) and groundwater (20%). In order to assess the potential of groundwater to support a well field in the Paolgkhali-Whykhong-Hnia area was carried out by Dhaka University and Groundwater Relief through OXFAM and UNHCR between Sep-Dec 2021. Following that study, it was decided to monitor groundwater at strategic locations for 2023 while the implementation of the well field takes shape. The monitoring comprises of automated records of groundwater levels and electrical conductivity in a total of 11 monitoring wells, detail chemical analysis of groundwater samples from a total of 13 monitoring wells, and microbiological analysis in a total of 100 existing wells including the 13 monitoring wells. Both the chemical and microbiological analysis were carried out twice, the first round of sampling was done in April (pre-monsoon), the next round of sampling was done in October (post-monsoon season).

Groundwater monitoring data suggests that there are two different aquifer systems in the area, (1) artesian, and (2) non-artesian. The artesian system exists mostly in the west of Cox-Teknaf highway and does not show any seasonality in the groundwater level, while the non-artesian system shows about 6 m of seasonality. In the non-artesian aquifers, the lowest water level is found in mid-April while the highest occurs in late October. Groundwater level is higher in the west and lower in the east, suggesting groundwater recharge in the hills and discharge in the Naf River.

The most significant findings for this particular project are the evidence of lack of hydraulic connection between shallow and deep aquifer in Palongkhali area, a potential area for well field. The implication is that high rate of proposed pumping from the deep aquifer in this area is unlikely to impact the water level of the shallow aquifer and consequently less impacts on the existing water wells of the local community.

The water quality analysis of both microbiological contamination and groundwater chemistry reveals that the majority of water is in excellent condition for drinking purposes. More than 70% of the sampled wells show no microbiological contamination. The remaining wells that show contamination is most likely sourced from the well head, rather than the aquifer. This is because no spatial or depth trend was observed in the data. In terms of the total dissolved solids and major ion chemistry all but one wells have excellent quality of water for drinking purposes. The one well showing sea water contamination is located near Naf river and probably has some construction issue. However, there is some concerns about the aesthetics of the water as many of the samples show higher bi-carbonate, iron, and manganese concentration. Water with high bicarbonate and iron may not appealing to the consumers, while both iron and manganese can be an issue for the proposed pipeline.

Based on the findings of this study the following recommendations can be made-

1. Although the monitoring was carried out for a year, the observation primarily shows the natural condition of the aquifer system as there is no major groundwater abstraction in this area. The proposed well field is yet to be implemented. It is suspected that there are multiple disconnected aquifers. Once the production wells stats pumping, the hydraulic response would be different in different aquifers. Therefore, monitoring should be continued in 8 of the 11 DU installed wells, 3 or 4 of the new wells installed by GWR in camp 21 for the entire period of 2023 and then based on the observation of 2023 selective monitoring can be continued on the aquifers under stressed from 2024 onward.
2. Monitoring wells in Hnila and Unchiprang are located a great distance away from the probable well field site, therefore, monitoring in three monitoring wells in those area has already been discontinued. Those wells can be handed over to community for uses. Also, well 2.3 probably has construction failure. Monitoring may be discontinued here.
3. Although the chemical analysis of groundwater did not show any health concern, the high bicarbonate and iron content may pose aesthetic issues. High iron may become an issue for the pipeline materials. Therefore, Iron and bicarbonate of the production wells must be tested and care should be taken during the implementation of the pipeline network based on the result of the test.
4. Monitoring network may be integrated with the Cox’s bazar DPHE office monitoring and modelling cells.