Groundwater and Surface Water Quality Assessment for Irrigation and Drinking Purposes of Khulna District, South-Western, Bangladesh.

Md. Badrul Alam, Chowdhury Rayhan Kabir Rocky, Nadia Sultana Tarakki, Abdullah Al Aftab, Chowdhury Quamruzzaman

Abstract—This research deals with the Water Quality of Khulna District, South-western Bangladesh according to WHO standard. The water analyses show that, Na+, Cl-, and HCO3- are dominant ions but as far as the water quality is concerned, except some locations, the water is not suitable for drinking purpose. The competency of groundwater for drinking varies from place to place with depth but shallow water is totally unsuitable for drinking. Most of the samples exceeds the WHO and Bangladesh standard. Approximately all the groundwater is moderate to very hard and the surface water is soft to moderately hard. Maximum water samples are mixed type of Ca-HCO3- and Na-HCO3-. Some shallow and surface water are Ca-HCO3- type and rest of deep water samples are Na-HCO3- type. The groundwater electrical conductivity (EC) of the study area shows some spatial variation and highest SEC value was found in southern part which gives indication of water quality deterioration. It also indicates the salinity of groundwater. Based on sodium absorption ratio (SAR) values it is observed that, the water is suitable for irrigation development

Index Terms—Water Quality, Concentration, WHO Standard, SAR, KR, Chloride Toxicity, Hardness and EC.

1 INTRODUCTION

Almost two billion people of the world depend directly upon aquifers for drinking water, and 40 per cent of the world’s food is produced by irrigation that relies largely on groundwater. In the future, aquifer development will continue to be fundamental to economic development and reliable water supplies will be needed for domestic, industrial and irrigation purposes. Numerous water quality problems exist in GW and surface water (SW) systems in Bangladesh, especially in its southwestern coastal belt, where salinity is a very alarming issue at present (Elahi and Hossain, 2011). The salinity started to increase in Khulna after the commencement of Farrakka Barrage operation of India in 1975, which significantly reduced the Ganges flow. Main objective of this study is quality assessment of ground water and surface water for irrigation and drinking purposes. Total Dissolved Solids (TDS), Electrical Conductivity (EC), Hardness, Sodium Adsorption Ratio (SAR) and Kelly’s Ratio (KR) are studied for quality assessment of the research area. The Study area lies in the south-western part of Bangladesh between latitude 22° and 23° North and longitudes 89°15' and 89°45' East (Figure: 1). The study area covers an area of about 2250 km², comprising eight Upazila, namely, Rupsa, Terokhada, Dighalia, Phultala, Dumuria, Batiaghata, Paikgacha, Dacope.

2 MATERIALS AND METHODOLOGY

For hydro-geochemistry study, thirty nine groundwater samples and six surface water samples were collected from selected locations of the study area (Figure: 2). For the chemical analysis of water samples, concentration of some major cations
(Na+, K+, Ca2+, Mg2+) and anions (HCO3-, Cl-)(Table: 1) are determined. Concentration of Fe2+ is also determined which is usually present in low concentration. The calculation principle of determining Ionic Balance is:

\[
\text{Ionic Balance} = \left(\frac{\sum \text{Cation} - \sum \text{Anion}}{\sum \text{Cation} + \sum \text{Anion}}\right) \times 100
\]

Where cations and anions are expressed in meq/l. The acceptable limit of this balance is ±10%.

For irrigation purpose, water is classified on the basis of electric conductivity (EC), sodium absorption ratio (SAR), Kelly’s ratio (KR), Chloride toxicity and Salinity Hazard.

### 2.1 Sodium absorption ratio (SAR)

The sodium adsorption ratio (SAR) is commonly used as an index for evaluating the sodium hazard associated with irrigation water supply determined on the basis of table 2. It is calculated by using the following equation where Cations are expressed in meq/l.

\[
\text{Sodium Absorption Ratio} = \frac{Na}{\sqrt[2]{(Na^+ + Mg^2+)}}
\]
2.2 Kelly’s ratio (KR)

Na⁺ measured against Ca²⁺ and Mg²⁺ is used to calculate Kelly’s ratio. The formula used to estimate Kelly’s ratio is expressed as

\[ \text{Kelly’s Ratio} = \frac{N_{Na}^{+}}{Ca^{2+} + Mg^{2+}} \]

Where cations are expressed in mg/l. SAR & KR value of ground water and surface water of the study area are shown in Table 3.

TABLE 3
SAR & KR VALUE OF GROUND WATER AND SURFACE WATER OF THE STUDY AREA

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Location</th>
<th>EC (µS/cm)</th>
<th>KR</th>
<th>TDM (mg/l)</th>
<th>Hardness (mg/l)</th>
<th>SAR (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW-1</td>
<td>Village</td>
<td>0.529489</td>
<td>0.4856</td>
<td>0.4567</td>
<td>0.3456</td>
<td>0.5678</td>
</tr>
<tr>
<td>SW-2</td>
<td>Village</td>
<td>0.345689</td>
<td>0.5678</td>
<td>0.4567</td>
<td>0.3456</td>
<td>0.5678</td>
</tr>
<tr>
<td>SW-3</td>
<td>Village</td>
<td>0.529489</td>
<td>0.4856</td>
<td>0.4567</td>
<td>0.3456</td>
<td>0.5678</td>
</tr>
<tr>
<td>SW-4</td>
<td>Village</td>
<td>0.345689</td>
<td>0.5678</td>
<td>0.4567</td>
<td>0.3456</td>
<td>0.5678</td>
</tr>
<tr>
<td>SW-5</td>
<td>Village</td>
<td>0.529489</td>
<td>0.4856</td>
<td>0.4567</td>
<td>0.3456</td>
<td>0.5678</td>
</tr>
<tr>
<td>SW-6</td>
<td>Village</td>
<td>0.345689</td>
<td>0.5678</td>
<td>0.4567</td>
<td>0.3456</td>
<td>0.5678</td>
</tr>
<tr>
<td>SW-7</td>
<td>Village</td>
<td>0.529489</td>
<td>0.4856</td>
<td>0.4567</td>
<td>0.3456</td>
<td>0.5678</td>
</tr>
<tr>
<td>SW-8</td>
<td>Village</td>
<td>0.345689</td>
<td>0.5678</td>
<td>0.4567</td>
<td>0.3456</td>
<td>0.5678</td>
</tr>
</tbody>
</table>

2.3 Chloride Toxicity

Chloride toxicity of groundwater is determined on the basis of table 4.

TABLE 4

<table>
<thead>
<tr>
<th>Term</th>
<th>Chloride (meq/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No toxicity</td>
<td>&lt; 4</td>
</tr>
<tr>
<td>Slightly toxic</td>
<td>4-10</td>
</tr>
<tr>
<td>Severe toxic</td>
<td>&gt; 10</td>
</tr>
</tbody>
</table>

2.4 Salinity Hazard

Based on the Electrical Conductivity (EC), water is classified by the table 5.

TABLE 5
WATER CLASSIFICATIONS FOR SALINITY HAZARD

<table>
<thead>
<tr>
<th>Term</th>
<th>EC (µS/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unrestricted</td>
<td>&lt; 700</td>
</tr>
<tr>
<td>Restricted</td>
<td>700-3000</td>
</tr>
<tr>
<td>Not suitable</td>
<td>&gt; 3000</td>
</tr>
</tbody>
</table>

2.5 Hardness

Hardness (HT) is customarily expressed as the equivalent of calcium carbonate (Todd, 1980). Thus:

HT = [Ca²⁺ (mg/l) × Molecular Weight of CaCO₃ / Atomic Weight Ca] + [Mg²⁺ (mg/l) × Molecular Weight of CaCO₃ / Atomic Weight Mg]

Where HT, Ca²⁺ and Mg²⁺ measured in milligram per litter and the ratios are in equivalent weights. Thus the above equation reduced to

HT = 2.5 Ca²⁺ + 4.1 Mg²⁺

Hardness of water is determined on the basis of table 6 shown below:
TABLE 6
QUALITY CLASSIFICATION OF WATER FOR DRINKING (SAWYER AND CARTY, 1967)

<table>
<thead>
<tr>
<th>Hardness (mg/l) as CaCO₃</th>
<th>Water Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-75</td>
<td>Soft</td>
</tr>
<tr>
<td>75-150</td>
<td>Moderately Hard</td>
</tr>
<tr>
<td>150-300</td>
<td>Hard</td>
</tr>
<tr>
<td>&gt;300</td>
<td>Very Hard</td>
</tr>
</tbody>
</table>

For drinking water quality assessment, Drinking water standard of World Health Organization (WHO_1983) and Government Republic of Bangladesh (DOE_1997) were used shown in table 7.

TABLE 7
CORRELATION CHART FOR DRINKING WATER.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Unit</th>
<th>WHO Std. 1983</th>
<th>DOE Std. 1997</th>
<th>B’desh Std. 1997</th>
<th>Obtained results for DW</th>
<th>Number of samples according to DW limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td>mg/l</td>
<td>300</td>
<td>75</td>
<td>75</td>
<td>1.50</td>
<td>1137</td>
</tr>
<tr>
<td>Magnesium</td>
<td>mg/l</td>
<td>50</td>
<td>30-35</td>
<td>30-35</td>
<td>1.33</td>
<td>324</td>
</tr>
<tr>
<td>Sodium</td>
<td>mg/l</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>12.81</td>
<td>1503</td>
</tr>
<tr>
<td>Potassium</td>
<td>mg/l</td>
<td>300</td>
<td>30-35</td>
<td>30-35</td>
<td>0.65</td>
<td>43</td>
</tr>
<tr>
<td>Iron</td>
<td>mg/l</td>
<td>0.2</td>
<td>0.09-1.9</td>
<td>0.9-1.9</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>Chloride</td>
<td>mg/l</td>
<td>250</td>
<td>150-400</td>
<td>150-400</td>
<td>88E</td>
<td>3289</td>
</tr>
<tr>
<td>Total Hardness</td>
<td>mg/l</td>
<td>300</td>
<td>200-400</td>
<td>200-400</td>
<td>9.2</td>
<td>4083</td>
</tr>
<tr>
<td>TDS</td>
<td>mg/l</td>
<td>1500</td>
<td>1000</td>
<td>1000</td>
<td>154.8</td>
<td>6732</td>
</tr>
</tbody>
</table>

3 RESULTS AND DISCUSSION

3.1 Electrical Conductivity (EC)

The Electrical Conductivity (EC) value of groundwater of the study area ranges from 0.56 mS/cm to 10.2 mS/cm. Maximum Electrical Conductivity (EC) was recorded at Atlia-1 at Terokhada (Sample ID: DTW-12) and minimum at Sajira at Dumuria (Sample ID: DTW-37) (Figure: 3).

3.2 Total Dissolved Solid (TDS)

TDS in groundwater at different locations of the study area ranges from 369.6 mg/l to 6732 mg/l where the maximum TDS value was found in Atlia, Terokhada (Sample ID: DTW-12) and the minimum in Sajira, Dumuria (Sample ID: DTW-37) (Figure: 4). The range of surface water TDS is from 184.8 mg/l to 3267 mg/l where the maximum TDS value was observed at Kamarkhula (Sample ID: SW-45) and the minimum at Kuriya (Sample ID: SW-43).

3.3 Sodium (Na+)

Maximum Na+ ion concentration of 1505.33 mg/l was observed in Nasirpur, Paikgacha (Sample ID: DTW-32) and minimum of 14.868 mg/l in Betaga, Dumuria (Sample ID: STW-31). The Na+ ion concentration ranges in surface water from 122 mg/l to 495.63 mg/l where the highest Na+ ion concentration was found in Romardanga, (Sample ID: SW-42) and minimum in Shaheberabad, Dacope (Sample ID: SW-44) (Figure: 5).

3.4 Potassium (K+)

The K+ ion concentration of the study area ranges from 0.652 mg/l to 45.825 mg/l in groundwater. Maximum K+ ion con-
concentration was found in Atlia, at TerokhadaUpazila (Sample ID: DTW-12) and the minimum in DighaliaUpazila (Sample ID: STW-2). The maximum K⁺ ion concentration of surface water is 11.682 mg/l in Romardanga, at Paikgacha (Sample ID: SW-42) and 1.776 mg/l is the lower limit of K⁺ ion concentration in Saheberabad, at Dacope (Sample ID: SW-44) (Figure: 6).

Fig. 6. Bar Diagram representing K⁺ concentration of sampled groundwater.

3.5Calcium (Ca²⁺)

The Ca²⁺ ion concentration of the study area ranges from 1.5 mg/l to 1137.44 mg/l in groundwater. Maximum Ca²⁺ ion concentration was found in Romardanga, Paikgacha (Sample ID: STW-35) and the minimum in Hatbati, Batiagata (Sample ID: DTW-27). The maximum Ca²⁺ ion concentration of surface water is 207.16 mg/l in Romardanga, Paikgacha (Sample ID: SW-42) and 12.48 mg/l is minimum in Kamarkhula, Dacope (Sample ID: SW-45) (Figure: 7).

Fig. 7. Diagram representing Ca²⁺ ion concentration of groundwater samples.

3.6Magnesium (Mg²⁺)

The Mg²⁺ ion concentration of the study area ranges from 1.33 mg/l to 324.44 mg/l in groundwater. Maximum Mg²⁺ ion concentration was found in Barasat, Terokhada (Sample ID: DTW-14) and the minimum in Hatbati, Batiaghata (Sample ID: DTW-27). The Mg²⁺ ion concentration of surface water ranges from 8.19 mg/l to 33.59 mg/l where the maximum concentration was found in Kamarkhula (Sample ID: SW-45) and in Saheberabad (Sample ID: SW-44) (Figure: 8).

Fig. 8. Bar Diagram representing Magnesium concentration of water samples.

3.7Bicarbonate (HCO₃⁻)

HCO₃⁻ ion concentration in groundwater range from 213.5 mg/l to 892.125 mg/l. The maximum HCO₃⁻ ion concentration 892.125 mg/l was observed in Baroikhali, in Dacope (Sample ID: STW-24) and the minimum of 213.5 mg/l in Romardanga, in Paikgacha (Sample ID: STW-35). In surface water HCO₃⁻ ion concentration ranges from 122 to 495.625 mg/l (Figure: 9).

Fig. 9. Bar Diagram representing HCO₃⁻ concentration of sampled groundwater

3.8Chloride (Cl⁻)

The Cl⁻ ion concentration of the study area ranges from 8.875 mg/l to 329.375 mg/l. The highest ion concentration of 329.375 mg/l was observed in Nasirpur, at PaikgachaUpazila (Sample ID: DTW-32) and the lowest of 8.875 mg/l in Jamira Bazar, at PhultalaUpazila (Sample ID: DTW-10) (Figure: 10).
3.9 Iron (Fe²⁺)

The Fe²⁺ ion concentration of the study area ranges from 0.0 to 5.574 mg/l in groundwater. Maximum concentration was found in Paikgacha DPHE Office, Paikgacha (Sample ID: STW-34) and the minimum in Barakpur-I, Dighalia (Sample ID: DTW-3). The maximum Fe²⁺ ion concentration range of surface water is 0.481 mg/l in Kuriya (Sample ID: SW-43) and 0.025 mg/l is the lower limit in Sarheberabad. Surface water (Sample ID: SW-44) (Figure 11).

3.10 Hardness

The presence of Hardness results from divalent metallic cations, of which calcium and magnesium are the most abundant in groundwater. Total hardness in groundwater at different locations of the study area ranges from 9.203 mg/l to 4088.032 mg/l (Figure: 12). Maximum samples are very hard type and the highest was found at Romardanga, Paikgacha (Sample ID: STW-35) and the minimum at Hatbati, Batiagata (Sample ID: DTW-27). Only one groundwater sample is soft at Hatbati, Batiagata (Sample ID: DTW-27). However for surface water total hardness varies from 168.921 mg/l to 719.702 mg/l where the maximum value was found at Romardanga (Sample ID: SW-42) and the minimum at Kamarkhula (Sample ID: SW-45).

3.11 Sodium Adsorption Ratio

For typical irrigation waters, the quality of irrigation water depends primarily on the presence of dissolved salts and their concentrations. Sodium Absorption Ratio (SAR) is one of the most important quality components, which influence the water quality and its suitability for irrigation. Average Sodium Absorption Ratio (SAR) ranges from 0.28 to 21.90 in groundwater and from 0.39 to 11.80 in surface water.

3.12 Kelley’s Ratio (KR)

A Kelley’s Ratio (KR) of more than one, indicates an excess level of sodium in waters. Hence, waters with a Kelley’s Ratio less than one are suitable for irrigation, while those with a ratio more than one are unsuitable. KR ranges from 0.12320 to 2.8787 in surface water and 0.17421 to 53.480913 in groundwater.

3.13 Chloride Toxicity

Chloride toxicity of groundwater is showed in the figure: 13 according to Ayers and Westcot (1989). From the figure it is observed that Cl⁻ concentration exceed the toxicity level in 24 samples. Five samples are slightly toxic. Others are not toxic.
Salinity Hazard

According to the FAO guidelines (Ayers and Wescott, 1989) for irrigation water quality, water with less than 700 μS/cm that is suitable for unrestricted use. The salinity hazard is presented in figure: 17 which show that, 19 samples exceed the restricted use. Rest are suitable for use in irrigation.

Hydrochemical characteristics of the study area are represented in Piper Trilinear Diagram and Box and Whisker diagram. The Piper Trilinear Diagram is constructed by plotting major ions in two triangles using HYDROCHEM, ascations and anions percentage in mg/l. Total cations and anions are each considered as 100% (Figure: 15). Maximum water samples are mixed type of Ca-HCO$_3^-$ and Na-HCO$_3^-$. Some shallow and surface water are Ca-HCO$_3^-$ type and rest of deep water samples are Na-HCO$_3^-$ type.

In Box and Whisker diagram, vertical axis represents the concentration of Cations and Anions (Figure: 16) in milligram per liter. Box and Whisker Diagram for the studied groundwater samples have been constructed by using AQUACHEM Software. It shows that Cl$^-$, Na$^+$ and Ca$^{2+}$ have the higher concentration in water sample.
4 CONCLUSION

According to the chemical characteristics, comparative charts, and hydro-chemical facies analyses it is concluded that the physical and chemical parameters of Deep water, Shallow water and surface water are unlike to each other. The value of Electrical conductivity, Total dissolved solid, and hardness of the water samples proved that, maximum water samples were not suitable for drinking purposes. The concentration value of major elements, trace element in the water samples indicates not suitable for drinking purposes. The concentration value of Ca2+ have the higher concentration. Because of the minimum Kelly’s ratio values for the GW and SW of the study area are less than 1 indicate good quality for irrigation. The majority of the groundwater samples are mixed type.Hardness of the all groundwater sample ranges from 9.203 mg/l to 4088 mg/l in groundwater and 68.92 mg/l to 719.709 mg/l in surface water which indicate maximum groundwater is hard type and the surface water is less hard than groundwater. According to Bangladesh, WHO, DOE drinking water standards some ground water and surface water of the study area is not suitable for human consumption and mostly be used for irrigation purpose only.

REFERENCES