Bangladesh Water Development Board

Groundwater Investigation, Assessment and Monitoring Activities by

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Importance of Groundwater Assessment for Bangladesh

Bangladesh is one of the largest deltas in the world having a very flat topography. Three major rivers, the Ganges, the Brahmaputra and the Meghna having a total catchment area of 1.7 million km^2, provides drainage to about 1,660,000 km^2 of the combined catchment, pass through this country. 93% of the catchment area of these rivers lies outside the country. The country has an average rainfall of about 2300 mm, ranging between 1500 and 5000 mm. Bangladesh has also a unique coastline, conical in shape, which causes a higher sea level during monsoon months. This is a disaster-prone country and almost every year, the country experiences disasters like tropical cyclones, storm surges, coastal erosion, floods, droughts and saline water encroachment in the coast. Because of its geographic location and low-lying topographic condition, Bangladesh is likely to be in extreme vulnerable situation under the current scenario of changing in climatic condition, especially the water sector and water dependent agriculture are the most sensitive. Therefore, to assess the current trend of hydrologic conditions for overall water resources development and management, including groundwater and to predict future changes due to human activities and climate change impacts, generation of adequate data and information by appropriate monitoring network is utmost important.

Importance of groundwater irrigation increased with the introduction of High Yield Variety (HYV) seeds, which require a timely and assured water supply. Currently, about 80% of dry season irrigation and 98% of drinking water supply has been provided from groundwater (BDP 2100, 2018). The first major irrigation project was started in the early sixties in the northwest of Bangladesh under Bangladesh Water Development Board (BWDB). Deep Tubewells (DTWs) and Shallow Tubewells (STWs) irrigation was extended rapidly during the late 1970's and the 1980's. Privatization and expansion of minor irrigation and withdrawal of Government subsidy in irrigation equipment lead to a very rapid growth of farmer financed STWs. Manually driven percussion method became popular for STW installation having depth of 20-45 m. Irrigation wells are relatively inexpensive, easy to install using local methods, easy to maintain and are shared between small groups of farmers and leads to uncontrolled installation of wells. STW has increased in numbers throughout the country from 133,800 in 1985 to about 16,00,000 in 2018 (BADC, 2019). The unconsolidated near surface Pleistocene to Recent fluvial and estuarine sediments underlying most of Bangladesh generally form potential aquifers (BWDB-UNDP, 1982), however, is not completely suitable for development since decades because of overexploitation and quality problems.

Over exploitation is usually the result of irrigation abstraction in rural areas and huge domestic and industrial usage in cities. Annually, an estimated 32 cubic kilometers of groundwater is withdrawn in the

country for irrigation (90%), as well as domestic and industrial (10%) purposes (World Bank Group 2019). The Dhaka Water Supply and Sewerage Authority (DWASA) sources 78% of its water supplies from groundwater through a network of about 890 production wells and in several parts of the city groundwater level has now dropped 60-75 m below ground surface due to excessive withdrawal than recharge. In addition, where about 46,000 manufacturing industries and 50,000 handlooms are in operation, largely depend on groundwater (BBS 2019). Relentless abstraction of groundwater leads rural and urban Bangladesh facing water crisis, including the non-functioning of wells during irrigation period and declination of groundwater table.

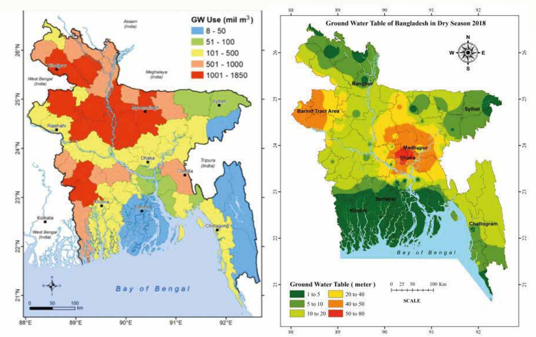

Figure 1: Extensive withdrawal of groundwater: groundwater use across the country showing maximum water use in northern part (World Bank Group 2019) (left); distribution of depths to groundwater level across Bangladesh showing alarming depletion in central and north-western part (BWDB 2019) (right).

This groundwater resource is increasingly facing quality problems in many areas where the exposure to pollution from agriculture, urbanized areas and industrial sites as well as arsenic contamination in shallow groundwater and high salinity in coastal aquifers makes the water unfit for human consumption. With climate change, groundwater balances in many areas would change and bringing in another level of uncertainty. With increasing water scarcity and frequent occurrence of water-related conflicts, the institutional arrangements governing water resource development, allocation, and management are receiving increasing policy attention. Uncontrolled development of the aquifer could severely limit the usefulness and the productive duration of the aquifer. Hence, research based assessment and monitoring of the groundwater resource in conjunctive with surface water is very important.

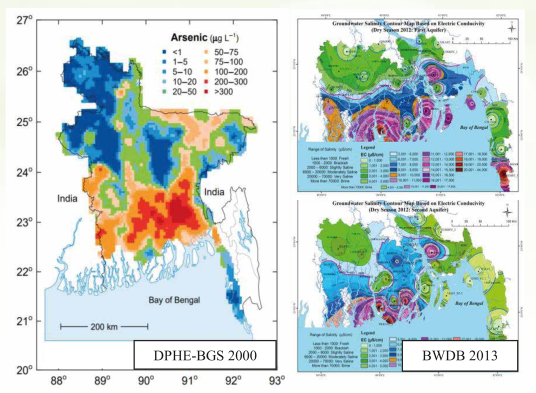

Figure 2: Existence of arsenic and salinity in groundwater: arsenic concentration in shallow groundwater (left); salinity distribution in the upper aquifer (down to the depth of 100 m) and in the main aquifer (the depths between 100-250 m) (right).

Establishment of Groundwater Monitoring Network

Bangladesh Water Development Board (BWDB) is mandated by the Government of Bangladesh to collect hydrological data over the country which has been performing since 1959. All collected data is processed and stored in Processing and Flood Forecasting Circle (PFFC) at Green Road, Dhaka, under BWDB. Extensive survey and monitoring of the hydrogeology and groundwater resources of Bangladesh was begun in the 1960's. The mandate of the Directorate of Ground Water Hydrology of BWDB also includes fundamental data collection, related to both quantity and quality. The hydrogeological data and information are required for understanding of the groundwater conditions. The more of this information the better the assessment results regarding the aquifers, water levels, hydraulic gradients, flow velocity and direction, water quality, and simulations of groundwater models. Analysis and interpretation of hydrological and hydrogeological data and information can guide for water resources planning and distribution of water for agriculture, industrial and water supply usage. Bangladesh Water Development Board has 1272 groundwater observation wells throughout the country, maintained under 7 Ground Water Hydrology Sub-divisions and mostly installed with the UNDP assistance since more than five decades, mainly at shallow depths (25-50 m). However, these wells need to re-install with time due to damage or lowering of water table below

the bottom of the well. Considering the quality problems in shallow and main aquifers and necessity to use deep groundwater BWDB has installed 42 clustered monitoring wells and 510 line wells upto the depth of 350 and 100 m respectively, in 19 coastal districts under the Bangladesh Climate Change Trust (BCCT) project, 'Establishment of Monitoring Network and Mathematical Model Study to Assess Salinity Intrusion in Groundwater in the Coastal Area of Bangladesh due to Climate Change'. Under the ongoing 'Bangladesh Regional Weather and Climate Services Project (BWCSRP), Component B: Strengthening Hydrological Information Services and Early Warning Systems', funded by the IDA, the World Bank, 69 clustered monitoring wells have been installed covering entire country. Each unit consists of 4 wells having the maximum depth of 300 m. Under the same project, 905 monitoring wells, including all clustered wells, are in process of automation with telemetry using data-logger for temperature, groundwater level and electric conductivity i.e. salinity.

Major Activities of Ground Water Hydrology

- Organizing and conduct groundwater survey (both qualitative and quantitative) and sub-soil investigation.
- Provide technical guidance of all field groundwater data collection network and to ensure quality control.
- Conduct qualitative study for the optimum utilization of groundwater resources and provide guidelines to prepare hydro-geological and hydro-chemical reports.
- Conduct drilling works, aquifer pump tests, BM works, installation of observation wells, groundwater quality study, maintenance of rigs and other equipment.
- Take steps for standardization and improvement of hydro-geological data (groundwater table, aquifer pump test, groundwater quality, exploratory boring log collection etc.).
- Co-ordinate the activities of different agencies and organizations involved in groundwater studies and render advise to groundwater planners and users. etc.

Investigation of Groundwater Aquifer Systems

Ground Water Hydrology Divisions of BWDB so far completed over 1500 nos. borehole drilling to explore the aquifer system of Bangladesh by collecting both core and washed sediment samples. In many holes, the borehole lithologic logs have been verified by conducting borehole geophysical logging using Gamma and conductivity probes. Based on these investigations, down to the depths of about 350m, it depicts that the unconsolidated Miocene to Recent fluvial and estuarine sediments underlying most of Bangladesh form multi-layered aquifers. But except the Holocene and the Dupi Tila formations of the Plio-Pleistocene age, others are too deep to consider for groundwater abstraction. The

sediments are cyclic deposits of mostly medium to fine sand, silt, and clay. Due to arsenic contamination in shallow groundwater and salinity intrusion in upper aquifers, the importance of exploitation of deep groundwater (down to 350-400 m bgl) has been increasing day by day.

Figure 3: Activities including drilling of boreholes to investigate groundwater aquifer in Bangladesh.

The individual layers cannot be traced for long distances, horizontally or vertically i.e. distribution of aquifer sediments in the subsurface is very complex. Aquifer-aquitard alteration is highly variable even within a short distance. Most of the groundwater withdrawn for domestic or agricultural purposes in the Barind and Madhupur Uplands areas is from the Dupi Tila aquifers. This aquifer is composed of light gray to yellowish-brown, medium to coarse sand with pebble beds and dated as about or more than 20,000 years old (Aggarwal et al., 2000). All of the water for Dhaka City is withdrawn from this aquifer and the water is as yet arsenic safe. Other than the Terrace areas, the remaining part of the Bengal Delta consists predominantly of Holocene alluvial and deltaic sediments. Age of Holocene aquifers ranges from 100 to more than 3,000 years (Aggarwal et al., 2000). Sediments of very different nature or different geological age can be found at similar depths. On a regional basis BWDB-UNDP (1982) described three aquifers, however, these are in many places connected hydraulically (Zahid et al., 2010). BWDB investigated multi-layered aquifer system in the Coastal Delta down to the depth of 350 m. Aggarwal et al. (2000) on the basis of isotopic studies classified the water at different depths in four types and made a three-tier division of the aquifers. DPHE-BGS (1999) and DPHE-BGS (2001), with slight adjustments of the BWDB-UNDP (1982) study also made a three-tier classification of the aquifers zones.

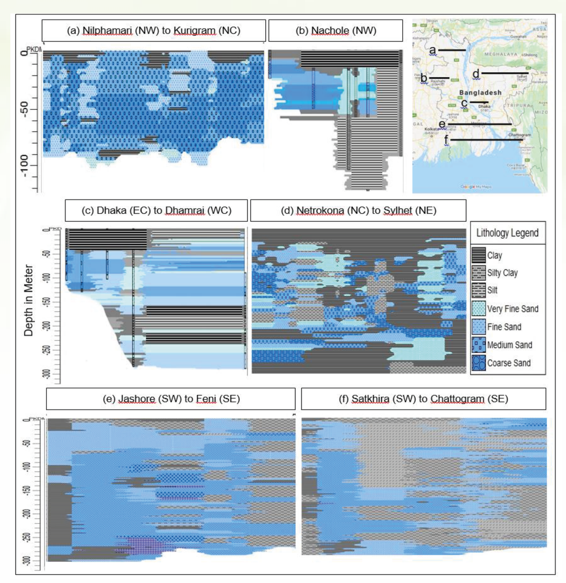

Figure 4: Lithologic cross-sections presenting multi-layered aquifer system in different parts of the Bengal Basin, Bangladesh, based on BWDB borehole lithologic logs: (a) Tista Fan in the northwest; (b) Pleistocene Barind Tract in the northwest; (c) Dupi Tila aquifer around Dhaka; (d) Sylhet Basin in the northeast; (e) Deltaic Floodplain in the south-central; (f) Tidal Delta in the southern coast.

There is no widely accepted code for hydrostratigraphic, i.e., aquifer nomenclature in the Bengal Basin, Bangladesh. The variety of ways in which aquifers have been named by different authors and institutions is one of the causes of the confusion associated with aquifer nomenclature. A hydrostratigraphic nomenclature based on the stratigraphic units, that form a classified aquifer, is important as a consistent nomenclature for the basis of rational and scientific investigation.

Trends of Groundwater Level and Recharge Potential

With increasingly growing demands on the groundwater supplies, areas of urban as well as rural Bangladesh have started facing water problems, including the drying up of wells during peak irrigation period and

continuous lowering of water table mainly in over-stressed areas. Two main groups of fluctuation can be identified: long-term, such as those caused by seasonal changes in natural replenishment and persistent pumping, and short-term, for example, those caused by the effects of brief periods of intermittent pumping and tidal and barometric changes.

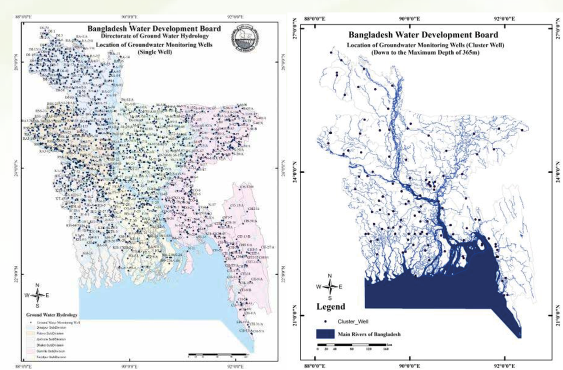

Figure 5: Location of about 60 years old 1272 nos. observation wells (left) and 110 clustered wells (right) of Bangladesh Water Development Board for the monitoring of groundwater storage and quality.

Figure 6: Examples of clustered groundwater monitoring wells in the coastal areas of Bangladesh.

Analysis of the groundwater table data, selected from 1272 nos. BWDB groundwater observation wells throughout the country, shows that in many areas groundwater withdrawal from the shallow aquifer for various purposes during dry periods is balanced with the vertical percolation of rainwater and inflow from surrounding aquifers during monsoon when pumping is ceased. Rapid rise in groundwater levels during the early part of the monsoon season is an indication of rapid recharge, although it may also indicate low specific yield (WARPO, 2000). A period of relatively constant levels during the monsoon indicates 'aquifer full' conditions. However, in many areas due to increased abstraction and where potential recharge is lower than actual recharge, the static or highest water level of the previous year declines during monsoon. Permanent decline of water table has observed in urban areas, in the Barind tract, and to some extent in many other areas due to excessive demand and withdrawal for urban, irrigation and industrial uses.

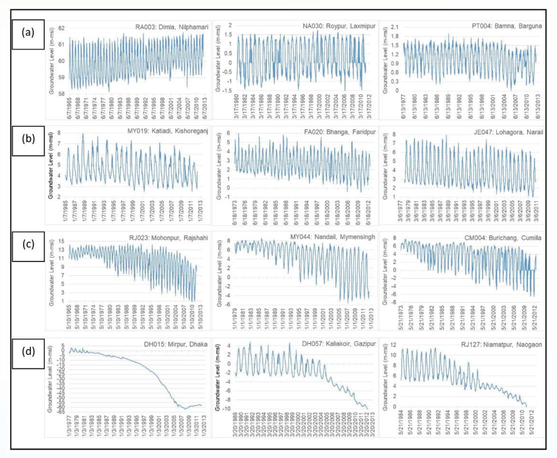

Figure 7: Groundwater level hydrographs of upper shallow aquifers from different areas of Bangladesh: (a) the lowered water level during dry irrigation period regains it's static water level in monsoon as of the previous years; (b) due to increased abstraction and where potential recharge is lower than actual recharge, the static or highest water level of the previous year declines during monsoon; (c) with increased abstraction, fluctuation of groundwater level has been increased with time; (d) permanent decline of water level is also observed as an alarming rate in urban areas and in the Barind tract.

Systematic observations at fixed time intervals are frequently adequate for the purposes of most national networks. However, where fluctuations

are rapid, like in Bangladesh, a continuous record is desirable. Under Climate Change Trust Fund (CCTF) project titled 'Establishment of Monitoring Network and Mathematical Model Study to Assess Salinity Intrusion in Groundwater in the Coastal Area of Bangladesh due to Climate Change', during 2011-2013, 42 units clustered groundwater monitoring wells have been installed at 42 locations. Each unit consist of 3 to 5 observation wells down to the depth of 350 m for measuring water table, collection of samples for water quality and performing different tests. Number of installed line wells are 102 (Each line consists of 5 wells down to the depth of 100 m) for the assessment of salinity distribution and surface water–groundwater interaction.

Automation of Wells with Data-loggers and Telemetry

Under the ongoing 'Bangladesh Regional Weather and Climate Services Project (BWCSRP), Component B: Strengthening Hydrological Information Services and Early Warning Systems', funded by the IDA, the World Bank, 69 clustered monitoring wells have been installed covering entire country. Each unit consists of 4 wells having the maximum depth of 300 m. Under the same project, 905 monitoring wells, including all clustered wells, are automated with telemetry using data-logger for temperature, groundwater level and electric conductivity.

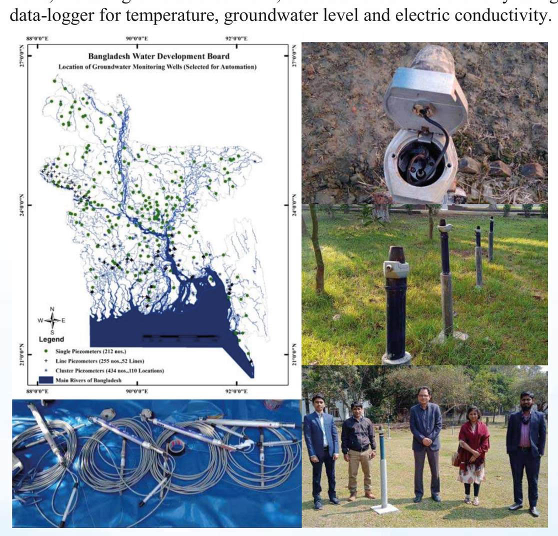

Figure 8: Locations of 905 nos. automated groundwater monitoring wells with telemetry for real time data transmission throughout Bangladesh.

Determination of Aquifer Hydraulic Properties

Aquifer pumping tests generally serve two main objectives. Firstly, a pumping test is performed in order to determine the hydraulic characteristics i.e. transmissivity, storage co-efficient, hydraulic conductivity etc., of aquifers Secondly, a pumping test provides information about the yield and drawdown of the well. These data can be used for determining the specific capacity or the discharge drawdown ratio of the well, etc. Ground Water Hydrology offices of BWDB has conducted about 350 constant-discharge aquifer pumping tests throughout the country, started in the upper aquifers down to the depth of about 70-80 m. Under BCCT project, for conducting 18 deep aquifer pump tests, 18 deep production wells down to the maximum depth of 350 m has been installed by BWDB. 124 numbers of slug tests have been conducted to estimate hydraulic conductivities of aquifer sediment. Different methods were used to analyze aquifer test data considering aquifers as confined or leaky confined in nature.

Figure 9: Performance of aquifer pumping tests to determine hydraulic properties of aquifer sediments.

Hydraulic conductivity (horizontal) for the Delta of the southern Bangladesh was measured between 2.5×10^{-5} and 7.0×10^{-5} m/sec for lower part (180-230 m depth) of the 2nd aquifer and between 3.43×10^{-5} and 2.3×10^{-4} m/sec for the 3rd aquifer, whereas vertical hydraulic conductivity is 10-100 times lower than horizontal hydraulic conductivity (230-330 m depth). Deep aquitard vertical hydraulic conductivity has measured as about 4.0×10^{-6} m/sec. For the 1st and the upper part of the 2nd aquifers in floodplain areas, vertical hydraulic conductivity ranges between 1.3×10^{-4} and 6.5×10^{-4} m/sec. Pumping tests have reported that the alluvial aquifer

system (50-100 m depth) in most parts of Bangladesh is primarily composed of a number of stratified aquifers with greater transmissivity (mean 1,270±770 m^2/day) and specific yield ranging from 0.01 to 0.20 with a national average of 0.06±0.04. The transmissivity of the shallow aquifers in the Brahmaputra floodplains are greater (3,500–7,000 m^2/day) than those in Ganges and Meghna floodplains (3,000–5,000 m^2/day), and terrace and deltaic aquifers (300–3,000 m^2/day) in Bangladesh.

Hydraulic conductivity values estimated by conducting slug tests in the 19 coastal districts of the country ranges between 1 and 25, 1 and 9, and 1 and 9 m/day for the shallow, the main, and the deep aquifers, respectively that is typical for sandy alluvial aquifers. Transmissivities were estimated between 100-2300, 100-2200, and 100-1600 m^2/day. Transmissivity (T) values of deep aquifers (250-350 m bgl) from long duration (up to 72 hours) constant discharge aquifer pump tests conducted by BWDB depict that northern floodplain and coastal delta deep aquifers have higher potential with T ranges between 769 and 3224 m^2/day, while southern deep aquifers close to coastal margin show moderate potential with T values between 493 and 916 m^2/day and southeast deep aquifers, west of eastern hill ranges, show low potential with T ranges between 144 and 370 m^2/day. Storage co-efficient values of deep aquifers for all studied areas were estimated between 0.0044 and 0.00016 that indicates leaky confined to confined in nature.

Assessment and Monitoring of Water Quality

Ground Water Hydrology Divisions has regular program to collect groundwater samples from 117 fixed observation wells to determine water quality. Under BCCT project, during 2011-2012 both dry and wet season groundwater as well as surface water samples were collected from the installed observation wells (957 Samples) and nearby surface water bodies (139 samples) and analyzed 25 chemical parameters. Both dry and wet season samples were collected from 905 automated wells under ongoing project during 2020-2021 throughout the country. It is proposed to collect groundwater samples from 110 clustered wells (about 440 samples), both in wet and dry periods, for the regular assessment and monitoring of country's groundwater quality.

Down to about 336 m depths, most of the groundwater of Bangladesh is generally characterized by circum-neutral pH (6.5–8.0), and the oxidation-reduction potential (Eh) varies generally between +200 and −130 mV. The groundwater is calcium carbonate-rich, but in the coastal belt, it is dominated by sodium chloride-type water. The groundwater exhibits low dissolved oxygen concentrations, characteristically high concentrations of iron and manganese, and low levels of sulfate that are consistent with characteristics of reducing environments.

Figure 10: Measurement of physical parameters of groundwater in the field and collection of water samples for laboratory analysis.

The groundwater of floodplain is classified into two groups, namely the Na^+–Cl^- type and the Na^+-Ca^{2+}-Mg^{2+}–HCO_3^- type. The major ion trends of the Na^+–Cl^- type groundwater are $Na^+ > Ca^{2+} > Mg^{2+} > K^+$, common for all aquifers down to 350 m bgl and $Cl^- > HCO_3^- > SO_4^{2-}$, mainly for deeper and $HCO_3^- > Cl^- > SO_4^{2-}$ for shallow samples. In the coastal delta groundwater samples down to the depth of 200 m, except few samples in the eastern coast, are classified as Cl^--SO_4^{2-}, Cl^--SO_4^{2-}-HCO_3^-, Na^+-Ca^{2+}, Na^+-K^+ types, dominated by Na^+-Cl^- and HCO_3^- types. Seawater intrusion is the major phenomena till this depth. Deep water (down to 336 m) of the south-central delta is also classified with this cluster. Few samples from the southeast and northeast coastal plain, down to 200 m depth, show Na^+-Ca^{2+} and HCO_3^--Cl^--SO_4^{2-} types with the signature of the mixture of freshwater and seawater. Most of the deep groundwater samples between 201 and 336 m depth ranges are classified as HCO_3^--Cl^--SO_4^{2-}, Na^+-K^+-Ca^{2+} types, dominated by HCO_3^- type those are within the limit of freshwater. The major ion trends of the upper Na^+-Cl^- groundwater type are $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and $Cl^- > HCO_3^- > SO_4^{2-}$ and for the deep groundwater is $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and $HCO_3^- > Cl^- > SO_4^{2-}$.

Presence of Arsenic in groundwater in Bengal Delta has disturbed the scenarios for its continued and planned use. It has been reported that out of 64 districts 61 are affected more or less. About three million tubewells, installed at shallow depths (10 to 50 m), discharge groundwater with arsenic concentrations more than the Bangladesh drinking water standard of 50 μg/l (DPHE-BGS, 2001). Deep tube well water, with the depth range between 100 and <300 m contain insignificant or no arsenic concentration. But, these wells often contain high concentrations of iron and manganese.

In the coastal zone, the salinity of the upper aquifers (down to 200-250 m depth bgl) is extremely variable and changes abruptly over short distances. In most areas, the water is too saline for domestic and irrigation use due to either to connate salts or estuarine flooding. In the shallow groundwater (<100 m depth bgl) freshwater (Cl <300 mg/l) is noticed in areas of the south-central and south-western coast while brackish water (Cl 300-600 mg/l) occurs at the north-central and north-eastern coast. Salinity (Cl >600 mg/l) occurs in the shallow groundwater of the other areas of the coast except the higher elevated part of Chattogram district. In the deep groundwater (> 250-300 m depth bgl), freshwater occurs except some parts of the central coast. Seasonal variability of salinity is also noticed.

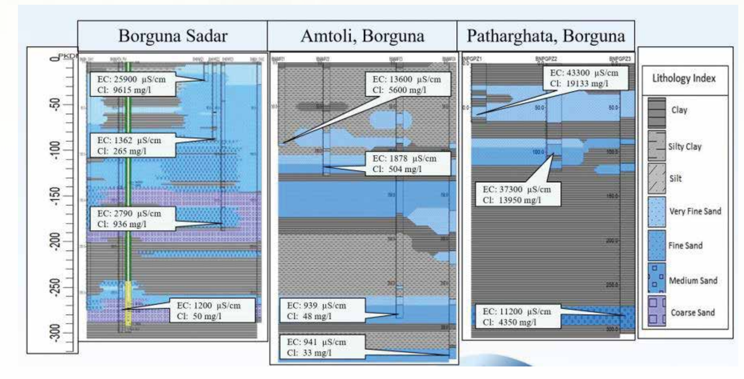

Figure 11: Example of the lateral and depth variations of salinity concentration in the multilayered aquifers of coastal districts.

Figure 12: BWDB laboratory equipped with Atomic Absorption Spectrophotometer, Ion Chromatograph, UV-VIS Spectrophotometer, Spectrophotometer and other instruments for water quality monitoring.

Sub-Soil Geotechnical Investigation

Ground Water Hydrology Divisions of BWDB also conduct geotechnical investigations including performance of in-situ Standard Penetration Test (SPT) and collection of soil/sediment samples for different laboratory analysis of soil engineering properties in order to design hydraulic structures of BWDB and for any other projects.

Figure 13: Performance of geotechnical investigation in order to design hydraulic structures of BWDB.

Way Forward

Investigation of the aquifer systems, understanding of formation behavior, regular monitoring of groundwater storage and quality are important for the sustainable development and integrated management of water resources. Sustainable use of available safe water including groundwater can be planned by analyzing data and information of the components of the hydrologic cycle. In Bangladesh where groundwater is the principal source of irrigation, industrial and potable water supply, regular assessment and monitoring of this resource is very important. Matching long term withdrawals of groundwater to recharge is the principal objective of sustainable groundwater resource planning. Maintaining the water balance of withdrawals and recharge is vital for managing human impact on water and ecological resources. Because of increasing demand of water and to reduce dependency on limited fresh groundwater resources, utilization of available surface water and conjunctive use should be emphasized as per National Water Policy 1999 and other guidelines of the Government. Groundwater resources that can safely be abstracted from both upper and deeper aquifers need to be

assessed properly. Regional modelling of the groundwater systems has to be developed for effective water resource management to plan agricultural, rural and urban water supplies and to forecast the groundwater situation in advance for dry seasons. Better operation and maintenance of tubewells under an appropriate system, improving the management efficiency, crop diversification etc. may increase crop production.

In present scenario, besides proper investigation of shallower aquifer formations, exploration on the deeper formation of aquifer systems (250-400 m deep), probable potential safe source of drinking water in many areas, is very important. Preparation of water budget and water allocation plans are important up to union level based on available data and information as well as conducting required survey and investigations. Augmentation of both natural and artificial recharge of groundwater (MAR) can be done in groundwater depleted and water stressed areas by implementing appropriate programs and techniques. Integrated water resources management based on proper research and monitoring is important requirement to protect values of groundwater. All of these tools can be implemented under the authority of the Water Act 2013 and Water Rules 2018. Extension and upgrading existing network of groundwater monitoring wells should be done spatially and vertically in different aquifers for estimating recharge, monitoring fluctuation of water table and movement of groundwater and water quality assessment. An individual organization needs to be created or identified for the management and tracking of groundwater resources i.e., assessment and uses of groundwater resources, preparation of water budget and water allocation plans as well as monitor changes in water storage and quality.

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