BRAC University Journal, Vol. XI, No. 2, 2016, pp. 85-100

EVALUATION OF THE AQUIFER SYSTEM AND GROUNDWATER QUALITY OF THE NORTH-WESTERN DISTRICTS OF BANGLADESH FOR DEVELOPMENT POTENTIAL

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ABSTRACT

Considering the comparatively low agricultural production in the area, assessment of the potential of increased agricultural production in Panchagarh, Thakurgaon, Dinajpur and Joypurhat districts was undertaken, through optimum utilization of available water resources. Physiographically, Thakurgaon, Dinajpur and Panchagarh areas are mostly under the Old Himalayan Piedmont Plain and Joypurhat and some areas of Dinajpur are under the Tista floodplain and Barind Tract. To explore the aquifer system in the area, a total of 15 new test drillings were conducted down to the maximum depth of 300 m and 50 observation wells were selected for observing the groundwater level trend. Groundwater samples were collected from 20 locations for analysis and interpretation of important physicochemical parameters. The important constituents that influence the water quality for irrigation were calculated using standard equations. From the spatial distribution of the borelogs from northwest to southeast reveals that down to the investigated depth of 300m the aquifer system is hydraulically connected regionally though one or more aquitards are encountered at local level. The maximum depth to groundwater table below ground surface is between 4.0 to 12.0 m during dry month of April. The groundwater table lowers beyond the suction limit (7.5 m) of no. 6 hand tube wells (HTW) in some parts of the study area. In general, groundwater quality of the areas is suitable both for domestic and agricultural uses except at a few localities where iron concentration exceeded the allowable limit. The most of the study area has potentiality for groundwater development having higher rainfall and recharge potential. However, when usable recharge is considered at base condition, shortage of groundwater is observed in few areas and no further installation of irrigation TWs is recommended in those areas.

Introduction

Panchagarh, Thakurgaon, Dinajpur and Joypurhat districts under Barind Multi Purpose Development Authority (BMDA) covers 28 Upazilas in the north western Bangladesh having gross area of 7,61,800 ha and cultivable area of 6,16,265 ha. Total population of the area is about 5.56 million and per capita land holding is only about 0.10 ha. This low land-man ratio indicates that intensive agricultural use of land is essential to uplift the socio-economic condition of the local people in the area. The area is located in a drought prone part of the country. Rainfall is too low in dry season to support agricultural production. Besides, there are some agro-socio-economic problems, such as availability of quality seed, unbalanced use of fertilizer, lack of appropriate marketing facilities, etc., which also hinders agricultural development. As a result, agricultural production in the study area is comparatively low. In the study area, climatic conditions are favorable and soils are suitable to grow crop round the year. With this realization, the study has been undertaken in order to facilitate the rest of the potential cultivable areas under irrigation along with some other development activities in the area. The successful development of water resources in the area depends on the reliable quantitative and qualitative assessment of groundwater resources, proper site selection, identification of appropriate number of irrigation wells without depleting the water table and zoning map suitable for different types of irrigation equipment.

The agricultural production in the area is constrained mainly by paucity of irrigation facilities. The present irrigation is mainly dependent on groundwater. So, proper assessment of annual recharge and consequences of continuous irrigation expansion, safe yield, drinking water supply and effects of river flows during dry period and wider environments are required. Surface water availability is very limited in the area resulting in more stress on groundwater. Major rivers in the area are Karatoya, Atrai, Dhepa, Tangon, etc., where dry season flow availability is decreasing. The surface water available in the area needs to be utilized judiciously in a planned manner with due consideration to environmental sustainability. Although a significant area is getting irrigation facilities, still potentiality exists for further irrigation development which can be achieved through optimum and rational utilization of available surface and groundwater resources. Due to limited scope of surface water during dry season, in most of the study area, irrigation is done using groundwater. In the study area the total numbers of existing STWs and DTWs for irrigation are 171,571 and 6,145 respectively (BADC, 2013). However, when usable recharge is considered at base condition, shortage of groundwater is observed in Fulbari and Hakimpur Upazilas of Dinajpur District and Akkelpur, Joupurhat Sadar, Khetlal and Kalai Upazilas of Joypurhat District (IWM-BMDA, 2015).

The main objective of the study is to assess the potential of increased agricultural production through optimum utilization of available water resources. The specific objectives are assessment of Upazila-wise groundwater resources for the study area and projection of groundwater condition for future groundwater utilization. The study includes the investigation of the availability of water resources to formulate plans for optimum utilization of the scarce water resources for optimum development, which, in the long run, will contribute to sustainable agricultural development of the area. Groundwater development by tubewells requires a complete understanding of aquifer properties and characteristics to mitigate lowering of the water table of the upper aquifer. Moreover, the areas, where groundwater table remains below the suction limit for a substantial amount of time in a year, require production wells for groundwater development. On the other hand, groundwater recharge characteristics not only depend on rainfall patterns but also on the lithologic condition in the area and river aquifer interactions.

Geological Setting of the Study Area

Thakurgaon, Dinajpur and Panchagarh areas are mostly under the physiographic unit of Old Himalayan Piedmont Plain of Bangladesh. The greater Joypurhat and some areas of Dinajpur District are under the physiographic unit of Tista floodplain and Barind Tract. Hydrogeological parameters of these areas are governed by the lithostratigraphic and prevailing tectonic activities, which is part of the regional hydrogeological setting and tectonic features. The Old Himalayan Piedmont Plain is characterized by the gently sloping land at the foot of the hills formed by colluvial and alluvial sediments deposited by rivers or streams. A portion of the Old Himalayan Piedmont Plain stretches into Bangladesh at the northwestern corner of the country. This occupies most of the Dinajpur region. This region is covered by Piedmont sands and gravels, which were deposited as alluvial fans of the Mahananda and Karatoya rivers and their distributaries issuing from the Terai area at the foot of the Himalayas. The piedmont deposits may possibly be as old as late Pleistocene or early Holocene, but they are younger than Madhupur clay. The drainage pattern is braided, with broad, smooth, but irregular-shaped ridges crossed by numerous, broad shallow channels. This plain gently slopes south from about 96 m down to 33 m above MSL (mean sea level). This physiographic unit underlies most of the northwestern corner of the country, i.e. the entire Thakurgaon and major parts of the Panchagarh and Dinajpur Districts. The Tista Floodplain is characterized by big sub-region stretches between the Old Himalayan Piedmont Plain in the west and the right bank of the N-S flowing Brahmaputra in the east. Most of the land is shallowly flooded during monsoons. There is a shallow depression along the Ghaghat river, where flooding is of medium depth. The big river courses of Tista, Dharla and Dudhkumar cut through the plain. The active floodplain of these rivers, with their

Sandbanks and Diyaras, is usually less than six kilometres wide.

The Barind Tract is characterized by an older pleistocene terrace forming a small plateau with a flat or - in some sectors - a slightly undulating surface. This terrace consists of reddish and yellowish and partially mottled clays and is characterised morphologically by a dendritic drainage pattern, which is typical of all older Pleistocene terraces in Bangladesh. The Barind unit is comparatively at higher elevation than the adjoining floodplains. The contours of the tract suggest that there are two terrace levels - one at 40 m and the other between 19.8 and 22.9 m. Therefore, when the floodplains go under water during monsoon the Barind Tract stands free from flooding and is drained by a few small streams. About 47% of the Barind region is classified as highland, about 41% as medium-high land and the rest as lowland.

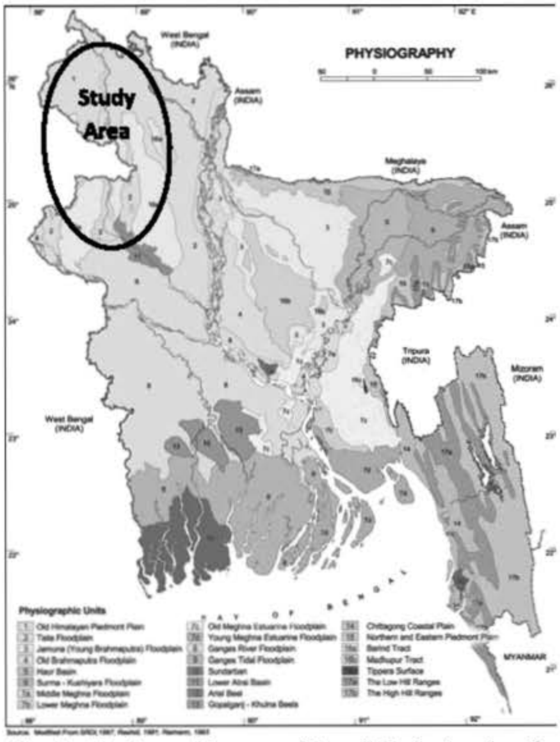


Fig. 1: Physiographic map of Bangladesh showing the location of the study area.

Methodology

Data Collection and Processing

For the hydrogeological study component, primary and secondary data have been collected for analysis. For the lithological characterization, available 565 borelogs were collected from BMDA and other sources and 15 borelogs are collected conducting exploratory drilling under this study. Most of the collected borelogs from secondary sources (BMDA and other) were upto a depth 80 m. Only 37 nos borelogs including project exploratory drillings had a depth ranges from 104.57-301.83 m. Lithologic logs are interpreted to determine the aquifer system i.e. depth, thickness, type and extension of aquifer units in the area.

Exploratory Drilling and Installation of Observation Well

Exploratory drilling locations have been selected considering spatial distribution of available lithologs and scope of filling the data gaps for better representation of hydrogeological variability. A total of 14 sites were selected for performing test drilling but during implementation 15 test drillings were done, of which 10 test drilling were down to 150 m depth and the rest are down to 300 m depth from the ground surface, and among them 12 observation wells were installed for observing the groundwater level condition of the areas. Locations of exploratory drilling conducted under this study (IADP) and one previous study (Unit II) are shown in Figure 2a.

Groundwater Sampling and Analysis

Groundwater samples were collected from 20 locations for analysis and interpretation of important physicochemical parameters in the area. Locations of the groundwater sampling wells are presented in Figure 2b. A total of 21 physico-chemical parameters were measured on the collected samples. Physical parameters, such as pH, Eh, EC, salinity, TDS, temperature, were measured in the field and hydro-chemical parameters such as Calcium, Magnesium, Sodium, Potassium, Bi-carbonate, Nitrate, Phosphate, Sulphate, Chloride, Iron, Boron, Fluoride, Carbonate, Arsenic and Manganese were examined in Department of Public Health and Engineering (DPHE) laboratory. The purpose of this water quality analysis is to evaluate water chemistry and suitability of the groundwater of any area for municipal and agricultural uses. The measured physical parameters and analyzed hydro-chemical parameters are presented in Table 1 and Table 2 respectively.

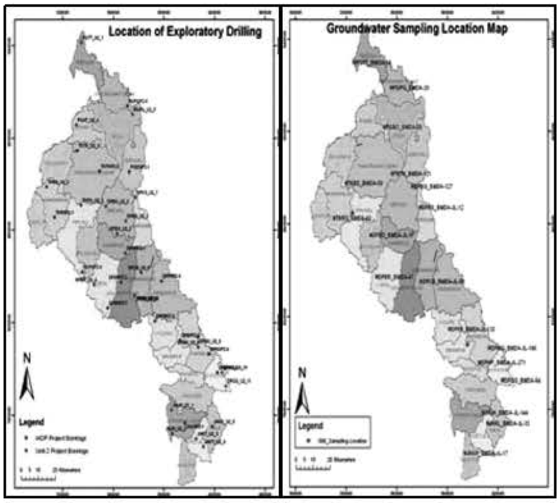


Fig. 2: Location of (a) exploratory drilling sites and (b) groundwater sampling wells for water quality analysis.

Groundwater Table

Bangladesh Water Development Board (BWDB) has about 135 groundwater monitoring wells within the study area, out of which the data from 117 wells have been used for the study considering the quality of the data. To fill up the data gap and for calibration and validation purpose of the model, additional 50 Groundwater monitoring wells were installed under this study during the period of November to December 2013 and the monitoring was continued upto February 2015. The measurements were taken once per day. The top levels of the observation wells were connected to the benchmark of Survey of Bangladesh (SoB) or JICA. In order to see the spatial distribution of groundwater table below ground surface, the contour maps have been prepared for the groundwater table of 30th April and 30th October. In addition to this, a trend analysis of collected groundwater table data has been done by preparing hydrographs to know seasonal variation/fluctuation of groundwater table and to predict future trend of groundwater table for different zones of the study area.

Result and Discussion

Aquifer System of the Study Area

Extension of aquifer units and characterization of aquifer sediments are very important in for the sustainable development and management of groundwater resources of an area. For better understanding of subsurface hydrogeology, a total of 37 deep exploratory borelogs have been used for the lithologic cross section of the project areas. Of these, as it was mentioned earlier, 15 exploratory borelogs have been collected from the present project and the depth ranges from 152.44-301.83 m and the rest 22 exploratory borelogs have been collected from a previous project (Unit-2) and the depth ranges from 104.57-201.22 m. 15 numbers for the lithologic cross sections have been prepared to describe the extension and thickness of aquifer in the study area. The location of the lithologic cross sections of the area and lithostratigraphic model are shown in Figure 3a and Figure 3b respectively.

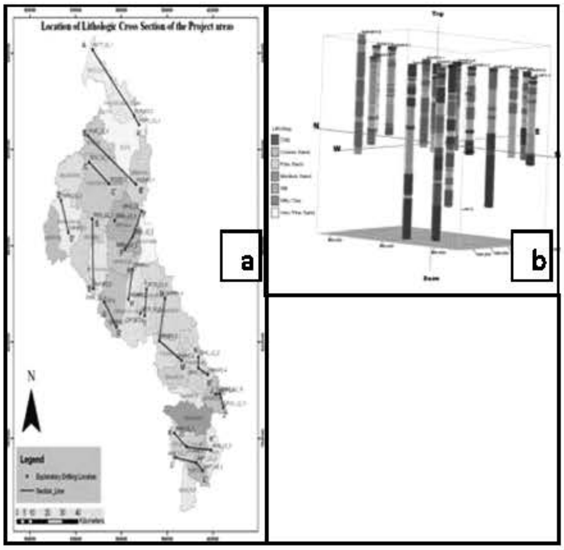


Fig. 3: (a) Location of lithologic cross-sections and (b) 3D diagram of lithostratigraphy using exploratory borehole lithologs.

Hydrogeology as well as the distribution of aquifer sediments in the subsurface is very complex. The hydrostratigraphic section reveals that the complexity of the aquifer system increases and the thickness of the aquifer decreases from north to south. Aquifer-aquitard alteration is highly variable even within a short distance. The spatial distribution and hydrostratigraphic section of the projected logs display the locations and nature of the aquifers, their thickness and other necessary information regarding depths that are helpful for large scale planning of the groundwater development. Interpretation of the hydrostratigraphic sections of the projected logs indicate within the study area that aquifer systems are composed of fine sands, medium and coarse sands with little gravels.

The spatial distribution of the projected borelogs and the hydrostratigraphic section along line X-X′ covering the entire study area from northwest to southeast (Figure 4) reveal that the aquifer system down to the investigated depth is hydraulically connected regionally though one or more aquitards are encountered at local level.

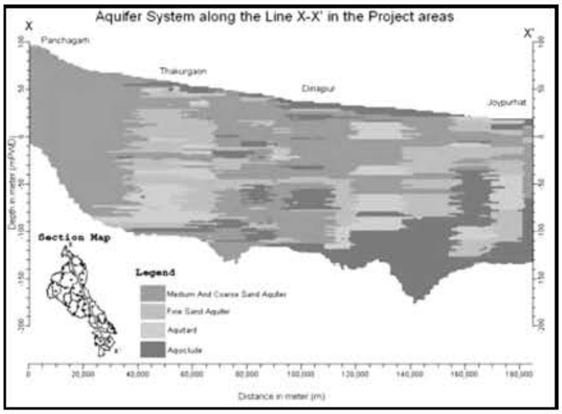


Fig. 4: Hydrostratigraphic cross section along line X-X′ in the study area.

Panchagarh District

In Panchagarh District there is only one thick medium and coarse sand aquifer present with variable depth and thickness. The thickness of the prolific aquifer in Tatulia upazila is about 104 m and in Panchagarh upazila is about 200 m which is interbedded with lenses of finer material and most favourable for large scale development. The prolific medium and coarse sand aquifer exists throughout the Panchagarh district, except Debiganj upazila. The thickness of this aquifer may increase with increasing depth. The thin overlaying strata are favourable for vertical recharge to groundwater. The aquifer is mostly unconfined in nature.

There is a thin aquitard layer present in the Atwari upazila. Below this aquitard, a thick medium and coarse sand aquifer encounters from 3 to150 m depth and may be extended throughout the area. In Debiganj upazila a thin aquitard overlies the upper aquifer. Below this aquitard, there are two medium and coarse sand aquifers present at depth ranges of 21-36 m and 70-85 m and specific yield of these aquifers ranges from 0.15-0.18. These aquifers are interbedded with fine to very fine sand and very fine sand aquifer. The specific yield ranges from 0.07-0.10. The aquifer system is poor for further development.

Thakurgaon District

The aquifer system of the northern part of Thakurgaon district is totally different from that of the southern part. Commonly, there is a thin aquitard layer present throughout the area. In the northern part (Modhupur area) below this thin aquitard layer, there are five medium and coarse sand aquifer units present at 3-21, 30-57, 60-79, 82-94, 97-121 and 125-153 m interbedded with 3 to 7 m thick aquitards. The specific yield varies from 0.15-0.22. In the southern part (Sigpara area) there is only one thin medium sand aquifer present from 15-27 m with the specific yield of 0.15 and one thick fine sand aquifer present at 27-91 m with a specific yield that varies from 0.07-0.10. Below this aquifer there is an aquitard present at 91-146 m, which is composed of very fine sand and silt, and the specific yield ranges from 0.04-0.07. The aquifer system of Ranishankail varies between north and south. In Kadiahat area there are two thick medium and coarse sand aquifer present from 3-100 m and 106-151 m, interbedded with lenses of finer material. The specific yield of these aquifers varies from 0.10-0.22. 6 m thick aquiclude is encountered between these two aquifers with specific yield of 0.03. The thin overlaying very fine sand layer is favourable for vertical recharge of groundwater. In Atgoa area there are three medium and coarse sand aquifer units present from 3-51, 73-88, 91-152 m and the specific yield ranges from 0.13-0.22. Between these aquifers, two aquicludes are present from 51-73 m and 88- 91 m and the specific yield is 0.03. The aquifers may be extended toward north. In another part there are four aquifer units encountered down to the depth of 301 m. The aquifers are present from 27-40, 52-58, 73-106 and 112-173 m. The upper two thin aquifers are composed of medium to fine sand. The lower two aquifers are composed of fine to medium sand. The specific yield of these aquifers ranges from 0.10-0.13.

Dinajpur District

In Khansama and Birganj areas, there is a top clay layer (3-6 m thick) present throughout the area with variable thickness. In Gobindapur area there are three aquifer units present from 3-64, 73-137 and 146-184 m down to the penetrated depth of 200 m. The first aquifer is composed of medium and coarse sand with trace gravel. The specific yield ranges from 0.15-0.20. The second aquifer is composed of fine and medium sand and the specific yield ranges from 0.10-0.15. The third aquifer is composed of fine sand and medium to coarse sand and the specific yield ranges from 0.10 to 0.17. In Balarampur area there are three aquifer units present from 6-48, 54-94 and 115-134 m. The upper aquifer in this area is mostly composed of medium to fine sand and medium to coarse sand. In Chakai areas there is also three aquifer units present from 6-30, 45-125 and 131-147 m. The upper aquifer is not productive for this area, which is composed of fine sand. The second aquifer is composed of fine sand and medium to fine sand. The upper aquifer of Gobindapur and Balarampur areas are semi-confined in nature and can be developed by low capacities pumps if the depth to the water table is satisfactory. The aquifer system, characterized by discontinuous inter-bedded lenses of clay, is semi-confined in nature throughout the section area. Inter bedded lenses of finer materials have a great impact on the subsurface flow systems; as a result special care must be taken while designing and regarding the spacing of tubewells of this area.

In Bhandhara area of Biral upazila there are mainly three aquifer units present from 6-48, 57-73 and 79-94 m. These aquifers are composed of medium sand and medium to coarse sand with the specific yield that ranges from 0.13- 0.20. These aquifers are separated from each other with thin clay layers. Below these aquifers there is a thick aquitard present down to the penetration depth of 189 m. In Dharmapur area there are two aquifer units present at 18-30 m and 60-121 m. Below these aquifers, there is a thick aquitard present down to 298 m. In this area the first aquifer is composed of medium sand and the specific yield ranges from 0.13-0.15. The second aquifer is composed of fine sand and medium to fine sand with a specific yield that ranges from 0.10-0.15. The section reveals that in Biral upazila the aquifer system is semi-confined in nature and not good for large scale groundwater development. In Kaharole upazila a thin aquitard is present at the surface, while in Dinajpur sadar upazila a thick aquiclude (27 m) is present at the surface. In Garlorpur area, below a thin aquitard, a thick aquifer is encountered down to the investigated depth of 152 m inter-bedded with very fine sand. In Kamolpur area three aquifer units are present from 27-57, 73-100 and 106-121 m down to the penetration depth of 152 m inter-bedded with very fine sand and silt. The aquifers consist of medium to fine sand and medium and coarse sand with a specific yield that ranges from 0.13-0.20.

The aquifer system at Chirirbandar upazila is very complex with irregular distribution of aquifer and aquitard sediments. There is an aquiclude layer present at the surface with variable thickness. In Manikgati area there are four aquifer units present at 18-36, 42-67, 70-9 and 112-149 m inter-bedded with aquitard with variable thickness that ranges from 3-21 m. The aquifers consist of medium to fine sand and medium and coarse sand. The specific yield ranges from 0.13-0.20. In Viral area only one thick aquifer is present at 51-94 m down to a penetration depth of 246 m. The aquifer is composed of fine to medium sand and medium sand with a specific yield that ranges from 0.10-0.15. The aquifer system of Parbatipur, Fulbari and Birampur upazila are semi confined in nature. There is only one aquifer throughout the area with different depths and thicknesses. In Pachnagar area under Parbatipur upazila the aquifer encounters at 6-125 m. The upper part of the aquifer consists of medium to fine sand and the lower part consists of fine to very fine sand. The specific yield of the aquifer ranges from 0.07-0.20. Below this aquifer there is thick aquitard layer present down to the drilled depth of 152 m. In Khazapur area under Fulbari upazila the aquifer is presents at 6-109 m inter-bedded with thick finer materials (very fine sand). The aquifer is composed of very fine to fine sand and medium to fine sand. The specific yield ranges from 0.07-0.15. Below this aquifer a thick aquiclude layer is present down to the penetration depth of 152 m. In Pannathpur area under Birampur upazila the aquifer is encountered at 6-112 m down to a penetration depth of 240 m and consists of fine sand, fine to medium and medium sand. The specific yield ranges from 0.10-0.15. The inter-bedded finer materials in the aquifer system reduce the transmissivity and permeability.

In Hayatpur area there are two aquifer units present at 9-97 and 128-140 m inter-bedded with finer materials (very fine sand). The aquifers are separated by thick clay layer (31 m thick). The specific yield ranges from 0.07-0.20. In Daria area there is one aquifer present at 3-76 m inter-bedded with lenses of finer materials (clay and very fine sand). Below this aquifer a thick very fine sand layer is present down to the penetration depth of 152 m and the specific yield is 0.07. The section also reveals that the aquifer system is semi-confined in nature and the inter-bedded lenses of finer materials have a great impact in the subsurface flow systems, as a result special care must be taken while designing and regarding the spacing of tubewells.

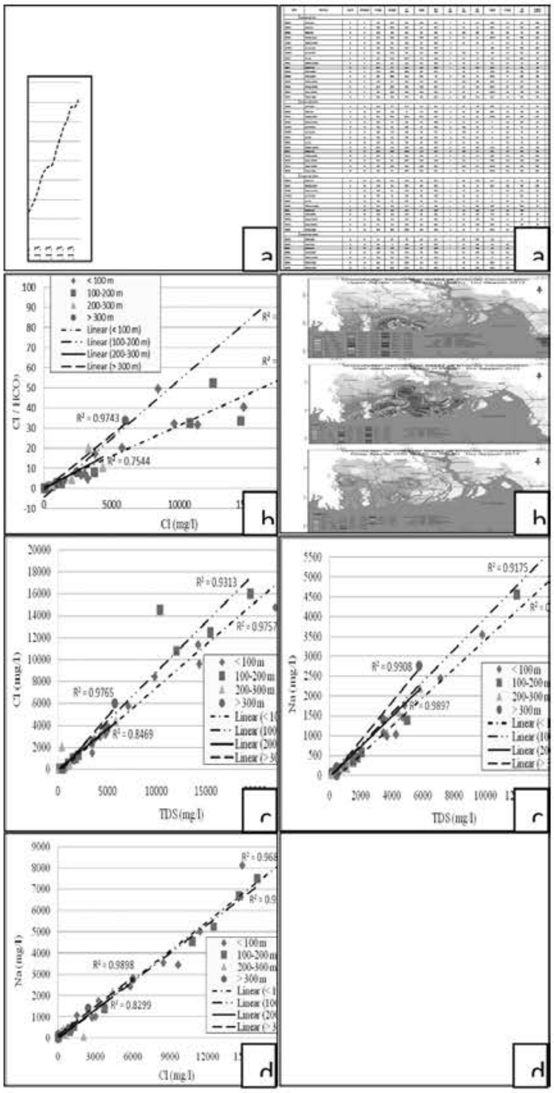


Fig. 5: Selected lithologic cross-sections: Panchagarh (a-a'), Thakurgaon (b-b'), Dinajpur (c-c') and Joypurhat districts (d-d').

A thin aquiclude is present at the surface which extends throughout the Ghoraghat upazila with variable thicknesses. In Bhalain area there is a thick aquifer present at 9-85 m inter-bedded with finer material and composed of fine sand and medium sand, medium to coarse sand. The specific yield ranges from 0.07-0.20. Below this aquifer a thick aquitard is present down to the penetration depth of 152 m. In Kushigaon area, three aquifer units are present at 9-54, 103-115 and 140-150 m. Among them the first aquifer is productive for this area. The upper layers indicate that the recharge potential of these areas is moderate and can be developed by low capacity pumps if the depth to water table is satisfactory. In Toshai area there are two aquifer units present at 9-60 and 173-183 m down to the penetration depth of 183 m. The aquifers are composed of medium and coarse sand and the specific yield ranges from 0.15-0.22. The aquifer system of Ghoraghat upazila is semiconfined in nature.

Joypurhat District

In Joypurhat District the lithology is very complex and changes within short distances. In Maladipur there are two aquifer units present at 3-24 and 30-54 meters. The aquifers are composed of fine sand, fine to medium sand and medium sand and the specific yield ranges from 0.10-0.15. The aquifers are extended throughout the sectional area with variable thicknesses. Below these aquifers a thick aquitard is encountered at 54-128 m and a mixture of fine and silt sequence is present down to the depth of 150 m. Presence of silt reduce the permeability of this layer. In Gopalpur area there is a continuous aquifer from 12 to 131 m with inter-bedded thick very fine to fine sand layer from 60-97 m. The aquifer is composed of very fine to fine sand, fine to medium sand and medium to fine sand and the specific yield ranges from 0.07-0.13. In Aora area under Kalai upazila, one aquifer is encountered at 6-57 m, which is composed of medium sand and medium to coarse sand and the specific yield ranges from 0.15-0.22. Below this aquifer a thick aquiclude layer is present down to the depth of 157 m interbedded with lenses of fine and very fine sand sequences.

At the subsurface geology of some part of Joypurhat upazila and Khetlal upazila an aquitard exists within the top ranges at 3-6 m. In Chandpura area a thick aquifer is present at 3-121 m, which is extend throughout the sectional area with variable thickness and depth. This aquifer presents for 6-82 and 6-57 meters at Khetlal and Binay areas, respectively. The continuous aquifer is composed of medium sand and medium to coarse sand with traces of gravel, interbedded with lenses of finer materials. The specific yield ranges from 0.10-0.22. In Binay area a medium to coarse sand layer is encountered at 152-163 m but its extension is not known.

Groundwater Table

From the analysis of the historical groundwater table data, it has been observed that groundwater level attains the lowest level, i.e. highest depth of groundwater table at the end of April and the variation of highest depth to groundwater table is mostly between 4.0 and 12.0 m. On the other hand, groundwater level attains the highest level, i.e lowest depth to groundwater table, at the end of October and the variation of lowest depth to groundwater table is mostly between 2.0 and 10.0 m. During dry season, i.e. in April, the groundwater table lowers beyond the suction limit of no. 6 hand tube wells (HTW) in some parts of the study area, especially in the major part of Joypurhat and Dinajpur district. As a result, HTW becomes inoperable in these areas in dry season, but during monsoon, in most of the area, the aquifer is recharged again and the HTWs becomes operable except in some parts of Khetlal, Kalai and Akkelpur upazilas of Joypurhat district. The long term available observed groundwater level (1982-2014) for different wells of BWDB have been collected and used for the study.

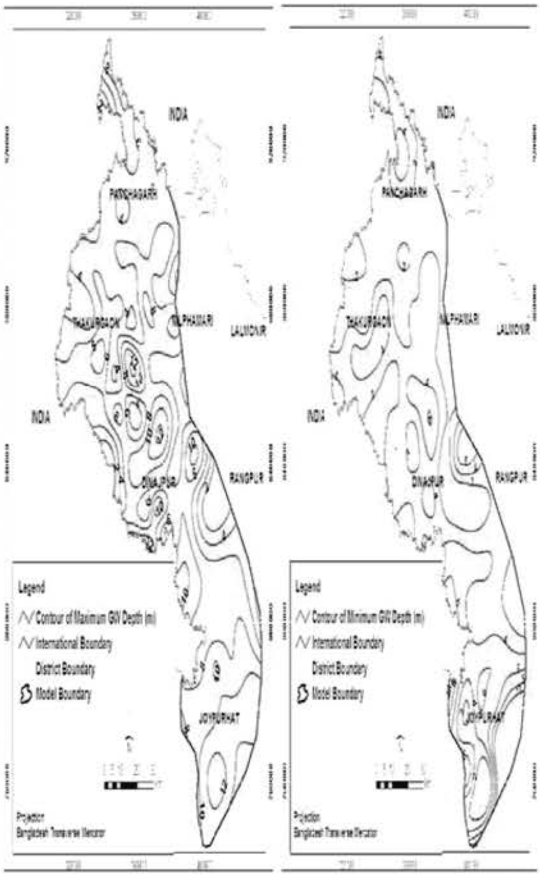


Fig. 6: Contour maps on (a) Maximum depth to groundwater table at the end of April, 2013 and (b) Minimum depth to groundwater table at the end of October, 2013 (left to right).

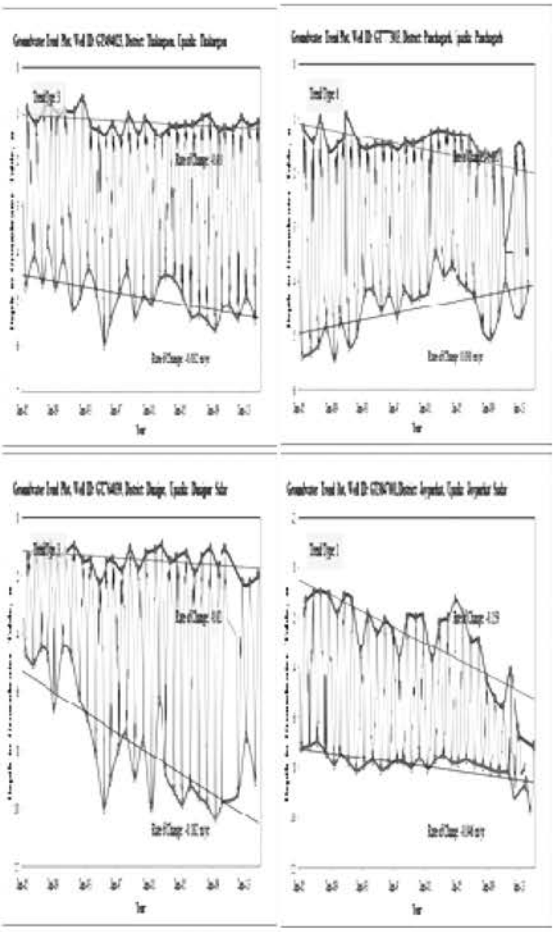


Fig. 7: Groundwater table trend analysis.

Groundwater Quality Parameters

Physical Parameter of Groundwater Samples

Temperature of collected groundwater samples from the project area ranges from 27.5 to 30.2°C. The pH of the groundwater indicates whether the water is acidic (pH < 7) or alkaline (pH > 7). pH value of the collected groundwater samples from the project area ranges from 6.1 to 8.9 in mostly the shallow aquifer (< 70 m). The samples with negative Eh (that is the reduced samples) have a correlation with depth. The water reduces with depth. On the other hand, oxidized water does not show any relationship with depth. Eh value of collected groundwater samples from the project area ranges from -130.2 to 83.1 mV. Electrical conductivity (EC) is the most useful among the on-site measurement. It is the measure of the ability of water to conduct electrical current. It is highly dependent on the amount of dissolved solids (such as salt) in the water. Specific conductance is an important water quality measurement because it gives a good idea of the amount of dissolved material in the water (Fetter, 1994). Higher electrical conductance is the reflection of higher ionic concentration (Hem, 1989). EC is distinctly influenced by temperature change. Therefore, temperature and EC are measured together. The most desirable limit of EC in drinking water is prescribed as 1500 µS/cm (WHO 2004). EC value of the collected groundwater samples from the project area ranges from 73 to 311 µS/cm. The EC can be classified as type I, if the enrichment of salts are low (EC < 1500 µS/cm); type II, if the enrichment of salts are medium (EC 1500 and 3000 µS/cm); and type III, if the enrichment of salts are high (EC > 3,000 µS/cm). According to the above classification of EC, 100 % of the total groundwater samples come under the type I (low enrichment of salts). Salinity of collected groundwater samples from the study area ranges from - 0.1 to 0.2 ppt. Total dissolved solid (TDS) is the amount of total solid dissolved in the water. As the value of TDS increases, the quality of the water decreases. TDS value of the collected groundwater samples from the area ranges from 36.5 to 155.8 mg/l. The water classification based on the TDS for analysed samples is suitable for drinking use (Davis and DeWiest 1966). Results of physical parameters for all samples are presented in Table 1.

Chemical Parameter of Groundwater Samples

Cations

Results of chemical parameters for the studied samples are presented in Table 2. Calcium concentration in the groundwater of the study area ranges from 7.6 to 32.7 mg/l, which is within the allowable limit of Bangladesh standard. Calcium is naturally present in water. It may dissolve from rocks such as limestone, marble, calcite, dolomite, gypsum, fluorite and apatite. Calcium is a determinant of water hardness, because it can be found in water as Ca^{2+} ions. Calcium is the most abundant earth metal and is a major solute component in most natural water. Its behavior in aqueous system is generally governed by the availability of the more soluble calcium containing solids and by sodium and gas phase equilibrium that involve carbon dioxide species or by the presence of sulfur in the state of sulphate (Hem, 1989). Ca^{2+} concentrations more than SO_4^{2-} indicates Ca^{2+} sourced from calcite/dolomite or silicates (Hounslow 1995). Fresh water is often dominated by Ca^{2+} and HCO_3^- ions, as a result of dissolution of calcite. Magnesium is also an alkaline-earth metal and has only one oxidation state of significance in water chemistry. In some aspects of water chemistry, calcium and magnesium may be considered as having similar effects, as in their contributions to the property of hardness (Hem, 1989). A large number of minerals contains magnesium, for example, dolomite (calcium magnesium carbonate; $CaMg(CO_3)^2$) and magnesite (magnesium carbonate; $MgCO_3$). Magnesium is washed from rocks and, subsequently, ends up in water. Magnesium concentration in groundwater of the study area ranges from 1 to 2.7 mg/l, which is within the allowable limit of Bangladesh standard.

Sodium compounds naturally end up in water. Naturally water contains sodium, it stems from rocks and soils. Groundwater contains a higher amount of sodium and it is the most abundant member of the alkali-metal group. The presence of sodium in groundwater primarily results from the chemical decomposition of feldspar, feldspathoid and some mica; other sources of sodium in groundwater are contamination with agricultural byproduct and industrial effluents (Hem, 1989). Concentrations of sodium in potable water are typically less than 20 mg/l and concentration in excess of 200 mg/l give rise to unacceptable taste. Contamination of surface water increases the concentration of sodium. Sodium concentration in groundwater of the project area ranges from 6.2 to 20.2 mg/l, which is within the limit of Bangladesh standard. Potassium concentration in groundwater of the study area ranges from 0.57 to 6.7 mg/l. Higher concentration of potassium is found in Pirganj under Thakurgaon district but that is also under the limit of Bangladesh standard. Potassium occurs in various minerals, from it may get dissolved in water through weathering processes. For examples feldspars (orthoclase and microcline), though not very significant for potassium compound production, and chlorine minerals, carnalite and sylvite, which are most favorable for production purposes. Some clay minerals contain potassium. It ends up in seawater through natural processes, where it mainly settles as sediments.

Anions

Chloride concentration in the groundwater of the study area ranges from 8 to 27 mg/l, which is under the limit of Bangladesh standard. Chloride is present in all natural water and indicates salinity of that water. Chloride concentrations are generally low in groundwater but where the groundwater receives inflow of high chloride surface water or any sanitation system or industrial waste or invasion by sea water a higher Cl^- may result. The type of water in which Cl^- is the dominant anion, there is a possibility that sodium is the predominant cation of that system (Hem, 1989). In some rocks fluoride has been reported to be in about the same amount as chloride. However, the quantity of fluoride in natural surface water is ordinarily very small compared to that of chloride. Fluoride in excessive concentrations, however, is undesirable in water used for drinking. Fluoride concentration in groundwater of the area ranges from less than 0.10 to 0.36 mg/l, which is under the limit of Bangladesh standard.

Carbonate concentration in groundwater of the area ranges from 0.04 to 1.19 mg/l, which is under the limit of Bangladesh standard. Carbonate is usually present in groundwater due to the weathering of carbonate minerals and the presence of carbon dioxide, which helps to dissolve these ions and make them readily available. Breakdown of organic matter also causes higher HCO_3^- in groundwater. In almost all-natural waters, it is concluded that the alkalinity is produced by the dissolved carbon dioxide species, bicarbonate and carbonate. Nitrate is the most prevalent form of nitrogen in groundwater and the presence of nitrogenous compounds indicates the presence of organic matter in that water. Principal sources of NO_3^- in water are nitrogen fixing plants and bacteria, chemical fertilizers sewage, decaying organic matter and etc. Most investigators have attributed the source of the extra nitrate (NO_3^-) to the drainage from nearby barnyard or septic tanks and cesspools (Hem, 1989). Contamination of groundwater by NO_3^- from fertilizers may also result in elevated Cl^- concentration in shallow aquifer (Richter and Kreitler 1993). Nitrate concentration in groundwater of the project area ranges from less than 0.10 to 8.43 mg/l. Higher concentration of nitrate was found in Tetulia of Panchagarh district and Bochagonj and Nawabgonj, of Dinajpur district, but these values are under the limit of Bangladesh standard.

Concentrations of dissolved HCO_3^- reflect the degree of water-rock interaction in groundwater systems as well as integrated microbial degradation of organic matter. Some minerals, like carbonates, dissolve quickly and significantly change the composition of the water already in the soil (Appelo and Postma 1999). Bicarbonate is usually present in groundwater due to the weathering of carbonate minerals and the presence of carbon dioxide, which helps to dissolve these ions and make them readily available. Breakdown of organic matter also causes higher HCO_3^- in groundwater. In almost all-natural waters, it is concluded that the alkalinity is produced by the dissolved carbon dioxide species, bicarbonate and carbonate. Bi-carbonate concentration in groundwater of the project area ranges from 33 to 149 mg/l, which is under the limit of Bangladesh standard.

The occurrence of sulfate in groundwater results from the oxidation of sulfur in igneous rocks and the solution of other sulpher bearing minerals. Sedimentary rocks (organic shale) may also play a vital role in this connection through oxidation of mercasite and pyrite (Matthess, 1982). The source of sulphate are the minerals pyrite (FeS_2), gypsum ($CaSO_4.H_2O$) and anhydrite ($CaSO_4$). Higher (SO_4^{2-}) concentration in water may be due to the influence of other sources such as agricultural wastewater, industrial effluents and others. Sulfate concentration in groundwater of the project area ranges from less than 1 to 11 mg/l. Higher concentration of sulfate is found in Pirganj under Thakurgaon district but the value is under the limit of Bangladesh standard. Widespread use of chemical fertilizers in the region may be the cause behind the higher concentration of PO_4^{3-} in shallow well samples. PO_4^{3-} is sorbed strongly onto solid phases, including Fe and Al oxides in soils. P concentrations in recharging groundwater generally do not reflect the large amounts of P applied to agricultural fields, especially through manures (Moore and Reddy 1994). The amount of P released into the water is related to the concentration of PO_4^{3-} that exceeds the capacity of Fe to create insoluble iron phosphates. Phosphate concentration in groundwater of the project area ranges from 0.35 to 3.69 mg/l. Higher concentration of phosphate is found in Ranisankoil and Baliadangi under Thakurgaon district but the value is under the limit of Bangladesh standard.

Trace Elements

Iron is a common constituent of anoxic groundwater. Most water problems that result from high Fe content are associated with the change from ferrous (dissolved) to ferric (semisolid) ion. Ferric oxide and hydroxides precipitates from solution during aeration and coat surrounding surfaces. In natural groundwater system where O_2 concentration is low or absent and the pH is from 6.5 to 7.5, Fe occurs primarily as dissolved ferrous ions (Fe^{+2}). Important Fe^{+2} bearing minerals are commonly present in aquifer sediments that comprise minerals like magnetite, ilmenite, pyrite, siderite, silicates (e.g. amphiboles, pyroxenes, olivine and biotite) and clay minerals (e.g. smectites). Oxidative dissolution of pyrite as a source for Fe^{+2} in groundwater is an important process (Appelo and Postma 1999). Iron concentration in groundwater of the study area ranges from 0.2 to 11.98 mg/l. Higher concentration of iron is found in Ranisankoil and Pirganj and Baliadangi under Thakurgaon district, Bochagonj and Birol under Dinajpur district and Joypurhat Sadar under Joypurhat district. According to Bangladesh standard limit, the iron concentration of groundwater of these areas are not suitable for drinking and irrigation purposes.

Boron is an indicator of groundwater salinity and reflect relict seawater influences either by marine inundation of low-lying area or saline intrusion of near coastal aquifer. Boron concentration in groundwater of the area is less than 0.20 mg/l, which is under the limit of Bangladesh standard. Manganese is an essential trace element, playing an important role as a cofactor for many enzyme systems. In the natural environment, manganese is found as reduced soluble or adsorbed Mn(II) and Mn(III) and Mn(IV) oxides. In groundwater Mn is very low but in surface water it can be high. Manganese concentration in groundwater of the area ranges from less than 0.05 to 0.56 mg/l, which is under the limit of Bangladesh standard.

The subsurface geology and hydrogeological conditions determine safety of an aquifer. The groundwater of different aquifers are hydraulically separated, at least locally, by low permeable clay layers that may limit downward movement of arsenic. The source of arsenic in groundwater of Bangladesh is predominantly geogenic and it is released from the sediment through natural processes (Bhattachryya et al. 1997; Nickson et al. 1998, 2000). However, huge irrigation pumping may induce percolation of arsenic rich groundwater through leaky aquitards or the sandy pockets along the aquitards, to deeper aquifers and eventually cause arsenic contamination in deeper aquifers. Arsenic concentration in groundwater of the study area ranges from less than 0.001 to 0.005 mg/l, which is within the allowable limit of Bangladesh standard (0.05 mg/l) and WHO (0.01 mg/l).

Hydrochemical Character of Groundwater Samples

Hydrochemical characteristics of the study area are evaluated in the present study by Piper Trilinear Diagram (Piper, 1944; Piper, et al., 1953). The chemical characteristics of groundwater samples of the study area that fall in different subdivisions of the diamond shaped field of the Piper's Trilinear Diagram are shown in Figure 8. From the Diagram it is seen that all the samples fall in the field-1, suggesting that alkaline earths exceed alkalies (Llyod and Heathcote, 1985). All these samples except samples no- 2, 3, 6, fall in the field-3, indicating week acids exceed strong acids. 20 samples fall in field-5 which is carbonate hardness (secondary alkalinity) exceeds 50%. It is also obvious from Figure 8 that sample no- 2, 3, 6 belong to field-9 of the Piper Trilinear Diagram which indicates no cation-anion pair exceeds 50%.

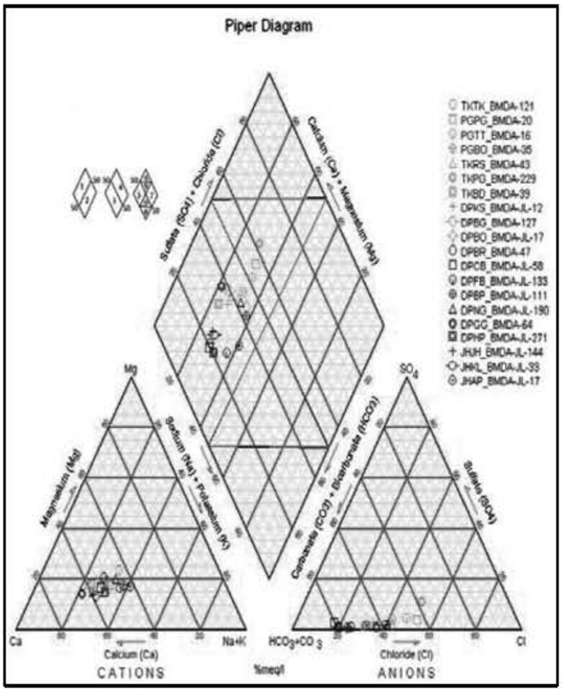


Fig. 8: Piper Trilinear Diagram for groundwater samples in the study area showing analysis represented by three-point plotting method.

Table 1. Physical parameters of groundwater samples of selected locations

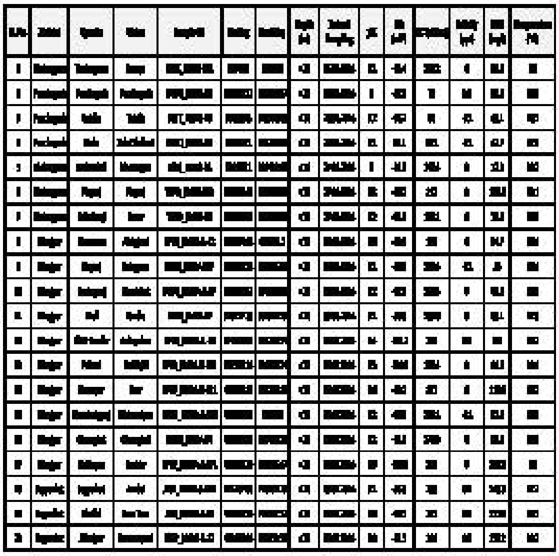
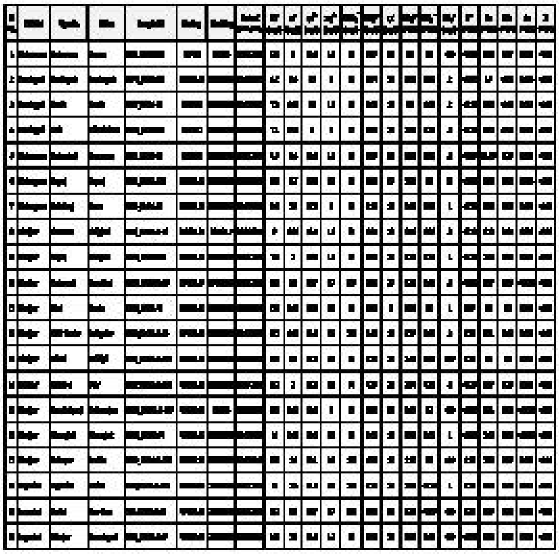


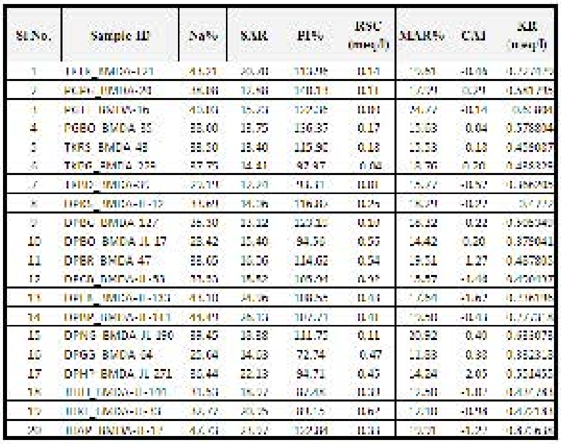
Table 2. Chemical parameters of groundwater samples of selected locations



Hydrochemical Evaluation of Groundwater for Irrigation

The important constituents that influence the water quality for irrigation, such as Soluble Sodium Percentage (SSP), Residual Sodium Carbonate (RSC), Kelley's Ratio (KR), Permeability Index (PI), Magnesium Adsorption Ratio (MAR), Sodium Adsorption Ratio (SAR) and Chloro-Alkaline Indices (CAI), were all calculated using established standard equations (Richards, 1954; Kelley, 1963; Doneen, 1964; Todd, 1980; Gupta, and Gupta, 1987; Raghaunath, 1987). The calculated results of the irrigation water parameter indices are given in Table 3

Table 3. Different parameter indices for rating groundwater quality and its sustainability in irrigation



Sl.No.	Sample ID	Na%	SAR	PI%	RSC (meq/l)	MAR%	CAI	KR (meq/l)
1	[illegible]	[illegible]	20.41	[illegible]	[illegible]	[illegible]	-0.05	[illegible]
2	[illegible]	36.08	17.48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	PGBO BMDA 35	33.00	13.75	136.37	0.17	15.03	0.04	0.578804
5	TKRS BMDA 48	33.30	13.40	115.90	0.13	15.33	0.13	0.439087
6	TKDG_BMDA 229	37.75	14.41	97.97	0.08	15.76	0.20	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	14.06	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	DFBC BMDA 127	36.30	13.32	123.10	0.10	16.32	0.22	[illegible]
10	DFBO BMDA JL 17	23.42	15.40	94.30	0.53	14.42	0.20	0.379041
11	DFBR BMDA 47	33.05	16.06	114.62	0.54	19.51	1.27	0.467803
12	[illegible]	[illegible]	16.52	[illegible]	[illegible]	15.57	-1.48	[illegible]
13	[illegible]	[illegible]	24.06	108.55	[illegible]	[illegible]	[illegible]	[illegible]
14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	DFNS BMDA JL 390	33.45	13.88	111.75	0.11	20.92	0.40	[illegible]
16	DFGG BMDA 34	22.04	14.03	72.74	0.47	11.83	0.38	[illegible]
17	DFHT BMDA JL 271	30.44	22.13	94.71	0.45	14.24	2.05	[illegible]
18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Salinity Hazard

Water with high salinity is toxic to plants and poses a salinity hazard. Soils with excessive concentrations of salts (calcium, magnesium, potassium and sodium) portend 'physiological' drought condition and reduce the osmotic activities of the plants. TDS values for all the samples were within permissible limit (< 1,000 mg/l) for irrigation use, which fall under the non saline category (Robinove et al., 1958). Electrical Conductivity, as an irrigation quality index, measures total salinity of the soil. The EC ranges from 73 to 311, with 80% of the samples falling into the excellent, low saline category signifying low salinity hazard and 20% falling into good, moderately saline category, signifying medium salinity hazard (USDA Classification).

Sodium Hazard

Irrigation water containing large amounts of sodium produces the undesirable effects of changing soil properties and reducing soil permeability. The Soluble Sodium Percentage (SSP) values obtained from the following equation below ranges from 25.69 - 47.73 (Table 3), indicating good to permissible irrigation qualities (Wilcox 1955). This means that all the samples are suitable for irrigation purpose.

$$SSP = \frac{(Na + K)}{Ca + Mg + Na + K} \times 100$$

Here, all the elements are expressed in meq/l.

Continuous usage of water with high SAR leads to a breakdown in the physical structure of the soil (Nagarajah, et al., 1988). The SAR of all the groundwater obtained from the study area ranges from 12.24 to 26.13 (Table 3). They are classified as good to doubtful and suitabile for irrigation (Richards, 1954).

$$SAR = \frac{Na}{\sqrt{\frac{(Ca + Mg)}{2}}}$$

Here, all the elements are expressed in meq/l.

USSL Diagram for Classification of Irrigation Water Quality

In the USSL diagram, groundwaters have been divided into C1, C2, C3, and C4 categories on the basis of salinity hazard and S1, S2, S3 and S4 categories on the basis of sodium hazard. According to USSL diagram, most of the ground water samples have low to moderate salinity and medium to high alkalinity (sodium) hazards as shown in Figure 9. The results indicate that 75 % groundwater samples are found in C1S2 and C1S3 classes with low to moderate salinity and moderate to high sodium hazards.

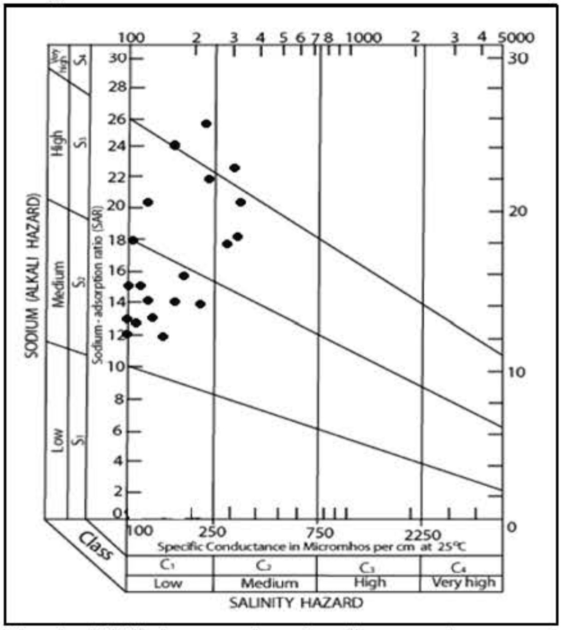


Fig. 9: USSL diagram for classification of irrigation water quality with respect to salinity hazard and sodium hazard.

Bicarbonate Hazard

Bicarbonate hazard is expressed in terms of Residual Sodium Carbonate (RSC) as shown in the equation below. There is a tendency for calcium and magnesium to precipitate from water having high concentrations of bicarbonates; thus increasing the relative proportion of sodium in the water in the form of sodium bicarbonate (Sadashivaiah, et al., 2008). Infertile land can also be caused by irrigated water influenced by high deposition of sodium resulting from high concentration of bicarbonates (Eaton, 1950). The concentration of bicarbonate and carbonate, when higher than calcium and magnesium, will influence the suitability of water for irrigation purposes. The RSC value was computed using the following formula.

$$RSC = (CO_3^{-2} - HCO_3^{-}) - (Ca^{-2} + Mg^{+2})$$

Here, all the elements are expressed in meq/l.

The RSC levels range from -0.466 to 0.917 meq/l (Table 3). All the groundwater samples have RSC levels less than 1.25 and are considered safe and good for irrigation purpose (Richards, 1954). Continuous usage of waters with RSC greater than 1 leads to salt build up, which may hinder the air and water movement by clogging the soil pores and leading to degradation of the physical condition of soil. Negative RSC values, as shown in some samples, indicate that sodium build up is unlikely since calcium and magnesium is in excess of what can be precipitated as carbonates in the locations of those samples.

Magnesium Hazard

Magnesium hazard is expressed in form of Magnesium Adsorption Ratio (MAR) as shown in the equation below. Magnesium content of water is one of the most important qualitative criteria in determining the quality of water for irrigation. Generally, calcium and magnesium maintain a state of equilibrium in most waters but higher magnesium content will adversely affect crop yields as the soils would become more saline (Joshi, et al., 2009). The values of MAR for all the groundwater samples vary from 11.82 % to 24.76 % (Table 3) with 100 % of the groundwater samples having MAR less than the maximum acceptable limit of 50% (Ayers and Westcot, 1985). These samples are considered safe and suitable for irrigation.

$$\mathrm{MAR} = \frac{\mathrm{Mg}}{\mathrm{Ca} + \mathrm{Mg}} \times 100$$

Here, all the elements are expressed in meq/l.

Permeability Hazard

Permeability Index (PI) is used to assess probable influence of water quality on physical properties of soils (Doneen, 1966). The soil permeability is affected by the long term use of irrigated water and the influencing constituents are the total dissolved solids, sodium bicarbonate and the soil type. The PI values range from 72.74 % to 140.13 % (Table 3). Class I and class II waters are considered to be good and suitable for irrigation while class III water is not suitable for irrigation (Doneen, 1964). The results indicate that groundwater in the study area fall within class I and class II which make the water suitable for irrigation purposes. The Formula used is:

$$\mathrm{PI} = \frac{\left(\mathrm{Na} + \sqrt{\mathrm{HCO_3}}\right)}{\mathrm{Ca} + \mathrm{Mg} + \mathrm{Na}} \times 100$$

Here, all the elements are expressed in meq/l.

Kelley's Ratio

The level of Na^+ measured against Ca^{2+} and Mg^{2+} is known as Kelley's ratio, and is used to rate irrigation waters (Kelley, 1940; Paliwal, 1967). All the tested samples are classified as good because all the KR values fall within the permissible limit of 1, indicating the good quality of the groundwater for irrigation purpose (Table 3). The formula used is:

$$\mathrm{KR} = \frac{\mathrm{Na}}{\mathrm{Ca} + \mathrm{Mg}}$$

Here, all the elements are expressed in meq/l.

Chloro-Alkaline Indices (CAI)

The Chloro-alkaline indices (CAI) indicate the ion-exchange between the groundwater and its host environment (Aghazadeh & Mogaddam, 2010). The Chloro-alkaline indices used in the evaluation of Base Exchange are calculated using the equation below and the results are shown in Table 3. Ion-exchange is said to be direct when the indices of exchange between Na/K in groundwater and Mg/Ca in host rock are positive. The exchange is considered as indirect when the indices are negative. The negative index of Base Exchange indicates the existence of chloro-alkaline disequilibrium (indirect Base Exchange reaction) existing in majority of the samples (80%) from the study area.The remaining 15 % of the samples gave positive ratios.

$$\mathrm{CAI} = \frac{\left|Cl^- - (Na^+ + K^+)\right|}{Cl^-}$$

Here, all the elements are expressed in meq/l.

Conclusion

In the study area, northwest to southeast, down to the investigated depth of 300 m the aquifer system is hydraulically connected regionally, though one or more aquitards are encountered at local level. Unconfined and homogeneous aquifers are encountered in the Panchagarh district and most parts of Thakurgaon district, such as Ranishankail, Boda and Thakurgaon Sadar, while semi confined aquifers interbedded with finer materials covering some parts of Thakurgaon district such as Pirganj and most parts of Dinajpur district. Semi confined and homogeneous aquifers dominate some part of Dinajpur district, such as Birampur, Nawabganj and Hakimpur and most parts of Joypurhat district.

Most parts of the study area has potentiality for groundwater development considering higher rainfall and recharge rate of groundwater. However, when usable recharge is considered at base condition, shortage of groundwater is observed in Fulbari and Hakimpur upazilas of Dinajpur district and Akkelpur, Joupurhat Sadar, Khetlal and Kalai upazilas of Joypurhat district. This is due to the higher abstraction than the usable limit and Boro coverage that is already equal to or more than 80% in those upazilas, which implies higher water requirement. It is also possible to bring some areas under the surface water irrigation scheme along the river where there is very low discharge by constructing Rubber Dams. At the same time, groundwater loss will also be minimized and recharge of groundwater would be enhanced. For present condition, during dry season, groundwater table goes below 10 m to 12 m from the ground surface in some parts of Dinajpur and Joypurhat districts. The areas where HTWs do not work properly in dry season, Tara pumps or over head water tanks may be installed to ensure the water for domestic and drinking purposes. No further installation of irrigation TWs for Fulbari, Hakimpur, Akkelpur, Joypurhat Sadar, Khetlal and Kalai upazilas is recommended as the present abstraction of these upazilas already exceeds the usable limit. Diversification to less water consuming crops should be inspired in upazillas like Fulbari, Ghoraghat, Hakimpur, Kaharole, Nawabganj, Parbatipur, Akkelpur, Joypurhat Sadar, Khetlal, Kalai, Panchbibi, Baliadangi and Haripur, there might be a shortage of irrigation water in these upazilas in future. So, maximum groundwater abstraction should be upto usable recharge in these upazilas.

In general, groundwater quality of the study areas, except a few, is suitable for both domestic and agricultural uses except Ranisankoil, Pirganj, Baliadangi, Bochagonj, Biral and Joypurhat Sadar where the concentration of iron is higher than the limit of Bangladesh standard. Arsenic which is now a burning issue of our country, its concentration is below the Bangladesh standard limit. The concentration of other chemical elements is also within the Bangladesh standard, i.e. the allowable limit.

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