IONIC CONSTITUENT OF GROUND WATER OF BALIADANGI UPAZILA FOR IRRIGATION, DRINKING AND INDUSTRIAL USAGE

A THESIS

BY

MD. SAIDUL ISLAM NAHID

Student No. 1305049
Session: 2013-2014
Thesis Semester: July-December, 2014

Submitted to the Department of Agricultural Chemistry
Hajee Mohammad Danesh Science and Technology University, Dinajpur in
partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE (M.S)

IN

AGRICULTURAL CHEMISTRY

DEPARTMENT OF AGRICULTURAL CHEMISTRY
HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY
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December 2014

DEDICATED

TO MY

BELOVED PARENTS

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December, 2014 The Author

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ABSTRACT

In this study, ground water Samples were collected and studied from Baliadangi Upazilla, Thakurgaon, Bangladesh in dry seasons of the year 2014 and analyzed their quality and suitability for agricultural, industrial and drinking purposes. To study the various physiochemical and microbiological parameters, water samples were collected from 15 deep tube wells, 18 shallow tube wells, and 17 hand tube wells. Analyses were included as pH, EC, TDS (Total Dissolved Solids), cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Zn^{2+}, Cu^{2+}, Mn^{2+} and Fe^{3+}), anions (HCO_3^-, SO_4^{2-}, PO_4^{3-} and Cl^-) and also computed several variables such as hardness, SAR (sodium adsorption ratio), SSP (soluble sodium percentage), RSC (residual sodium carbonate), permeability index, permeability salinity, Gibb’s ratio (Anion & Cation) and Kelly’s ratio to evaluate the suitability of groundwater supply for specific use. Some correlations and compositional relations were also evaluated. Overall we found that the groundwater samples were acidic in nature (pH varied from 5.4 to 6.9) and could be suitable for drinking, agricultural and industrial uses. According to TDS and SAR values, all samples were classed as ‘freshwater’ and ‘excellent’ categories. The soluble sodium percentage (SSP) of all the samples was under ‘excellent’ and ‘good’ classes. Regarding hardness maximum samples were within ‘soft’ class, some were ‘moderately hard’ and only three samples (sample no. 18, 27 and 45) were ‘hard’. All samples were ‘suitable’ according to RSC. Based on the contents Zn^{2+}, Mn^{2+}, Fe^{3+}, SO_4^{2-}, NO_3^- and Cl^-, groundwater samples of the study area were within the ‘safe’ limit for drinking. In comparison with the national and international standards, the water sources of the study area (Baliadangi, Thakurgaon) were within the safe limit and recommended for drinking, agricultural, industrial and livestock use.

CHAPTER I

INTRODUCTION

Groundwater is an important source of freshwater for agriculture, drinking and domestic uses in many regions of the world including Bangladesh. Demand of groundwater has been increasing day by day for irrigation by bringing more area under cultivation. As a drinking water, the bottled water market currently has an average annual growth rate of 7.4% between 2002 and 2007, which is parallel to the growth of this industry all over the world. Availability of groundwater for irrigation has contributed to manifold increases in crop productivity in Bangladesh. Increasing population, food insecurity, growing economics and poor water management are putting unprecedented pressure on the world’s freshwater resources (UNCSD, 2012).

Approximately 97% of the earth’s useable fresh water is stored as groundwater (Delleur, 1999). Also, groundwater constitutes an important component of the water cycle and it is partly used to maintain soil moisture, stream flow and wetlands, as well as being the sources of drinking water, agricultural and industrial supplies in many parts of the world. Qiu (2010) estimated that groundwater constitutes approximately 40 % and 70 % of the total global water resources being used for irrigation and domestic purpose, respectively. Therefore, the requirement for the assessment of suitability of groundwater resources for drinking and irrigation purposes is becoming increasingly important and this is demonstrated by the relatively large number of recent studies in this field (Peiyue et al., 2011; Tadesse et al., 2009). Generally, the suitability of groundwater for agriculture and domestic purposes largely depends on the site specific quality of the water, with possible temporal variations caused by climatic conditions, as well as the residence time of water within the aquifer materials and anthropogenic activities.

Quality of water is very important and essential for irrigation, industrial purposes and drinking. Groundwater quality reflects inputs from the atmosphere, soil and water rock reactions as well as pollutant sources such as mining, land clearance, agriculture, acid precipitation, and domestic and industrial wastes. The quality of groundwater is constantly changing in response to daily, seasonal and climatic factors. Continuous monitoring of water quality parameters is highly crucial because the changes in the quality of water have far reaching consequences in terms of its effects on man and biota. Irrigated agriculture is dependent on adequate water supply of usable quality. Water quality concerns have often been neglected because good quality water supplies have been plentiful and readily available.

Therefore, the objectives of this study are:

- To know the baseline cation and anion concentrations of the groundwater of Baliadangi Upazilla
- To measure the influential factors that affects on water quality
- To evaluate the suitability of these water sources for irrigation, drinking and industrial uses
- To classify the waters according to their suitability for irrigation, drinking and industrial uses
- To compare the results with the international and Bangladeshi standards

CHAPTER II

REVIEW OF LITERATURE

Water contains variable quantities of organic and inorganic substances. It is very necessary to determine the quality of water. These qualities have effects on soil properties due to long-term irrigation, and its suitability for drinking and industrial usage. Some related research works significant to the subject matter have been conducted in Bangladesh and abroad. However some of research works and reports are reviewed from home and abroad on water quality for irrigation, drinking and industrial purposes. The water quality is based on some basic parameters under the following order.

1. pH

The acidity or basicity of irrigation water is expressed as pH (< 7.0 acidic; > 7.0 basic). The normal pH range for irrigation water is from 6.5 to 8.4. Abnormally low pH's are not common in Colorado, but may cause accelerated irrigation system corrosion where they occur. High pH's above 8.5 are often caused by high bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) concentrations, known as alkalinity. High carbonates cause calcium and magnesium ions to form insoluble minerals leaving sodium as the dominant ion in solution. As described in the sodium hazard section, this alkaline water could intensify the impact of high SAR water on sodic soil conditions. Excessive bicarbonate concentrates can also be problematic for drip or micro-spray irrigation systems when calcite or scale builds up causes reduced flow rates through orifices or emitters. In these situations, correction by injecting sulfuric or other acidic materials into the system may be required.

The pH of ground water Madhupur under Tangail district was within the range from 8.2 to 8.5 (Zaman and Majid, 1995). Rahman and Zaman (1995) conducted a study at Shahzadpur thana in Sirajgonj district and reported that the pH ranged from 8.2 to 8.7. The pH ranges of surface and ground water of Meherpur from 7.8 to 8.1 (Quddus and Zaman, 1996). The pH of Pangsha of Rajbari district was within the range from 8.0 to 8.3 (Mohiuddin, 1995). The range of pH values of Buriganga river water was varied from 6.95 to 8.30 (Zaman et al., 2002). The pH values of Nilphamary District were varied from 6.7 to 7.8 (Islam et al., 2009). Another report of Hakim et al., (2003), the pH of surface water in Khagrachari was 6.75 to 7.27. Shahidullah (1995) worked on water quality of Phulpur thana in Mymensing and observed that the pH varied within range of 8.1 to 8.3. The pH values of northern Bangladesh were 6.24 to 8.10 (Jahidul et al., 2010). The pH range of some selected area of Dhaka city for groundwater was varied from 7.3 to 8.0 (Islam et al., 2005). The range of pH values of groundwater at Chirirbandar in Dinajpur district was 7.1 to 7.7 (Hasanuzzaman et al., 2007).

2.EC and salinity

The electrical conductivity (EC) of water, is the principal parameter used now-a-days to measure a solution's salt content. The irrigation water salinity is mainly measured by the EC and it reflects the salt concentration (Agarwal et al,. 1982). Joshi et. al, (2009) concludes that the water available for plants in the soil solution decreases proportionately as the EC increases. EC can be measured quickly and easily, either in the laboratory or in the field. The readings are temperature dependent; therefore, measurements typically are corrected to an equivalent value at 25 degrees Celsius. Water quality was classified into four salinity classes on the basis of EC by Richards (1968). These classes were ‘low salinity water’ (C1) containing EC less than 250 μScm^{-1}; ‘medium salinity water’ (C2) having EC from 250 to 750 μScm^{-1}; ‘high salinity water’ (C3) having EC from 750 to 2250 μScm^{-1} and ‘very high salinity water’ (C4) containing EC in the range of 2250 to 5000 μScm^{-1}. Water that containing below 250 μScm^{-1} EC value is considered as quite safe water, second class uses for moderate leaching, ‘high salinity’ and ‘very high salinity’ unsuitable for irrigation. With reasonable irrigation practices, there should be no salinity problems with irrigation water with EC of less than 750 μScm^{-1}. Increasing problems can be expected between EC 750 and 2250 μScm^{-1}. An EC may be greater than 2250 μScm^{-1} will cause severe problems, except for a few salt-tolerant crops. Nearly all irrigation waters that have been used successfully for a considerable time have EC less than 2250 μScm^{-1}.

Wilcox (1955) classified water quality into five groups on the basis of EC value. These classes are ‘excellent’ containing less than 250 μScm^{-1} , ‘good’ having EC from 250-750 μScm^{-1}, ‘permissible’ containing EC range from 750 to 2000μScm^{-1}, ‘doubtful’ having EC from 2000 to 3000 μScm^{-1}, ‘unsuitable’ when EC is greater than 3000 μScm^{-1}. The water EC of Madhupur sadar Thana ranged from 340 to 980μScm^{-1} (Zaman and Majid, 1994). After one year the range of EC of the same place was 220 to 570μScm^{-1} (Zaman and Majid, 1995). The EC of water quality is varied from 0.4 to 7.4$dScm^{-1}$ and 31.1 to 44.8$dScm^{-1}$ at the respected depth of 13-38 m and 38-210 m. This concept was claimed by Gupta (1984). In sort, the concept of quality of groundwater is deteriorated with the increasing depth. Rahman and Zaman (1995) found EC value of some selected river and ground water for irrigation was 500 to 834μScm^{-1} at Shahzadpur Thana in Sirajgonj district. Islam et al. (2009) worked with groundwater in Nilphamari district and found EC values of samples were 259 to

572µScm^{-1}. The EC values were ranged from 29 to 200µScm^{-1} at Khagrachari district (Hakim et al., 2003). The mean EC value of Buriganga river was 222.80 µScm^{-1} for monsoon and 663.10 µScm^{-1} (Zaman et al., 2002). A significant variation in the EC values of groundwater was detected ranging from 198 to 552µScm^{-1} at northern of Bangladesh (Islam et al., 2010). The EC values of some selected area from Dhaka city were within the range of 428 to 580µScm^{-1} (Islam et al., 2005). The EC values were varied from 121 to 300 µScm^{-1} of groundwater at Dinajpur district (Islam et al., 2000). Hasanuzzaman et al., (2007) worked on groundwater of Chirirbandar in Dinajpur district and observed the EC values were ranged from 452 to 749µScm^{-1}.

The groundwater which contains high saline is mainly responsible for the increasing salt contain of irrigation water, particularly where drainage is poor (Soderstrom and soderstrom 1989). In Sadar and Trishal thana under Mymensingh district few deep tube wells were ‘moderate salinity’ and some were ‘low salinity’ group and maximum were suitable for irrigation for all crops (Khan and Basak, 1986). Sometimes highly saline water may be suitable for irrigation where well drainage, light texture, fertile soil are available. On the other hand, low saline water may be harmful for some crop if soil texture is heavy (Michael, 1978).

3. Total dissolved solids (TDS)

Total Dissolved Solids (TDS) is a measure of the combined content of all inorganic and organic substances contained in a liquid in: molecular, ionized or micro-granular (colloidal sol) suspended form. Generally, the operational definition is that the solids must be small enough to survive filtration through a sieve the size of two micrometer. Total dissolved solids are normally discussed only for freshwater systems, as salinity comprises some of the ions constituting the definition of TDS. The principal application of TDS is in the study of water quality for streams, rivers and lakes, although TDS is not generally considered a primary pollutant (e.g. it is not deemed to be associated with health effects) it is used as an indication of aesthetic characteristics of drinking water and as an aggregate indicator of the presence of a broad array of chemical contaminants.

Carroll (1962) and Freeze and Cherry (1979) revealed that the solid residue almost invariably consist of inorganic constituents and very small amount of organic matter. They classified ground water into four categories on the basis of TDS. These were 'fresh water' (TDS = 0-1000 mg/L); 'brackish water' (TDS = 1000-10000 mg/L); 'saline water' (TDS = 10000-100000 mg/L) and 'brine water' (TDS > 100000 mg/L). On the other hand, Davis and De Wiest (1966) classified ground water into three groups on the basis of TDS. These were, 'major', 'minor' and 'trace'. The major elements are Na, Mg, Ca, Cl, HCO_3 and SO_4; minor elements are B, CO_3, No_3, K, Fe and trace elements are PO_4, Cu, Mn, and Mo. Generally concentration the total major elements are more than 90% of the TDS and trace elements are less than 1 ppm.

TDS is important to be considered in the calculation of irrigation water quality, because many of the toxic solid materials may be imbedded in the water, which may cause harm to the plants (Matthess, 1982). In the absence of non-ionic dissolved constituents, TDS and EC are indicative of saline water (Michael, 1992). In terms of 'Degree of restrictions on use', TDS values <450, 450-2000 and >2000 mg/l represent the irrigation water as 'none', 'slight to moderate' and 'severe', respectively (UCCC, 1974). The TDS value of river and groundwater at Shahzadpur in Sirajgang district the range was between 510 and 560 mg/L (Rahman, 1993). On another report the TDS value of river and groundwater in Shahzadpur were within the range of 348 to 560 mg/L (Rahman and Zaman, 1995). Zaman and Majid (1995) reported that the TDS value of Madhupur groundwater varied from 100 to 600 mg/L. The estimated amounts of TDS ranged from 255 to 422 mg/L (Hasanuzzaman et al., 2007). The TDS ranged from 107 to 1044 mg/L of northern Bangladesh (Jahidul et al., 2010). Islam et al. (2000) worked on groundwater of Dinajpur district and found the TDS was ranged from 180 to 462 mg/L. The amount of TDS in the Dhaka city was reported to vary from 180 to 462 mg/L (Islam et al., 2005). The TDS values of water samples of Khagrahcari district were varied from 20 to 140 mg/L (Islam et al., 2003). The TDS values of northern part of Bangladesh were ranged from 260 to 817 mg/L (Islam et al., 2010). The amount of TDS in monsoon and winter seasons ranged from 120 to 165 mg/L of Buriganga River (Zaman et al., 2002). The value of TDS in the Khagrachari area was reported to vary from 20 to 120 mg/L (Hakim et al., 2003). The TDS amount of groundwater of Nilphamari district was ranged from 355 to 797 mg/L (Islam et al., 2009).

Primary sources for TDS in receiving waters are agricultural and residential runoff, leaching of soil contamination and point source water pollution discharge from industrial or sewage treatment plants. The most common chemical constituents are calcium, phosphates, nitrates, sodium, potassium and chloride, which are found in nutrient runoff, general storm water runoff and runoff from snowy climates where road de-icing salts are applied. The chemicals may be cations, anions, molecules or agglomerations on the order of one thousand or fewer molecules, so long as a soluble micro-granule is formed. More exotic and harmful elements of TDS are pesticides arising from surface runoff. Certain naturally occurring total dissolved solids arise from the weathering and dissolution of rocks and soils. The United States has established a secondary water quality standard of 500 mg/L to provide for palatability of drinking water. The recommended concentration of TDS is 500 mg/L (WHO, 2004).

4. Calcium, magnesium, sodium and potassium

According to the Davis and De Weist (1966) calcium, magnesium and sodium are considered as major elements, while Potassium as minor elements. The Bangladesh standard for calcium in drinking water is 75 mg/L. There is no WHO guideline value, and calcium does not have any particular health impacts at levels typically found in natural waters. Calcium is a major contributor to hardness. The Bangladesh standard for potassium is 12 mg/L and for magnesium is 30-35 mg/L. There are no WHO guideline values for both elements. Magnesium contributes to hardness. The Bangladesh standard for sodium is 200 mg/L. High Na+ content can cause displacement of exchangeable Ca2+ and Mg2+ from the clay mineral of the soil (Matthess, 1982). A higher concentration of Na^+ in drinking water may be a risk for a person suffering from cardiac, renal, and circulatory diseases (WHO, 2004). A sodium-restricted diet is recommended to patients suffering from hypertension or congenial heart diseases and also from kidney problems. For such people, extra intake of Na^+ through drinking water may prove critical.

Calcium, Magnesium, potassium and sodium values of surface and groundwater of Shahzadpur thana ranged from 2.0 to 4.40, 1.09 to 2.19, 0.10 to 0.42 and 0.91 to 1.39 me/L, respectively (Rahman and Zaman 1995). The values of Ca, Mg, Na and k in groundwater and surface water of Meherpur Thana were found within the range of 2.06 to 2.80, 1.01 to 1.60, 0.28 to 0.68 and 0.12 to 0.32me/L respectively (Quddus and Zaman, 1996). Zaman and Mohiuddin (1995) stated that Ca, Mg, Na and K content present in groundwater of Pangsha thana under Rajbari district varied from 1.20 to 2.90, 1.00 to 1.30, 0.43 to 3.05 and 0.05 to 0.18 me/L, respectively. Endale-Bekele et al. (1992) appraised the quality of the Awash River for irrigation and showed that Na toxicity for sensitive crops exit the river’s course that lies between Melka Werer and Metchka. Some irrigation waters contain enough dissolved K to obviate the need for potassium fertilization (James et al., 1982). Ranges of calcium, magnesium, sodium and potassium values of some parts of Nilphamari district were respectively 0.86 to 2.55, 1.26 to 3.65, 0.45 to 2.15 and 0.25 to 1.45 (Islam et al., 2009). The ionic concentrations of Ca, Mg, K and Na were found to vary from 0.20-7.20, 0.70-6.60, 2.50-10.00 and 4.00-14.25 me/L at Khagrachari district (Hakim et al., 2003). Mean values of Ca, Mg, K and Na ions of Buringanga river for winter season were 1.97, 2.84, 0.61 and 1.12 me/L and for monsoon season were 0.75, 1.03, 0.17 and 0.23 me/L (Zaman et al. 2002).

5. Bicarbonate, chloride, phosphate and sulfate

Hill (1940) and Piper (1994) conducted a study and showed that the concentration of bicarbonate were higher than other ions. High carbonates cause calcium and magnesium ions to form insoluble minerals leaving sodium as the dominant ion in solution. Davis and De Wiest (1996) analyzed some water samples and found that HCO_3^- concentrations were higher and $SO_4^=$ concentrations were lower. The contents of $CO_3^=$, HCO_3^- and Cl^- varied from 0.05 to 0.42, 0.63 to 5.20 and 0.12 to 7.65me/L respectively in some river’s water in Western United States (Richards, 1968). The concentration of $CO_3^=$, HCO_3^- and Cl^- in groundwater of Madhupur ranged from 0.80 to 2.40 and 0.10 to 0.50 me/L respectively (Zaman and Majid, 1994). Zaman and Majid (1995) reported the concentrations of HCO_3^-, Cl^- and $SO_4^=$ in groundwater of some village of Madhupur thana vary from 0.80 to 2.52, 2.20 to 0.80 and 0.12 to 2.16 me/L respectively. The respective concentrations of HCO_3^-, Cl^- and $SO_4^=$ in groundwater of Pangsha were found within the limit of 2.24 to 3.52, 0.24 to 2.25 and 0.13 to 0.27 me/L (Zaman and Mohiuddin, 1995). Quddus and Zaman (1996) stated that contents of HCO_3^-, Cl^- and $SO_4^=$ in groundwater of some villages of Meherpur sadar ranged from 2.60 to 3.10, 0.75 to 0.95 and trace to

7.20 me/L respectively. The concentrations of bicarbonate, chloride and sulfate were ranged from 0.88-1.85, 0.41-1.05 and 0.011-0.05 me/L of northern part of Bangladesh (Islam et al., 2010). Islam et al., (2003) found the values of bicarbonate and chloride at Khagrachari district that was varied from 0.10 to 0.90, 0.10 to 1.20.

Phosphorus in groundwater is mostly present in the form of PO_4^{3-}, or phosphate. NDWQS data are presented in terms of milligrams of phosphorus per liter of water. To convert to phosphate, phosphorus levels must be multiplied by 3.1. There is no WHO guideline value for phosphorus. Bangladesh has a drinking water standard of 6 mg/L for phosphate (PO_4^{3-}), which is equivalent to 1.96 mg/L, if it is assumed that phosphorus is present entirely as phosphate. This is a reasonable approximate on for groundwater, though a small fraction of dissolved phosphorus is probably present in other forms. The geochemical behavior of phosphate is similar to that of arsenic in that both have strong affinities to sorbs onto iron oxyhydroxide. Thus, they are released to water upon reductive dissolution of iron oxyhyroxide, and are removed from water by iron oxyhyroxides through co-precipitation or sorption.

High carbonates cause calcium and magnesium ions to form insoluble minerals leaving sodium as the dominant ion in solution. Excessive bicarbonate concentrates can also be problematic for drip or micro-spray irrigation systems when calcite or scale builds up causes reduced flow rates through orifices or emitters. In these situations, correction by injecting sulfuric or other acidic materials into the system may be required. Higher concentration of SO_4^{2-} in drinking water is associated with respiratory problems (Subba Rao, 1993). Excess concentration of Cl^- gives a salty taste and has a laxative effect in people not accustomed to it.

Relationship between nitrates and other physiochemical variable were studied by Kumar et al. (1992) in Andra Pradesh, India. They gave a concept of nitrate concentration. These were,

- Nitrate concentration increased with a decrease in pH.
- Nitrate concentration increased with the increase in TDS, sulfate, chloride and hardness.
- Nitrate concentration had no change with the concentration of fluorine and water depth.

6. Sodium adsorption ratio (SAR)

The index used is the Sodium Adsorption Ratio (SAR) that expresses the relative activity of sodium ions in the exchange reactions with in the soil. This ration measures the relative concentration of sodium to calcium and Magnesium. In terms of affecting soil structure and water infiltration, the most important salt type is sodium. However, sodium alone provides little information about the water quality and its affect on soil water infiltration. Irrigation water with high sodium could be usable provided the calcium and magnesium levels in the water are high. Therefore, the sodium absorption ratio (SAR) concept developed, which expresses sodium as a ratio to calcium plus magnesium.

An important chemical parameter for judging the degree of suitability of water for irrigation is sodium content or alkali hazard, which is expressed as the sodium adsorption ratio (SAR). SAR measures the potential dangers posed by excessive sodium in irrigation water (Alagbe, 2006). The sodium hazard or SAR is expressed in terms of classification of irrigation water as low (S1: <10), medium (S2: 10 to 18), high (S3: 18 to 26) and very high (S4: > 26). A high SAR value implies a hazard of sodium (alkali) replacing Ca^{++} and Mg^{++} in the soil through a cation exchange process that damages soil structure, mainly permeability, and which ultimately affects the fertility status of the soil and reduces crop yield (Gupta, 2005).

SAR values in irrigation water have a close relationship with the extent to which Na is absorbed by soils. If water used for irrigation is high in Na^+ and low in Ca^{++}, the ion exchange complex may become saturated with Na^+, which destroys soil structure because of dispersion of clay particles. As a result, the soil tends to become deflocculated and relatively impermeable. Such soils become very difficult to cultivate. The total concentrations of soluble salts in irrigation water can be classified as low (S1: <10), medium (S2:10-18), high (S3:18-26) and very high (S4: >26) (Rao, 2006). The zones (S1-S4) have the value of EC less than 250 μS/cm, 250-750μS/cm, 750-2250 μS/cm and more than 2250 μS/cm respectively. Wilcox (1948) proposed a chart for classifying irrigation water into four classes to represent alkali hazard on the basis of SAR and EC.

Rahman and Zaman (1995) found the SAR values of surface and groundwater within the range of 0.56 to 0.85 and this was categorized as ‘low sodium’ water at Shahzadpur thana in Sirajgonj district. SAR values of Meherpur thana were found within the range of 0.21 to 0.49 and were classified as S1, that means ‘low sodium’ water (Quddus and Zaman, 1996). The range of SAR value of Gazipur sadar thana was 0.50 to 0.94 (Quayum, 1995). The SAR of groundwater at Chirirbandar in Dinajpur district was ranged from 0.22 to 0.68 (Hasanuzzaman et al., 2007). Sodium adsorption ratio varied from 0.63 to 1.83 of Khagrachari district (Islam et al., 2003).

7. Soluble sodium percentage (SSP)

Soluble Sodium Percentage (SSP) is another measure of irrigation water Na^+ hazard. SSP is the ratio of Na^+ in epm (equivalents per million) in water to the total cation epm multiplied by 100. Irrigation water with an SSP greater than 60% may result in Na^+ accumulation and possibly a deterioration of soil structure, infiltration, and aeration.

Eaton (1950) classified water quality on the basis of SSP into three groups. These were, ‘unsafe’ (greater than 60), ‘good’ (up to 40) and ‘excellent’ (up to 20). Wilcox (1955) also divided water quality of the basis of this term into five classes. These were, ‘excellent’, ‘good’, ‘permissible’, ‘doubtful’ and ‘unsuitable’, which contains SSP values <20; 20-40; 40-60; 60-80 and >80 respectively. The groundwater’s SSP value of Gazipur sadar thana ranged from 18.31 to 40.95 (Quayum, 1995). In another investigation, Zaman and Mohiuddin (1995) analyzed groundwater samples from Pangsha thana under Rajbari district and found the SSP value from 14.93 to 46.04. Water of all locations of this investigation considered as the ‘Safe’ for irrigation all type of soil. A study conducted by Zaman and Majid (1995) revealed that the SSP value of groundwater samples from Madhupur thana were between 2.14 to 31.50. Maximum water samples were considered as ‘excellent’ and few were considered as ‘good’ for irrigation. Quddus and Zaman (1996) observed that the SSP values of some sample of groundwater and surface water from Meherpur sadar ranged from 8.14 to 14.17 and all samples were considered as ‘excellent’ for irrigation all type of soil.

8. Residual sodium carbonate (RSC)

The residual sodium carbonate (RSC) equals the sum of the bicarbonate and carbonate ion concentrations minus the sum of the calcium and magnesium ion concentrations, where the ions are expressed in me/L. A negative RSC indicates that sodium buildup is unlikely since sufficient calcium and magnesium are in excess of what can be precipitated as carbonates. A positive RSC indicates that sodium buildup in the soil is possible. High levels of Ca^{++} and Mg^{++} can offset the negative effects of high carbonates on water infiltration. Over time, the repeated use of irrigation water with a high RSC value can lead to soil alkalinity or create a sodic soil if the water contains an appreciable amount of Na^+ (SAR > ~4). If RSC values are high (> ~2) while SAR values are low (< ~4), it is unlikely that infiltration problems will occur, although soil pH is still likely to rise to a detrimental level. When irrigation water containing residual alkalinity is used on clay soils containing exchangeable calcium and magnesium, sodium from the residual alkalinity in the water will replace calcium and magnesium in the soil. An increase in the sodium content of a clay soil may cause structural damage. Residual Sodium Carbonate (RSC) predicts the accumulation of sodium in the soil based on the potential precipitation of calcium/magnesium carbonate. A negative RSC indicates water is unlikely to cause structural degradation. An RSC greater than 1.25 indicates a potential hazard to soil structure. Additions of a calcium source, such as gypsum, or acidification of the water prior to use may be required.

Eaton (1950) classified the irrigation water on the basis of RSC; water containing RSC <1.25, 1.25-2.50 and >2.50 me/L and categorized as ‘suitable’, ‘marginal’ and ‘unsuitable’. Rahman and Zaman (1995) analyzed 19 groundwater and surface water from Shahzadhpur thana under Sirajgonj district and all samples were free from residual sodium carbonate and were suitable for irrigation. The RSC value of 23 groundwater samples from some villages of Madhupur thana under Mymensingh, where 22 samples were free from residual sodium carbonate, that means suitable for irrigation. But one sample showed 0.38me/L value of RSC. 14 samples out of 15 samples of groundwater from Pangsha thana, Rajbari district were ‘suitable’ and rest one is ‘marginal’ for irrigation with 1.34 me/L RSC value (Zaman and Mohiuddin (1995). Quddus and Zaman conducted a study on 25 surface and groundwater samples of Meherpur sadar and all samples showed negative values of RSC, that means all were ‘suitable’ for irrigation.

9. Hardness (H_T)

Many industrial and domestic water users are concerned about the hardness of their water. Hard water requires more soap and synthetic detergents for home laundry and washing, and contributes to scaling in boilers and industrial equipment. Hardness is caused by compounds of calcium and magnesium, and by a variety of other metals. General guidelines for classification of waters are: 0 to 60 mg/L (milligrams per liter) as calcium carbonate is classified as soft; 61 to 120 mg/L as moderately hard; 121 to 180 mg/L as hard; and more than 180 mg/L as very hard. Chemically, hardness is often defined as the sum of polyvalent cation concentrations dissolved in the water. The most common polyvalent cations in fresh water are calcium (Ca^{++}) and magnesium (Mg^{++}).

Hardness is usually divided into two categories: carbonate hardness and noncarbonated hardness. Carbonate hardness is usually due to the presence of bicarbonate [$Ca(HCO_3)_2$ and $Mg(HCO_3)_2$] and carbonate ($CaCO_3$ and $MgCO_3$) salts. Noncarbonated hardness is contributed by salts such as calcium chloride ($CaCl_2$), magnesium sulfate ($MgSO_4$), and magnesium chloride ($MgCl_2$). Total hardness equals to the sum of carbonate and noncarbonated hardness. In addition to calcium (Ca^{++}) and magnesium (Mg^{++}), iron (Fe^{++}), strontium (Sr^{++}), and manganese (Mn^{++}) may also contribute to hardness (APHA et al. 1998). However, the contribution of these ions is usually negligible. Hardness is usually reported as equivalents of calcium carbonate ($CaCO_3$) and is generally classified as soft, moderately hard, hard, and very hard. It is best to report results as the actual equivalents of $CaCO_3$ since the inclusive limits for each category may differ between users of the information. Calcium and magnesium are needed to support calcification of larval skeletal structures and to support newly fertilized freshwater fish eggs (Timmons et al. 2002). Additionally, hardness has been associated with mitigation of the toxicity of some metals to gill-breathing organisms. The mitigating effects are likely due to the individual polyvalent cations (e.g., Mg^{++}, Ca^{++}) causing hardness as opposed to hardness itself (Burton Jr. and Pitt 2002). Some of the mitigating effects may be due to the formation of less available metallic hydroxides and carbonates by associated increases in alkalinity or due to competition of the polyvalent hardness ions for active sites on/in the organism (antagonistic effects).

Hardness can also affect the utility of water for industrial purposes. Hard water is often the source of scale formed in hot water heaters and industrial systems where water is heated. This scale results from the precipitation of calcium carbonate, which becomes less water soluble as the temperature increases (Snoeyink and Jenkins 1980). In these situations, water is usually softened by precipitating the $CaCO_3$ or by using ion exchange softening methods.

Groundwater classified into four groups on the basis of hardness by Sawyer and McCarty (1967). Water for hardness values from 0 to 75, 75 to 150 and 150 to 300 and above 300 mg/L as $CaCO_3$ were classified as ‘soft’, ‘moderately hard’ ‘hard’; ‘very hard’ respectively. According to this classification, Quayum (1995) classified the groundwater of Gazipur sadar thana into ‘soft’ class. 19 surface and groundwater sample of Shahzadpur thana under Sirajgonj district were analyzed by Rahman and Zaman and found the hardness values varied from 159.83 to 324.20 mg/L. That means 15 samples were ‘hard’ and 4 samples as ‘very hard’. The hardness value for 25 surface and groundwater samples from some villages of Meherpur sadar thana ranged from 166.47 to 201.38 mg/L (Quddus and Zaman, 1996). The computed variable hardness ranged from 84 to 491 mg/L for groundwater in northern Bangladesh (Jahidul et al., 2010). The range of value of hardness for groundwater of Dhaka city was 173 to 237 mg/L (Islam et al., 2005).

CHAPTER III

MATERIALS AND METHODS

Location, climate and geological setting:

The location of the study area is Baliadangi Upozilla under Thakurgaon district. This area is located at most northern region of Bangladesh. This region is an area of extremes. In summer the mean maximum temperature is well above 33.5°C whereas in winter the mean minimum is below 10°C. The summer is dry, with a scorching westerly wind, but the rainy season is very wet. Bangladesh has a tropical monsoon climate. This climate is characterized by high humidity, high temperature and heavy rainfall.

Baliadangi is located at 26.1°N and 88.28°E. It has 28477 units of house hold and total area 284.12 km^2 (109.70 sq mi). Baliadangi has 8 Unions/Wards, 78 Mauzas/Mahallas, and 78 villages. As of the 1991 Bangladesh census, Baliadangi has a population of 147163. Males constitute 51.32% of the population, and females 48.68%. Baliadangi has an average literacy rate of 23.8% (7+ years), and the national average of 32.4% literate (BBS, 2006). The soil type of this study area is poorly sorted sands, gravels with thin surface clay and medium to coarse grained. The groundwater aquifer of Bangladesh was classified into three zones by the previous UNDP study. These zones are upper aquifer, main aquifer and deep aquifer (UNDP, 1982). Our water sample collected from the main aquifer and deep aquifer. These aquifers are combined of medium and course sediments and inert-bedded with gravel. These types of sediments mainly occur into 140 m depth below the ground surface. This aquifer also may be semi-confined or leaky. It also consists of stratified, interconnected and unconfined water zones. This study area contains main water bearing zone. The depth varied from less than 5 m in the northwest region of Bangladesh.

Collection of water sample and sampling techniques

The groundwater samples were collected in March 2014 from Baliadangi Upazilla, Thakurgaon, when water levels are generally lower relative to other seasons of the year (Shamsudduha et al., 2009). Water samples were collected monthly from 15 deep tubewells, 18 shallow tubewells and 17 Hand tubewells (Figure 1). The information of different water samples collected for analysis was mentioned in Table 1. Samples were collected in two liter plastic bottles that had been cleaned with hydrochloric acid (1:1) and then rinsed with tap water followed by rinsing with distilled water. Before collecting each sample, bottles were rinsed 3 to 4 times with sample.

The collected samples were sealed immediately to avoid exposure to air. All reagents used in chemical analysis were of analytical grade. Samples were carried to the laboratory and analyzed in Department of Agricultural Chemistry, Hajee Mohammad Danesh Science and Technology University, Dinajpur. The samples were analyzed as quickly as possible on arrival at the laboratory.

Most the wells were being used for domestic water supply and were being pumped during the sampling period therefore purging mostly lasted for 5-10 minute. The samples earmarked for ion analysis were filtered on site through 0.45 µm cellulose filters with the aid of a hand operated vacuum pump. The bottles and caps meant for collecting major ions were rinsed three times with the filtered water after which they were filled to the brim and caped. Samples for cations analysis were preserved with few drops of Mark ultra-pure nitric acid to a pH <2. All the samples were then kept in an ice chest containing ice blocks and transported to the laboratory.

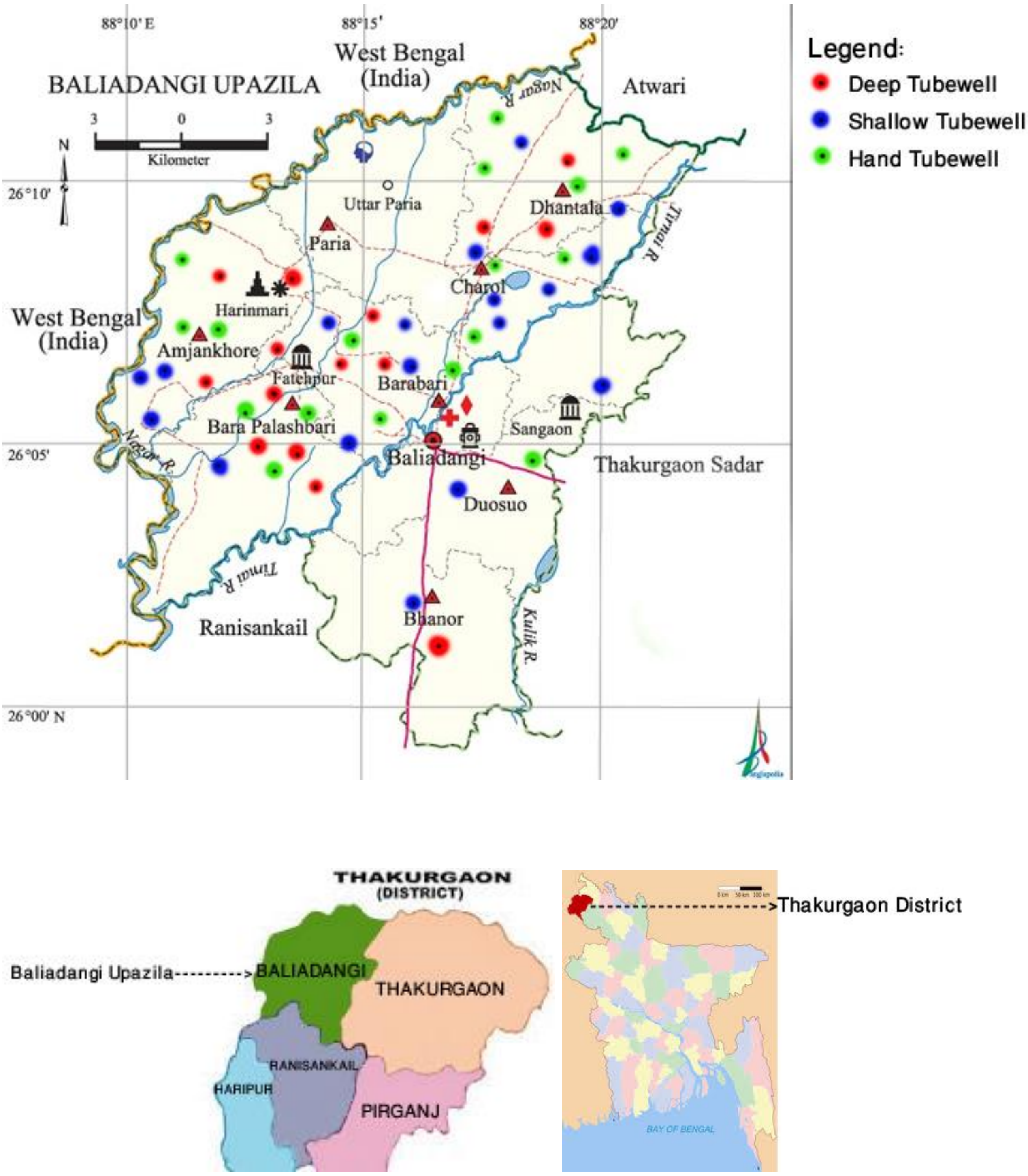


Figure 1: Map of sampling sites of the Baliadangi Upazilla (15 deep tube wells, 18 shallow tube wells and 17 Hand tube wells) under the district of Thakurgaon along with the map of Bangladesh.

Table-1: Information regarding different water sources

Sample No.	Sampling Site		Well Type	Depth of Sink (ft)	Date of Collection	Time of Collection
	Location	Union				
1	Mahat Bosti	Amjankhor	HTW	45	8/3/2014	02:00pm
2	Hauda	Barabari	STW	70	11/3/2014	09:30am
3	Tarauthi	Barabari	DTW	300	11/3/2014	09:45am
4	Sindibindi	Dhantala	STW	70	9/3/2014	01:15pm
5	Taka Hara	Dhantala	DTW	350	9/3/2014	01:10pm
6	Dhukur Jhari	Dhantala	STW	75	9/3/2014	01:20pm
7	Dolua	Dhantala	DTW	350	9/3/2014	12:55pm
8	Patila Bhasa	Charol	STW	60	9/3/2014	12:00pm
9	Mahat Para	Charol	DTW	300	9/3/2014	12:30pm
10	Sahabajpur	Charol	HTW	60	9/3/2014	02:30pm
11	Charol	Charol	STW	70	9/3/2014	12:40pm
12	Dangi Bajar	Barabari	HTW	45	11/3/2014	10:00am
13	Adhar	Barabari	HTW	50	11/3/2014	10:15am
14	Dogachi	Charol	STW	75	9/3/2014	04:00pm
15	Chan Pukur	Dhantala	HTW	50	9/3/2014	03:40pm
16	Silpati	Dhantala	HTW	45	9/3/2014	01:25pm
17	Madhupur	Charol	STW	80	9/3/2014	03:20pm
18	Votepara	Charol	HTW	65	9/3/2014	03:55pm
19	Das Para	Barabari	DTW	350	11/3/2014	10:30am
20	Barabari	Barabari	STW	80	11/3/2014	11:00am
21	Singia	Dhantala	STW	70	9/3/2014	03:05pm
22	Lahiri	Charol	STW	75	9/3/2014	04:15pm

Table 1. (Contd.)

Sample No.	Sampling Site		Well Type	Depth of Sink (ft)	Date of Collection	Time of Collection
	Location	Union				
23	kashibari	Amjankhor	HTW	50	8/3/2014	02:30pm
24	Rotnoi	Amjankhor	STW	80	8/3/2014	02:45pm
25	Udoipur	Amjankhor	DTW	300	8/3/2014	03:00pm
26	Hauda School	Barabari	HTW	50	11/3/2014	11:15am
27	Pardeshi Para	Charol	HTW	60	9/3/2014	04:10pm
28	Horinmari	Amjankhor	DTW	300	8/3/2014	03:45pm
29	Dhantala	Dhantala	HTW	60	9/3/2014	04:00pm
30	Koikuri	Bara PolashBari	STW	90	8/3/2014	09:00am
31	BashBari	Amjankhor	STW	75	8/3/2014	03:15pm
32	Ziakhor	Dousou	DTW	350	11/3/2014	03:30pm
33	Keriati	Barabari	STW	70	11/3/2014	11:30am
34	Mohishmari	Dousou	STW	75	11/3/2014	02:30pm
35	Nangapur	Dhantala	HTW	50	9/3/2014	12:55pm
36	Taranjubari	Amjankhor	DTW	300	8/3/2014	04:00pm
37	Balia Hat	Bara PolashBari	DTW	350	8/3/2014	10:00am
38	Ziabari	Bara PolashBari	DTW	400	8/3/2014	09:30pm
39	Moral Hat	Bara PolashBari	DTW	300	8/3/2014	10:00am
40	Chotoria	Bara PolashBari	HTW	45	8/3/2014	10:15am
41	Ziabari	Bara PolashBari	HTW	70	8/3/2014	09:45am
42	kalomegh Hat	Dousou	HTW	60	11/3/2014	03:00pm
43	Holdibari	Dousou	STW	75	11/3/2014	02:00pm
44	Polashbari	Dousou	STW	80	11/3/2014	09:00am
45	Belsara	Bara PolashBari	HTW	45	8/3/2014	10:30am

Table 1. (Contd.)

Sample No.	Sampling Site		Well Type	Depth of Sink (ft)	Date of Collection	Time of Collection
	Location	Union				
46	Borgochiya	Bara PolashBari	Deep	350	8/3/2014	10:45am
47	School Hat	Amjankhor	HTW	50	8/3/2014	01:45pm
48	Belhara	Barabari	DTW	300	11/3/2014	12:00pm
49	Beurjhari	Amjankhor	STW	75	8/3/2014	01:15pm
50	Jogihar	Amjankhor	DTW	350	8/3/2014	01:00pm

Analytical procedures

In order to assess the suitability classes for irrigation, domestic and industrial uses, we measured pH, EC, TDS, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Zn^{2+}, Cu^{2+}, Mn^{2+}, Fe^{3+}, PO_4^{3-}, HCO_3^{-}, SO_4^{2-}, NO_3^{-} and Cl^{-}.

1. pH

Irrigation water can be classified as acid, neutral or alkaline. The degree of acidity or alkalinity of water can be described by a pH value. pH values range from 0 to 14; any value below 7.0 is considered acid, a value of 7.0 is neutral, and a pH above 7 is alkaline. Thus, water with a pH of 5.8 is acidic, whereas water with a pH of 7.9 is alkaline.

The concentration of the hydrogen ion [H+] activity in a solution determines the pH. Mathematically this is expressed as:

$$pH = -\log [H+]$$

> The pH value is the negative power to which 10 must be raised to equal the hydrogen ion concentration.

The pH of water samples were determined by the pH meters (WTW-pH-522 Model). This method was mentioned by Ghosh et al. (1983). This test was done in the laboratory of Soil Science Department, Hajee Mohammad Danesh Science and Technology University, Dinajpur.

2. Electrical Conductivity (EC)

The electrical conductivity is mainly representing the concentration of total salinity or TDS in water. The EC values of collected samples were measured by the conductivity bridge (Model WTW LF 521) in the laboratory of Agricultural Chemistry, Hajee Mohammad Danesh Science and Technology University, Dinajpur. This method was also mentioned by Ghosh et al. (1983).

3. Total Dissolved Solids (TDS)

Total Dissolved Solids was determined by weighing the solid residue obtained by evaporating a measured aliquot of filtered water samples to dryness, according to the procedure described by Chopra and Kanwar (1980).

4. Bicarbonate

Bicarbonate of water samples were determined by acidimetric method of titration using phenolphthalein indicator ($C_{20}H_{14}O_4$) for carbonate. Bicarbonate forms rose red color complex at the end of titration. The bicarbonate was estimated titrimetrically (Chopra and Kanwar, 1980) and (Ghosh et al., 1983).

$$NaHCO_3 + H_2SO_4 \text{---------}\rightarrow Na_2SO_4 + H_2O + CO_2$$

5. Chloride

Chloride of water samples was analyzed by argentometric method of titration using potassium chromate indicator (K_2CrO_4) which worked in a neutral or slightly alkaline solution. Silver chloride (AgCl) was quantitatively precipitated before red silver chromate (Ag_2CrO_4) was found. The reactions are given below:

$$AgNO_3 + NaCl \text{-----------}\rightarrow AgCl + NaNO_3$$

$$2AgNO_3 + K_2CrO_4 \text{-----------}\rightarrow Ag_2CrO_4 + KNO_3$$

Chloride was determined titrimetrically following the procedure described by Ghosh et al. (1983) and Clesceri et al. (1989).

6. Phosphorus

All samples were tested by the colorimetric method to determine phosphorus. In this method stannous chloride is used as a reducing agent (Clesceri et al., 1989). This method involves the formation of molybdophosphoric acid. This acid is reduced the intensity complex molybdenum blue by stannous chloride. The color intensity was read at 660 nm wavelength with a spectrophotometer (Coleman Junior Model No. 6A) within 15 minutes after stannous chloride addition following the method outlined by Olsen et al. (1954). The principle of this method is given below as a reaction:

$$H_3PO_4 + 12\ H_2MoO_4 \text{ ----------}\rightarrow H_3P\ (Mo_3O_{10})_4 + 12\ H_2O$$

7. Sulfate sulfur

Sulfate was estimated turbidimetrically with the help of spectrophotometer. Turibidimetric reagent ($BaC_{l2}.2H_2O$) was added in a definite volume of sample. Sulfate ion reacted with barium chloride to form barium sulfate. Readings were taken in spectrophotometer (Coleman Junior Model No. 6A) after 30 minutes of $BaCl_2$ addition at 420 nm wavelength following the method of Wolf (1982).

8. Calcium

For determination of calcium from water samples, Complexometric titration was used. In this titration disodium ethylene diamine tetra-acetated ($Na_2H_2C_{10}H_{12}O_8N_2.2H_2O$) was used as a chelating agent. This analytical method was carried out to element possible interfacing ions such as Fe, Mn, Cu, Zn, Ni and PO_4 adding respective masking agents in the presence of calcon indicator ($C_{20}H_{13}N_2NaO_5S$) at pH 12 (Page et al., 1982). These masking agents are sodium hydroxide (NaOH), Potassium ferrocyanide [$K_4\ Fe\ (CN)_6.\ 3H_2O$], hydroxylamine-hydrochloride ($NH_2OH.HCl$) and triethanolamine ($C_6H_{15}NO_3$).

9. Magnesium

Magnesium was analyzed by Complexometric titration method. Here disodium ethylene diamine tetra-acetated ($Na_2H_2C_{10}H_{12}O_8N_2.2H_2O$) was used as a chelating agent. Some masking agents are used in this titration. These are used to eliminate some interfering ions. These masking agents are Eriochrome Black T indicator (C20H12N3NaO7S), Calcium tungstate (CaWO4), Potassium ferrocyanide [K_4 Fe $(CN)_6$. $3H_2O$], hydroxylamine-hydrochloride ($NH_2OH.HCl$) and triethanolamine ($C_6H_{15}NO_3$).

10. Sodium and Potassium

Sodium and Potassium were determined with the help of a flame emission spectrophotometer (Gallenkamp Cat. No. 23/FH-500) by using sodium and potassium filters, respectively. The sample was aspirated into a gas flame and excitation was carried out in a reproducible condition and carefully controlled. The air pressure was 10 PSI. Interference filters were used in desired spectral line.

11. Zinc, copper, iron and manganese

Zinc, copper, iron and manganese were analyzed by atomic absorption spectrophotometer (Hitachi, Model -170-30) at the wavelengths of 213.8 nm, 324.8 nm, 248.3 nm and 279.5 nm, respectively.

Evaluation of water quality

Use of poor water quality can create four types of problems, namely toxicity, water infiltration, salinity and miscellaneous (Ayers and Westcot, 1985). To assess water quality for irrigation, there are four most popular criteria: TDS or EC, sodium adsorption ratio (SAR), chemical concentration of elements like Na+, Cl^- and/or B^- and residual sodium carbonate (RSC) (Michael, 1992 and Raghunath, 1987). For current irrigation water quality assessment, the following parameters were considered. Whether groundwater is suitable for a particular purpose depends on the criteria or standards of acceptable quality for that specific use. The following formulae related to the irrigation water classes rating were used to classify water samples using the chemical data.

a) According to Richards (1954), sodium adsorption ratio (SAR) is expressed as:

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

b) **Todd (1980) defined soluble sodium percentage (SSP) as**:

$$SSP = \frac{\text{Soluble Na concentration (meq/L)}}{\text{Total cation concentration (meq/L)}} \times 100$$

c) **Residual Sodium Carbonate (RSC)**:

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

d) **Hardness or Total Hardness (H_T):**

$H_T = 2.5 \times Ca^{2+} + 4.1 \times Mg^{2+}$ (Freeze and Cherry, 1979)

e) **Potential Salinity** = $Cl^- + (SO_4^{2-}/2)$

f) **Permeability Index (P.I.)** = $\frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+}$

g) **Kelly's ratio** = $Na^+ / (Ca^{2+} + Mg^{2+})$

Kelly's ratio (KR) represents the alkali hazards of water and is calculated by this equation, where all the concentrations were expressed in me/L. Kelly's ratio is used to find whether groundwater is suitable for irrigation or not. Sodium measured against calcium and magnesium was considered by Kelly (1951) for calculating Kelly's ratio. Groundwater having Kelly's ratio more than one (1) is generally considered as unfit for irrigation.

h) Gibbs Ratio and Gibbs diagram

A diagram is proposed by Gibbs (1970); this diagram is known as the Gibbs diagram. To understand the relation between the chemical components and respective aquifer lithologies, this diagram is used. This diagram is divided into three distinct fields. These are 'evaporation dominance', 'rock dominance' and 'precipitation dominance'. Two types of Gibbs ratio are needed to make the Gibbs diagram. These ratios are 'Gibbs ratio for anion' and 'Gibb's ratio for cation'. **Gibbs ratio 1 for anion** = $Cl^- / (Cl^- + HCO_3^-)$ and **Gibbs Ratio 2 for cation** = $Na^+ + K^+ / (Na^+ + K^+ + Ca^{2+})$

Here concentrations for all ionic constituents for calculating all parameters are in meq/L except hardness (mg/L).

Statistical Analysis

Statistical analysis of the data generated out of the chemical analysis of water samples, were done with the help of a scientific calculator following the standard procedure as described by Gomez and Gomez (1984). Correlation studies were also computed following the procedure described by aforesaid authors.

Checking correctness of Analysis

There are some methods are described by Clesceri et al. (1989) for checking the correctness of chemical analysis of water samples. These methods are given below:

Anion-cation Balance

Anion-cation balance means, the total sum of anion and cation must be balanced, because of all potables of water are electrically neutral. The unit of this term is me/L. The acceptable percentage limit of this difference is 5-10%. The equation is,

$$\%\ \text{difference} = \frac{\sum \text{cations} - \sum \text{anions}}{\sum \text{cations} + \sum \text{anions}} \times 100$$

CHAPTER IV

RESULTS

The results of water samples of Baliadagi upazilla were generated from chemical analysis. These results have been presented in the Table 2, Table 3 and Table 4. All results are described below:

a) pH

The pH values of water samples that were collected from Baliadangi upazilla varied from 5.4 to 6.9 (Table 3). The mean value of all samples is 5.8. Maximum values are greater than the mean value. The pH values of 26 samples (52% samples) ranged from 5.8 to 6.9. Only one samples (Sample no. 36) contain high pH value 6.9. 26 samples from 50 samples were containing higher pH values than the mean value. From these 26 samples 6 samples contain 5.8 pH values. The standard deviation (SD) of all samples is 0.24. The pH range of deep tubewells (15 samples), shallow tubewells (18 samples), and hand tubewells (17 samples) was varied from 5.5 to 6.9, 5. to 6.1 and 5.5 to 6.2, respectively. The average values of deep tubewells, shallow tubewells, and hand tubewells were 5.9, 5.8 and 5.8, respectively.

b) Electrical Conductivity (EC)

The EC value of all samples varied from 81 to 727 µScm^{-1} and mean value was 170 µScm^{-1} (Table 3). The Standard Deviation (SD) was 123.71. The EC values of deep tubewells, shallow tubewells and hand tubewell were ranged from 93 to 174µScm^{-1}, 87 to 230µScm^{-1} and 81 to 727µScm^{-1}, respectively. 16% water sample contains EC value varied from 81-100 µScm^{-1}. Only one sample's (sample no 27) EC value was 727 µScm^{-1} (table no. 3). Rest of all samples contained less than 400 µScm^{-1} EC value. There were no any sample contained 800 µScm^{-1} but one sample contained more than 500 µScm^{-1}.

c) Total Dissolved Solids (TDS)

The values of total dissolved solids of collected water samples varied from 48 to 549 mg/L and the mean value was 113 mg/L (Table 3). 80% values of TDS were less than the mean value and 20% values were higher than the mean value. The SD of all samples of TDS value was 98.24. TDS values of DTW, STW and HTW respectively varied from 57 to 104 mg/L, 53 to 140 mg/L and 48 to 549 mg/L.

d) Total cations

Among the cations, Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} were found dominate but Fe^{3+}, Mn^{2+}, Zn^{2+} and Cu^{2+} were present in comparatively very small amounts. The results have been given under the following head:

i) Calcium

The concentration of Ca of all samples varied from 0.27 to 1.2 meq/L and the mean value was 0.59 meq/L (Table 2). Standard deviation (SD) was 0.21. 62% values (31 samples) were less than the average value and 38% (19 samples) values were higher than the average value.

Table-2: Chemical constituents of water collected from different sources of Birganj, Dinajpur

Sample no.	**Ca^{2+} (meq/L)**	**Mg^{2+} (meq/L)**	**Na^{+} (meq/L)**	**K^{+} (meq/L)**	**Cu^{2+} (mg/L)**	**Zn^{2+} (mg/L)**	**Mn^{2+} (mg/L)**	**Fe^{3+} (mg/L)**
1	0.47	1.96	0.34	0.14	0.03	0.01	0.02	0.19
2	0.80	1.35	0.88	0.26	0.02	0.05	0.03	0.18
3	0.60	1.08	0.88	0.14	0.04	0.03	0.01	0.10
4	0.47	1.42	0.88	0.14	0.02	0.01	0.04	0.17
5	0.40	1.01	0.88	0.26	0.04	0.02	0.03	0.14
6	0.40	1.01	0.88	0.26	0.02	0.04	0.01	0.11
7	0.33	1.15	0.88	0.26	0.05	0.02	0.02	0.11
8	0.87	1.22	0.34	0.26	0.01	0.01	0.03	0.18
9	0.53	0.95	0.88	0.26	0.02	0.03	0.01	0.12
10	0.40	0.88	0.88	0.38	0.03	0.01	0.02	0.18
11	0.53	1.01	0.88	0.26	0.02	0.01	0.02	0.20
12	0.53	0.95	0.34	0.26	0.03	0.01	0.04	0.12
13	0.47	1.22	0.34	0.26	0.03	0.03	0.03	0.18
14	0.53	0.74	0.34	0.26	0.01	0.01	0.01	0.19
15	0.53	0.95	0.88	0.26	0.02	0.02	0.02	0.13
16	0.67	0.95	0.88	0.26	0.02	0.02	0.02	0.13

Table 2. (Contd.)

Sample no.	**Ca^{2+} (meq/L)**	**Mg^{2+} (meq/L)**	**Na^{+} (meq/L)**	**K^{+} (meq/L)**	**Cu^{2+} (mg/L)**	**Zn^{2+} (mg/L)**	**Mn^{2+} (mg/L)**	**Fe^{3+} (mg/L)**
17	0.60	0.95	0.88	0.26	0.04	0.04	0.04	0.12
18	1.07	2.36	0.88	0.26	0.02	0.02	0.02	0.10
19	1.00	1.28	0.34	0.26	0.01	0.03	0.02	0.11
20	0.53	1.08	0.88	0.14	0.03	0.01	0.03	0.19
21	0.33	2.30	0.34	0.14	0.01	0.02	0.01	0.18
22	0.60	0.95	0.34	0.14	0.01	0.02	0.02	0.08
23	0.53	0.88	0.88	0.26	0.01	0.04	0.01	0.19
24	0.53	1.22	0.34	0.26	0.03	0.02	0.02	0.18
25	0.53	0.61	0.88	0.14	0.02	0.03	0.02	0.10
26	0.47	0.81	0.88	0.26	0.02	0.01	0.04	0.12
27	1.20	2.23	0.88	0.26	0.02	0.02	0.02	0.10
28	0.33	0.81	0.88	0.26	0.01	0.02	0.02	0.09
29	1.07	1.42	0.34	0.26	0.02	0.04	0.03	0.19
30	0.60	1.22	0.88	0.26	0.01	0.02	0.01	0.18
31	0.27	0.47	0.88	0.38	0.01	0.01	0.02	0.10
32	0.60	1.28	0.88	0.26	0.02	0.03	0.02	0.19
33	0.53	1.28	0.88	0.14	0.05	0.01	0.02	0.18
34	0.67	1.08	0.88	0.26	0.00	0.01	0.04	0.10
35	0.53	1.15	0.88	0.26	0.02	0.01	0.02	0.17
36	0.40	1.22	0.88	0.26	0.03	0.03	0.02	0.12
37	0.40	1.28	0.88	0.26	0.04	0.02	0.03	0.10

Table 2. (Contd.)

Sample no.	**Ca^{2+} (meq/L)**	**Mg^{2+} (meq/L)**	**Na^{+} (meq/L)**	**K^{+} (meq/L)**	**Cu^{2+} (mg/L)**	**Zn^{2+} (mg/L)**	**Mn^{2+} (mg/L)**	**Fe^{3+} (mg/L)**
38	0.53	1.15	0.88	0.26	0.01	0.03	0.01	0.14
39	0.67	1.35	0.88	0.26	0.03	0.01	0.02	0.19
40	0.47	1.49	0.34	0.14	0.04	0.02	0.02	0.18
41	0.67	1.55	0.34	0.14	0.04	0.02	0.02	0.15
42	0.80	1.42	0.34	0.26	0.03	0.04	0.02	0.19
43	0.60	1.82	0.34	0.14	0.03	0.02	0.04	0.12
44	0.73	1.82	0.34	0.26	0.04	0.01	0.02	0.10
45	1.20	2.50	0.34	0.26	0.04	0.03	0.02	0.16
46	0.47	0.81	0.88	0.38	0.03	0.01	0.03	0.19
47	0.47	0.74	0.88	0.26	0.01	0.01	0.01	0.18
48	0.53	1.15	0.88	0.14	0.02	0.01	0.02	0.11
49	0.53	1.15	0.88	0.14	0.03	0.03	0.02	0.19
50	0.53	1.08	0.34	0.26	0.02	0.02	0.04	0.18
Min	0.27	0.47	0.34	0.14	0.00	0.01	0.01	0.08
Max	1.20	2.50	0.88	0.38	0.05	0.05	0.04	0.20
Mean	0.59	1.23	0.70	0.24	0.02	0.02	0.02	0.15
SD	0.21	0.44	0.26	0.07	0.01	0.01	0.01	0.038
CV %	35.98	35.74	37.26	27.96	48.74	51.13	40.78	25.61

ii) Magnesium

The mean value of magnesium was 1.23 meq/L. The range of the concentration of Mg varied from 0.47 to 2.5 meq/L (Table 2). The standard deviation (SD) of all water samples was 0.44. About 64% values (32 samples) were under the mean value and 36% values (18 samples) were above the mean values.

iii) Potassium

The range of the concentrations of Potassium for all samples was 0.4 to 0.38 meq/L and average value was 0.24 meq/L (Table 2). The Standard deviation (SD) of water samples for K was 0.07. About 26% (13 samples) values from all water samples were lower than the mean value and 74% (37 samples) were higher than the mean values.

iv) Sodium

The mean value of sodium was 0.7 meq/L. The range of the concentration of Mg varied from 0.34 to 0.88 meq/L (Table 2). The standard deviation (SD) of all water samples was 0.26. About 34% values (17 samples) were under the mean value and 66% values (33 samples) were above the mean values.

v) Iron

All samples of water contained very small amount of Iron. The concentrations of iron value were varied from 0.08 to 0.2 mg/L and the mean value was 0.038 mg/L (Table 2). The Standard Deviation (SD) was 0.062. Out of 50 samples, 24 samples (48%) contained Iron value lower than the average and 26 samples (52%) contained iron value higher than the mean value.

vi) Zinc

The concentration of zinc ion for all water samples were varied from 0.01 to 0.05 mg/L with the mean value was 0.02 mg/L (Table 2). The Standard Deviation (SD) was 0.01. About 68% values (34 samples) were under the mean value and 32% values (16 samples) were above the mean values.

vii) Manganese

The range of the concentration of Manganese for all water samples were 0.01 to 0.04 mg/L with the 0.02 mg/L mean value (Table 2). The Standard Deviation (SD) was 0.009. About 70% (35 samples) values from all water samples were lower than the mean value and 30% (15 samples) were higher than the mean values.

viii) Copper

The water samples were contained very low amount of copper values. The range of Cu concentration was varied from traces to 0.05 mg/L and the mean value was 0.02 (Table 2). The Standard Deviation (SD) was 0.01. Out of 71 samples, 28 samples (56%) contained Cu values less than the mean value and 22 samples (44%) contained Cu values higher the mean values.

e) Total anions

Water samples were analyzed for PO_4^{3-} SO_4^{2-}, HCO_3^- and Cl^-. The results of all samples were reported in the Table 3. There we can see that bicarbonate and chloride were found dominating while phosphate and sulfate were found in traces. The results are given below:

i) Phosphate

The concentration of phosphorus for all water samples was varied from 0.01 to 0.06 mg/L and the mean value was 0.02 (Table 3). The Standard Deviation (SD) was 0.01. About 64% values (32 samples) contained lower value than the mean value and 36% values (18 samples) contained higher value than the mean value.

Table 3: Chemical constituents of water collected from different sources of Birganj, Dinajpur.

Sample no.	PO_4^{-3} (mg/L)	SO_4^{-2} (meq/L)	Cl^- (meq/L)	HCO_3^- (meq/L)	pH	EC (µScm^{-1})	TDS (mgL^{-1})	Hardness (mgL^{-1})
1	0.04	0.10	1.6	1.12	5.8	96	59	119.64
2	0.05	0.10	1.8	1.20	5.7	215	131	106.42
3	0.06	0.09	1.6	0.96	5.9	140	85	83.14
4	0.01	0.09	1.6	0.96	5.4	116	71	93.07
5	0.01	0.04	1.4	1.12	5.5	111	68	69.82
6	0.01	0.08	1.4	0.88	5.8	92	55	69.82
7	0.02	0.11	1.6	0.96	5.7	96	58	73.12
8	0.02	0.07	1.6	0.88	5.7	185	113	103.11
9	0.01	0.05	1.6	0.80	5.6	139	85	73.16
10	0.02	0.10	1.6	0.96	5.8	112	68	63.17
11	0.02	0.10	1.4	1.12	5.7	125	76	76.48
12	0.02	0.04	1.0	1.04	5.5	103	63	73.16
13	0.02	0.10	1.0	1.12	5.6	112	68	83.11
14	0.02	0.09	0.6	1.12	5.9	143	87	63.20
15	0.01	0.12	1.4	0.96	5.6	150	92	73.16
16	0.05	0.11	1.6	1.04	5.8	216	133	79.83

Table 3. (Contd.)

Sample no.	**PO_4^{-3} (mg/L)**	**SO_4^{-2} (meq/L)**	**Cl^- (meq/L)**	**HCO_3^- (meq/L)**	**pH**	**EC (μScm^{-1})**	**TDS (mgL^{-1})**	**Hardness (mgL^{-1})**
17	0.03	0.09	1.6	0.88	5.6	145	88	76.49
18	0.02	0.12	2.0	1.60	5.7	102	549	169.57
19	0.02	0.04	2.0	0.80	5.6	174	99	113.10
20	0.02	0.10	1.6	0.88	5.9	201	122	79.80
21	0.02	0.10	1.8	1.04	5.9	87	53	129.58
22	0.02	0.10	1.0	1.12	5.9	143	87	76.49
23	0.01	0.08	1.2	1.20	5.7	147	89	69.84
24	0.01	0.12	1.4	0.80	5.6	118	90	86.44
25	0.02	0.10	1.0	0.96	5.9	93	57	56.56
26	0.01	0.09	1.2	1.04	6.0	86	52	63.19
27	0.03	0.12	2.2	1.52	5.7	727	442	169.59
28	0.02	0.13	1.2	0.96	6.0	114	65	56.52
29	0.04	0.04	2.0	0.80	5.7	412	253	123.07
30	0.02	0.09	2.0	0.88	6.0	185	112	89.78
31	0.04	0.07	1.0	1.12	5.9	95	58	36.58
32	0.01	0.10	1.8	0.96	5.9	148	64	93.10
33	0.02	0.10	1.8	0.88	5.6	133	80	89.77
34	0.02	0.11	1.8	0.88	5.7	174	106	86.47
35	0.01	0.09	1.4	1.12	5.7	146	89	83.12
36	0.02	0.12	1.2	1.20	6.9	105	64	79.78
37	0.01	0.12	1.6	0.96	5.9	139	85	83.10

Table 3. (Contd.)

Sample no.	**PO_4^{-3} (mg/L)**	**SO_4^{-2} (meq/L)**	**Cl^- (meq/L)**	**HCO_3^- (meq/L)**	**pH**	**EC (µScm^{-1})**	**TDS (mgL^{-1})**	**Hardness (mgL^{-1})**
38	0.02	0.11	1.8	1.12	6.0	148	91	83.12
39	0.05	0.09	1.8	0.96	5.8	170	104	99.75
40	0.01	0.10	1.2	1.20	5.9	112	68	96.40
41	0.05	0.09	1.6	0.88	6.0	158	96	109.72
42	0.02	0.10	1.6	0.88	6.2	367	225	109.74
43	0.04	0.11	1.8	0.80	5.7	164	101	119.67
44	0.02	0.07	2.0	0.80	5.9	230	140	126.33
45	0.03	0.11	2.0	1.52	6.1	652	398	182.88
46	0.05	0.11	1.4	0.88	5.9	161	97	63.19
47	0.01	0.09	0.8	1.28	5.8	81	48	59.86
48	0.05	0.05	1.6	0.96	6.2	151	93	83.12
49	0.02	0.10	2.0	0.72	6.1	122	73	83.12
50	0.03	0.10	1.0	0.96	6.3	140	85	79.80
Min	0.01	0.04	0.6	0.72	5.4	81	48	36.58
Max	0.06	0.13	2.2	1.60	6.9	727	549	182.88
Mean	0.02	0.09	1.52	1.02	5.8	170	113	90.24
SD	0.01	0.02	0.36	0.19	0.2	124	98	29.10
CV %	54.61	24.64	23.70	18.57	4.1	73	87	32.25

ii) Sulfate

The value of sulfate ion of all water samples were ranges between 0.04 to 0.13 meq/L and the mean value was 0.09 meq/L (Table 3). The Standard Deviation of all water samples was 0.02. The concentrations of all samples were very small amount. Out of 50 samples, 31 samples (62%) were over the mean value and 38 samples (19%) were less than mean value.

iii) Bicarbonate

The range of bicarbonate value of all water samples were varied from 0.72 to 1.6 meq/L with 1.02 meq/L the mean value (Table 3). The Standard Deviation (SD) was 0.36. About 40% (20 samples) were below than the average value and 60% (30 samples) were higher than the mean value.

iv) Chloride

The concentration of chloride ion of water samples were varied from 0.6 to 2.2 meq/L and the mean value was 1.52 meq/L (Table 3). The Standard Deviation was 0.19. Out of 50 samples, 29 samples (58%) were higher than the mean value and 21 samples (42%) were lower than the mean value.

f) Hardness (H_T)

The value of Hardness for all samples was ranged from 36.58 to 182.88 mg/L and the mean value of the hardness was 90.24 mg/L (Table 3). The standard deviation of water samples was 29.1. Out of 50 samples, 17 samples (34%) were over the mean value and 33 samples (66%) were less than the mean value.

g) Sodium Adsorption Ratio (SAR)

The range of all water samples of SAR was 0.25 to 1.45 meq/L and the mean value was 0.77 meq/L (Table 4). The Standard Deviation was 0.34. About 38% samples (19 samples) were less the mean value and 62% (31 samples) were higher than the mean value.

h) Soluble Sodium Percentage (SSP)

All water samples contained SSP value ranged from 7.39 to 38.98 meq/L and the Standard Deviation (SD) was 9.48 (Table 4). The mean value of water samples for SSP was 24.19 meq/L. Out of 50 samples, 19 samples (18% value) were less than the mean value and 31 samples (62% value) were upper than the mean value.

Table 4: Evaluation of water quality of water samples.

Sample no.	SAR (meq/L)	SSP (meq/L)	RSC (meq/L)	Preme-ability Index	Potential Salinity	Gibb's ratio (Anion)	Gibb's ratio (Cation)	Kelly's ratio
1	0.31	10.95	-0.82	0.58	1.17	0.41	0.50	0.31
2	0.85	25.36	-0.35	0.73	1.25	0.40	0.59	0.85
3	0.96	31.46	-0.08	0.84	1.01	0.38	0.63	0.96
4	0.91	28.65	-0.28	0.78	1.01	0.38	0.69	0.91
5	1.05	31.07	-0.01	0.90	1.14	0.44	0.74	1.05
6	1.05	33.05	-0.01	0.90	0.92	0.39	0.74	1.05
7	1.02	32.22	0.12	0.91	1.01	0.38	0.77	1.02
8	0.33	11.83	-0.48	0.66	0.91	0.35	0.41	0.33
9	1.02	32.13	0.12	0.91	0.83	0.33	0.68	1.02

Table 3. (Contd.)

Sample no.	SAR (meq/L)	SSP (meq/L)	RSC (meq/L)	Preme-ability Index	Potential Salinity	Gibb's ratio (Anion)	Gibb's ratio (Cation)	Kelly's ratio
10	1.10	32.34	0.32	0.99	1.01	0.38	0.76	1.10
11	1.00	30.49	-0.15	0.85	1.17	0.44	0.68	1.00
12	0.39	14.35	-0.48	0.74	1.06	0.51	0.53	0.39
13	0.37	13.75	-0.68	0.66	1.17	0.53	0.56	0.37
14	0.42	16.38	-0.68	0.69	1.16	0.65	0.53	0.42
15	1.02	32.02	-0.08	0.87	1.02	0.41	0.68	1.02
16	0.98	30.54	-0.01	0.86	1.10	0.39	0.63	0.98
17	1.00	31.37	0.06	0.88	0.93	0.35	0.66	1.00
18	0.67	18.85	-1.43	0.53	1.66	0.44	0.52	0.67
19	0.32	10.70	-0.28	0.67	0.82	0.29	0.37	0.32
20	0.98	31.20	-0.01	0.86	0.93	0.35	0.66	0.98
21	0.30	10.30	-0.83	0.57	1.09	0.37	0.59	0.30
22	0.38	14.64	-0.55	0.71	1.17	0.53	0.44	0.38
23	1.05	32.10	-0.21	0.86	1.24	0.50	0.68	1.05
24	0.36	13.38	-0.35	0.73	0.86	0.36	0.53	0.36
25	1.17	38.98	-0.14	0.93	1.01	0.49	0.66	1.17
26	1.10	34.69	-0.08	0.92	1.09	0.46	0.71	1.10
27	0.67	18.85	-1.23	0.55	1.58	0.41	0.49	0.67
28	1.16	34.33	0.06	0.98	1.03	0.44	0.77	1.16
29	0.30	10.33	-0.48	0.62	0.82	0.29	0.36	0.30
30	0.92	28.07	0.19	0.85	0.93	0.31	0.66	0.92

Table 3. (Contd.)

Sample no.	**SAR (meq/L)**	**SSP (meq/L)**	**RSC (meq/L)**	**Preme-ability Index**	**Potential Salinity**	**Gibb's ratio (Anion)**	**Gibb's ratio (Cation)**	**Kelly's ratio**
31	1.45	38.38	0.26	1.16	1.15	0.53	0.83	1.45
32	0.91	27.39	-0.08	0.80	1.01	0.35	0.66	0.91
33	0.92	29.21	-0.02	0.82	0.93	0.33	0.66	0.92
34	0.94	29.46	0.05	0.85	0.93	0.33	0.63	0.94
35	0.96	29.42	-0.28	0.81	1.17	0.44	0.68	0.96
36	0.98	30.61	-0.42	0.79	1.26	0.50	0.74	0.98
37	0.96	30.11	-0.08	0.84	1.02	0.38	0.74	0.96
38	0.96	28.38	0.12	0.87	1.17	0.38	0.68	0.96
39	0.88	26.29	-0.22	0.77	1.00	0.35	0.63	0.88
40	0.34	12.97	-0.75	0.63	1.25	0.50	0.50	0.34
41	0.32	11.33	-0.62	0.63	0.93	0.35	0.42	0.32
42	0.32	11.25	-0.62	0.63	0.93	0.35	0.43	0.32
43	0.31	11.21	-0.62	0.61	0.86	0.31	0.44	0.31
44	0.30	10.39	-0.56	0.61	0.83	0.29	0.45	0.30
45	0.25	7.39	-1.70	0.43	1.57	0.43	0.33	0.25
46	1.10	32.23	0.12	0.96	0.93	0.39	0.73	1.10
47	1.13	34.79	-0.41	0.85	1.33	0.62	0.71	1.13
48	0.96	29.45	-0.08	0.84	0.98	0.38	0.66	0.96
49	0.96	30.47	0.32	0.90	0.77	0.26	0.66	0.96
50	0.38	14.14	-0.61	0.69	1.01	0.49	0.53	0.38
Min	0.25	7.39	-1.70	0.43	0.77	0.26	0.33	0.25

Table 3. (Contd.)

Sample no.	SAR (meq/L)	SSP (meq/L)	RSC (meq/L)	Preme-ability Index	Potential Salinity	Gibb's ratio (Anion)	Gibb's ratio (Cation)	Kelly's ratio
Max	1.45	38.98	0.32	1.16	1.66	0.65	0.83	1.45
Mean	0.77	24.19	-0.30	0.78	1.06	0.41	0.61	0.77
SD	0.34	9.48	0.43	0.14	0.19	0.08	0.12	0.34
CV %	43.52	39.21	-142.32	18.33	18.06	20.58	20.32	43.52

i) Residual Sodium Carbonate (RSC)

The value of RSC for all samples was ranged from -1.7 to 0.32 meq/L and the mean value was -0.3 meq/L (Table 4). The Standard Deviation (SD) was 0.43. For the RSC value 44% (22 samples) values were less than the mean value and 56% (28 samples) values higher than the mean value.

j) Permeability Index

The range of the value of Permeability Index (PI) for all water samples was varied from 0.43 to 1.16 and the mean value was 0.78 (Table 4). The standard deviation (SD) was 0.14. About 56% values (28 samples) were higher than the mean value and 44% values (22 samples) were higher than the mean value.

k) Potential salinity

The range of calculated values for the Potential salinity of water samples was 0.77 to 1.66. The average value of this term was 1.06 (Table 4). The standard deviation (SD) was 0.19. Out of 50 samples, 20 samples (40%) were higher than the mean value and 30 samples (60%) were lower than the mean value.

l) Gibbs ratio

The ranges of Gibbs ratio for anions and cations were varied from respectively 0.26 to 0.65 and 0.33 to 0.83 (Table 4). The average values for both ratios were 0.41 (for anions) and 0.61 (for cations). The standard deviation (SD) of Gibbs ratio for anions was 0.08 and Gibbs for cations was 0.12.

m) Kelly’s Ratio

The Kelly’s ratio for all water samples were ranged from 0.09 to 1.19 with the mean value was 0.43 (Table 4). The standard deviation (SD) was 0.23. About 40% values (20 samples) were less than the mean value and 60% values (30 samples) were higher than mean value.

CHAPTER V

DISCUSSION

Identification and analysis of water quality is essential and important for domestic, irrigation, industrial, commercial and other purposes for groundwater. The dominated and major elements are calcium, magnesium, sodium, potassium, iron, zinc, manganese, copper, sulfur, phosphorus, bicarbonate and chloride. Other evaluations such as pH, EC, TDS, Premeability Index, Potential Salinity, SAR, SSP, RSC, Gibbs ratio, Kelly's ratio etc. are also very important to determine the water quality. Results for all water samples are discussed under the following heads.

1. pH

From the Table-3 it is seen that 48% of water samples containing 5.4 to 5.8 pH value and pH value of rest samples ranged from 5.9 to 6.9. The pH value of all samples indicated that these samples of water were slightly acidic. The acidity or basicity of irrigation water is expressed as pH (< 7.0 acidic; > 7.0 basic). The normal pH range for irrigation water is from 6.5 to 8.4 (Ayers and Westcot, 1985). Water becomes more acidic as pH values below 7.0 decreases numerically. In fact, there is a ten-fold increase in acidity for every decrease by one whole pH unit. For example, water with a pH of 5.5 is ten times more acidic than water with a pH of 6.5; and water with pH of 4.5 is 100 times more acidic than water with a pH of 6.5. Similarly, for every whole unit increase in pH above 7, there is a ten-fold increase in alkalinity. Although the pH is not directly related to soil, plant and animal health, but has been applied widely and successfully over many years to ensure the wholesomeness of water. Many important properties of water are determined by pH; for example, both the suitability of groundwater for domestic and commercial uses and the ability of water to transport potentially harmful chemicals are controlled by pH.

2. Electrical Conductivity (EC)

The EC values were distinctly dissimilar among samples. The EC value of all samples varied from 81 to 727 µScm^{-1} and mean value was 170 µScm^{-1} and these values were reported in Table 3. On the basis of EC water quality was divided into four salinity groups, according to the Richards, (1968) (Figure 2). By following this category, 56 samples were ‘low salinity water’ (C1) and 4 samples were ‘medium salinity water’ (C2), which is classified on the basis of criteria as shown in Table 7. Wilcox (1955) classified water quality into five groups on the basis of EC value. According to Wilcox, 56 samples were ‘excellent’ and 4 samples ‘good’ (Table 5). All samples were ‘excellent’ from DTW and SWT. From HTW water samples, four samples (samples no. 27, 29, 42, 45) were ‘good’ and another samples were ‘excellent’. EC is an indirect measure of water salinity and one of the most convenient and common method to test water quality.

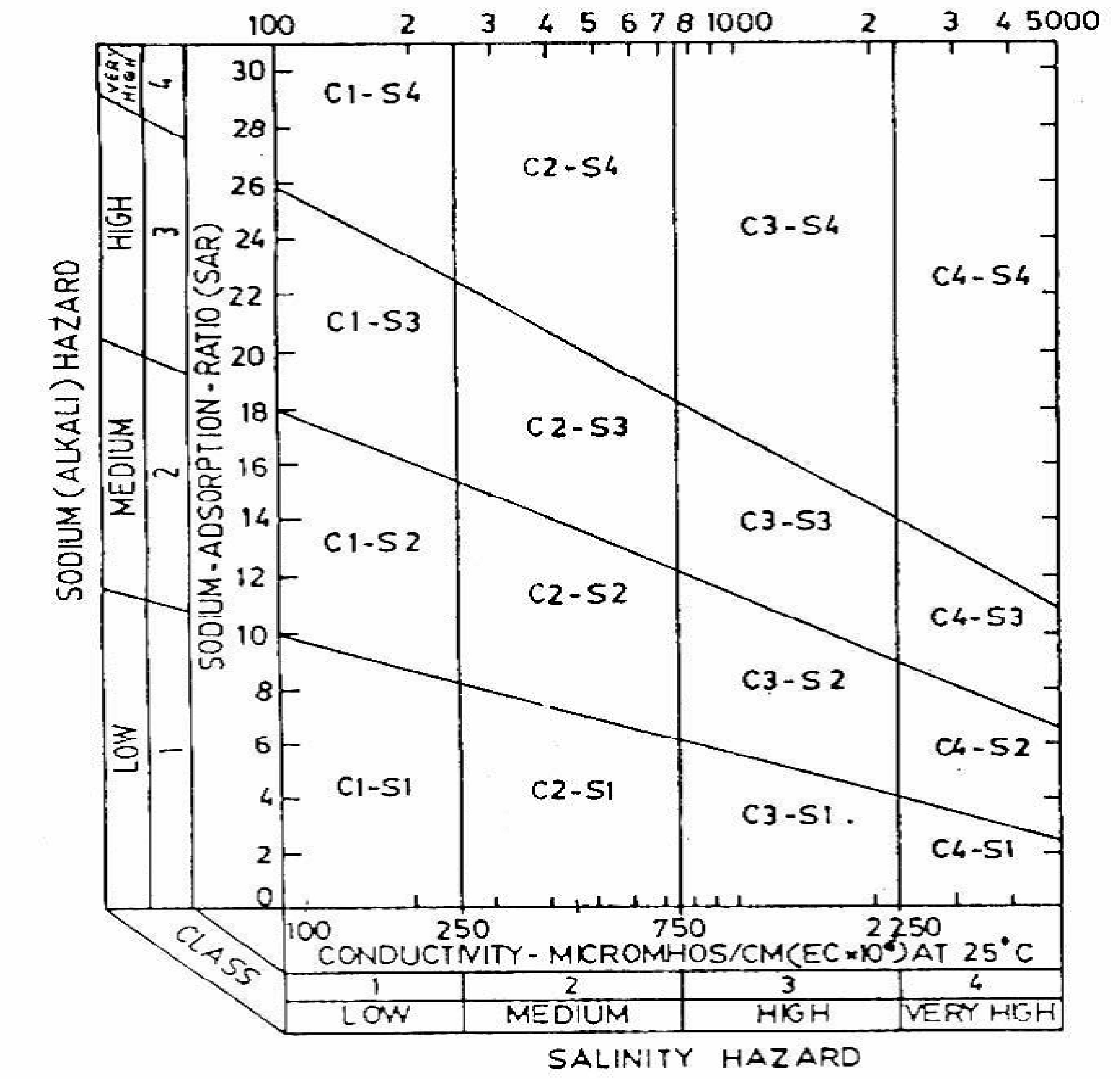


Figure 2: Diagram for classification of irrigation waters (Richards, 1968)

3. Total Dissolved Solids (TDS)

TDS is considered as one of the important criteria for judging water quality for irrigation, drinking and industrial purposes. From the results it is seen that, groundwater contain higher TDS value than surface water. Groundwater contains higher TDS due to appreciable amount of dissolved bicarbonate, chloride and sulfate compounds containing Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} (Karanth, 1994). According to Carroll (1962) and Freeze and Cherry (1979), water quality is divided into four groups on the basis of TDS. By following this classification, all samples were considered as ‘fresh’ group (Table 5). Because of TDS values of all samples were less than 1000 mg/L (Table 3). The recommended concentration of TDS is 500 mg/L (WHO, 2004) for drinking water. On the basis of this condition, all samples except three samples (sample no. 18, 27 and 45) were considered as safe for drinking water. Todd (1980) reported that when the value of TDS higher than 500 mg/L, then that was considered as ‘undesirable’. So sample no. 18 was considered as undesirable for drinking purpose.

4. Sodium Adsorption Ratio (SAR)

Results of Sodium Adsorption Ratio (SAR) for all groundwater samples were ranged from 0.25 to 1.45 meq/L (Table 4). All water samples for SAR were ‘excellent’ for irrigation indicated in Table 5, which is classified on the basis of criteria as shown in Table 11. This result also indicates that good amounts of Ca and Mg were found in water samples. This is very constructive for good tilt and structure of soil. It also improves the permeability of water and air.

According to Alagbe, (2006), the sodium hazard or SAR for all water samples is expressed in terms of classification of irrigation water as ‘low’ (S1: <10) in Figure2.

5. Soluble sodium percentage (SSP)

All water samples contained SSP value ranged from 7.39 to 38.98 meq/L and the Standard division (SD) was 9.48 (Table 4). According to Eaton (1950), 49 samples were considered as ‘excellent’ for irrigation. Wilcox (1955) also divided water quality of the basis of this term into four classes (Table 7). On the basis of this classification, thirty samples were considered as ‘good’ for irrigation. Rest of them were ‘excellent’ for irrigation purpose (Table5).

6. Residual Sodium Carbonate (RSC)

The value of RSC for all samples was ranged from -1.7 to 0.32 meq/L and the mean value was -0.3meq/L (Table 4). Eaton (1950) classified the irrigation water on the basis of RSC; water containing RSC <1.25, 1.25-2.50 and >2.50 meq/L and categorized as 'suitable', 'marginal' and 'unsuitable' (Table 12). According to this classification all water samples were considered as 'suitable' for irrigation (Table 5).

7. Hardness (H_T)

The value of Hardness for all samples was ranged from 3.87 to 32.76 mg/L and the mean value of the hardness was 10.16 mg/L (Table 3). According to McCarty (1967), Groundwater and surface water was classified into four groups on the basis of hardness (Table 10). By following this classification, maximum samples were considered as 'soft' (Table 5), some were 'moderately hard' and three samples (sample no. 18, 27 and 45) were 'hard'. Hardness is the result of presence of divalent cations such as Ca and Mg in waters (Todd, 1980).

Table 5: Quality classification of water samples for irrigation

Sample no.	**Water Class Based on**						**Alkalinity-salinity class**
	EC	**TDS**	**SAR**	**SSP**	**RSC**	**Hardness(mgL-1)**	
1	Ex	Fre	Ex	Ex	Suit	MH	C1-S1
2	Ex	Fre	Ex	Good	Suit	MH	C1-S1
3	Ex	Fre	Ex	Good	Suit	MH	C1-S1
4	Ex	Fre	Ex	Good	Suit	MH	C1-S1
5	Ex	Fre	Ex	Good	Suit	Soft	C1-S1

Table 5. (Contd.)

Sample no.	Water Class Based on						Alkalinity-salinity class
	EC	TDS	SAR	SSP	RSC	Hardness(mgL-1)	
6	Ex	Fre	Ex	Good	Suit	Soft	C1-S1
7	Ex	Fre	Ex	Good	Suit	Soft	C1-S1
8	Ex	Fre	Ex	Ex	Suit	MH	C1-S1
9	Ex	Fre	Ex	Good	Suit	Soft	C1-S1
10	Ex	Fre	Ex	Good	Suit	Soft	C1-S1
11	Ex	Fre	Ex	Good	Suit	MH	C1-S1
12	Ex	Fre	Ex	Ex	Suit	Soft	C1-S1
13	Ex	Fre	Ex	Ex	Suit	MH	C1-S1
14	Ex	Fre	Ex	Ex	Suit	Soft	C1-S1
15	Ex	Fre	Ex	Good	Suit	Soft	C1-S1
16	Ex	Fre	Ex	Good	Suit	MH	C1-S1
17	Ex	Fre	Ex	Good	Suit	MH	C1-S1
18	Ex	Fre	Ex	Ex	Suit	Hard	C1-S1
19	Ex	Fre	Ex	Ex	Suit	MH	C1-S1
20	Ex	Fre	Ex	Good	Suit	MH	C1-S1
21	Ex	Fre	Ex	Ex	Suit	MH	C1-S1
22	Ex	Fre	Ex	Ex	Suit	MH	C1-S1
23	Ex	Fre	Ex	Ex	Suit	Soft	C1-S1
24	Ex	Fre	Ex	Ex	Suit	MH	C1-S1
25	Ex	Fre	Ex	Good	Suit	Soft	C1-S1

Table 5. (Contd.)

Sample no.	**Water Class Based on**						**Alkalinity-salinity class**
	EC	**TDS**	**SAR**	**SSP**	**RSC**	**Hardness(mgL-1)**	
26	Ex	Fre	Ex	Good	Suit	Soft	C1-S1
28	Ex	Fre	Ex	Good	Suit	Soft	C1-S1
29	Good	Fre	Ex	Ex	Suit	MH	C2-S1
30	Ex	Fre	Ex	Good	Suit	MH	C1-S1
31	Ex	Fre	Ex	Good	Suit	Soft	C1-S1
32	Ex	Fre	Ex	Good	Suit	MH	C1-S1
33	Ex	Fre	Ex	Good	Suit	MH	C1-S1
34	Ex	Fre	Ex	Good	Suit	MH	C1-S1
35	Ex	Fre	Ex	Good	Suit	MH	C1-S1
36	Ex	Fre	Ex	Good	Suit	MH	C1-S1
37	Ex	Fre	Ex	Good	Suit	MH	C1-S1
38	Ex	Fre	Ex	Good	Suit	MH	C1-S1
39	Ex	Fre	Ex	Good	Suit	MH	C1-S1
40	Ex	Fre	Ex	Ex	Suit	MH	C1-S1
41	Ex	Fre	Ex	Ex	Suit	MH	C1-S1
42	Good	Fre	Ex	Ex	Suit	MH	C2-S1
43	Ex	Fre	Ex	Ex	Suit	MH	C1-S1
44	Ex	Fre	Ex	Ex	Suit	MH	C1-S1
45	Good	Fre	Ex	Ex	Suit	Hard	C2-S1
46	Ex	Fre	Ex	Good	Suit	Soft	C1-S1

Table 5. (Contd.)

Sample no.	**Water Class Based on**						**Alkalinity-salinity class**
	EC	**TDS**	**SAR**	**SSP**	**RSC**	**Hardness(mgL-1)**	
47	Ex	Fre	Ex	Good	Suit	Soft	C1-S1
48	Ex	Fre	Ex	Good	Suit	MH	C1-S1
49	Ex	Fre	Ex	Good	Suit	MH	C1-S1
50	Ex	Fre	Ex	Ex	Suit	MH	C1-S1

Legend: Ex=Excellent, Fre=Fresh, Suit=Suitable, MH=Moderately Hard,

8. Total cations

The amount of cations of water samples were reported in Table 2. The sum of cations ranged from 2.09 to 4.73 meq/L (Table 6). The standard deviation (SD) was 0.54 with 0.54 meq/L the mean value. Dominated cations were calcium, magnesium, sodium, potassium. Others were (copper, zinc, iron and phosphorus) very low in amount (table 2). The maximum values for copper, manganese, iron were respectively 0.05, 0.04 and 0.2 meq/L. These maximum values were for only few samples. And the minimum values for the same ions were undetectable. Another ion zinc was also very low in amount. For this reason these ions could not

affect the total sum of cations. Calculating of total cations is very important for correctness of analysis.

9. Total anions

The determined anions namely phosphate, sulfate, bicarbonate and chloride were reported in table 3. The major ions were HCO_3^- and Cl^- (Rao et al., 1982). All water samples were free from carbonate. Values of sulfate and phosphate for all samples were also very low in amount. The minimum value of sulfate was undetectable and the maximum value was 0.13 meq/L. The chloride values of water samples were ranged from 0.72 to 1.6 meq/L. Excess chloride above the background levels may be due to groundwater contamination as a result of seepage from septic systems, landfill, fertilizers or animals. Total anions are used to checking the correctness of analysis.

10. Correctness of analysis of water samples

The acceptable limits for cations and anions balance were ranged from 5-10%. The percent difference between anion and cation of water samples was varied from 3 to 13 % (Table 6). Total anions and cations must be balanced because all potable waters were electrically neutral. All samples were the acceptable limits, only three sample (sample no. 18, 27 and 45) contained 12.93, 11.3 and 13.04%, respectively. According to this condition all water samples were seemed to be reproducible and accurate.

11. Permeability Index and Permeability Salinity

The range of the value of Permeability Index (PI) for all water samples was varied from 0.43 to 1.16 and the mean value was 0.78 (Table 4). The range of calculated values for the Permeability salinity of water samples was 0.77 to 1.66. The average value of this term was 1.06 (Table 4). Permeability Problem occurs when normal infiltration rate of soil is appreciably reduced and hinders moisture supply to crops which is responsible for two most water quality factors as salinity of water and its sodium content relative to calcium and magnesium. Highly saline water increases the infiltration rate. Relative proportions of other different cations or balance of some cations and anions defined by SAR, SSP, KR, MAR, TH, RSBC etc. also the indicators of permeability problem.

Table 6: Cation-anion balance

Sample no.	**Sum Cation**	**Sum Anion**	**Cation-Anion**	**Cation+ Anion**	**Difference**	**5-10%**
1	3.09	2.72	0.37	5.81	0.06	6.36
2	3.47	3.00	0.47	6.47	0.07	7.27
3	2.80	2.56	0.24	5.36	0.04	4.43
4	3.07	2.56	0.51	5.63	0.09	9.08
5	2.83	2.52	0.31	5.35	0.06	5.85
6	2.66	2.28	0.38	4.94	0.08	7.75
7	2.73	2.56	0.17	5.29	0.03	3.24
8	2.86	2.48	0.38	5.34	0.07	7.12
9	2.74	2.40	0.34	5.14	0.07	6.59
10	2.72	2.56	0.16	5.28	0.03	3.05
11	2.89	2.52	0.37	5.41	0.07	6.77
12	2.36	2.04	0.32	4.40	0.07	7.21
13	2.46	2.12	0.34	4.58	0.07	7.43
14	2.06	1.72	0.34	3.78	0.09	9.10
15	2.75	2.36	0.39	5.11	0.08	7.61
16	2.88	2.64	0.24	5.52	0.04	4.38
17	2.81	2.48	0.33	5.29	0.06	6.16

Table 6. (Contd.)

Sample no.	**Sum Cation**	**Sum Anion**	**Cation-Anion**	**Cation+ Anion**	**Difference**	**5-10%**
18	4.67	3.60	1.07	8.27	0.13	12.93
19	3.16	2.80	0.36	5.96	0.06	6.06
20	2.82	2.48	0.34	5.30	0.06	6.42
21	3.28	2.84	0.44	6.12	0.07	7.24
22	2.31	2.12	0.19	4.43	0.04	4.30
23	2.74	2.40	0.34	5.14	0.07	6.64
24	2.53	2.20	0.33	4.73	0.07	6.92
25	2.26	1.96	0.30	4.22	0.07	7.06
26	2.54	2.24	0.30	4.78	0.06	6.22
27	4.67	3.72	0.95	8.39	0.11	11.30
28	2.56	2.16	0.40	4.72	0.09	8.55
29	3.27	2.80	0.47	6.07	0.08	7.78
30	3.14	2.88	0.26	6.02	0.04	4.25
31	2.29	2.12	0.17	4.41	0.04	3.92
32	3.21	2.76	0.45	5.97	0.08	7.58
33	3.01	2.68	0.33	5.69	0.06	5.85
34	2.99	2.68	0.31	5.67	0.05	5.42
35	2.99	2.52	0.47	5.51	0.09	8.55
36	2.88	2.40	0.48	5.28	0.09	9.01
37	2.92	2.56	0.36	5.48	0.07	6.62
38	3.10	2.92	0.18	6.02	0.03	3.01

Table 6. (Contd.)

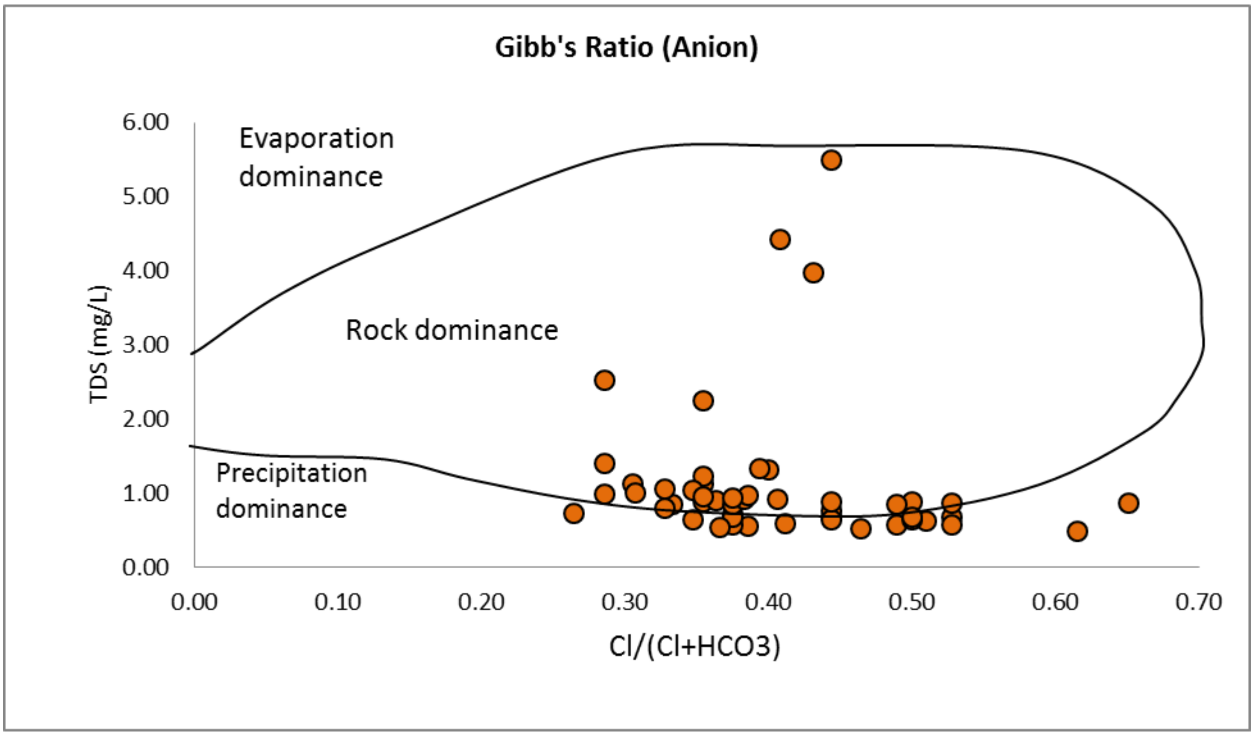
Sample no.	Sum Cation	Sum Anion	Cation-Anion	Cation+ Anion	Difference	5-10%
39	3.35	2.76	0.59	6.11	0.10	9.61
40	2.61	2.40	0.21	5.01	0.04	4.13
41	2.98	2.48	0.50	5.46	0.09	9.23
42	3.01	2.48	0.53	5.49	0.10	9.59
43	3.02	2.60	0.42	5.62	0.07	7.44
44	3.25	2.80	0.45	6.05	0.08	7.51
45	4.58	3.52	1.06	8.10	0.13	13.04
46	2.73	2.28	0.45	5.01	0.09	8.99
47	2.53	2.08	0.45	4.61	0.10	9.75
48	2.99	2.56	0.43	5.55	0.08	7.71
49	2.89	2.72	0.17	5.61	0.03	3.00
50	2.39	1.96	0.43	4.35	0.10	9.92

12. Gibbs ratio

The ranges of Gibbs ratio for anions and cations were varied from 0.26 to 0.65 and 0.33 to 0.83, respectively (Table 4). The average values for both ratios were 0.41 (for anions) and 0.61 (for cations). Gibbs diagram for study area is shown in Figure 3. In this diagram, Gibbs ratios (for anions and cations) of all water samples are plotted against the Total Dissolved Solids (TDS). This diagram is very important to know the groundwater chemistry, which is occurred due to the evaporation dominance, rock dominance and precipitation dominance. From this diagram, maximum samples fall into the precipitation dominance and some samples fall into the rock dominance.

13. Kelly's Ratio

The Kelly's ratio for all water samples were ranged from 0.09 to 1.19 with the mean value was 0.43 (Table 4). In case of Average Kelly's Ratio (KR) all the samples accept sample no. 31 were found less than the permissible value of 1.0 showing a good balance of sodium, calcium and magnesium ions. The result also indicates a good tilth condition of the soil with no permeability problem.



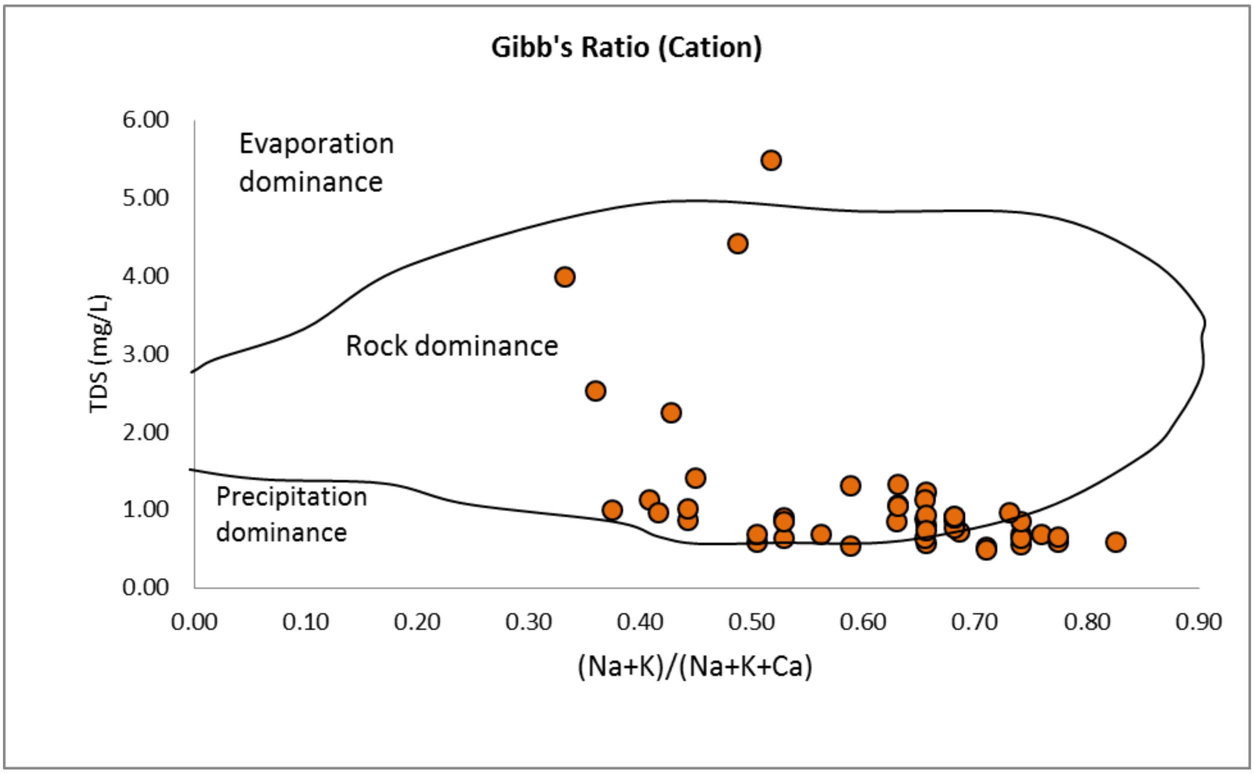


Figure 3: Mechanism controlling the quality of water samples of Baliadangi Upazilla (Gibbs, 1970)

14. Suitability of water samples for irrigation proposes

The EC value of all samples varied from 81 to 727 µScm^{-1} and mean value was 170 µScm^{-1} and these values were reported in Table 3. Wilcox (1955) classified water quality into five groups on the basis of EC value. According to Wilcox, 46 samples were 'Excellent' and 4 samples were 'good' for irrigation. Higher concentration of EC indicated higher concentration of dissolved constituents that may affected the irrigation water quality. All water samples contained SSP value ranged from 7.39 to 38.98 meq/L and the Standard Deviation (SD) was 9.48 meq/L (Table 4). According to Eaton (1950), 49 samples were considered as 'excellent' for irrigation. Wilcox (1955) also divided water quality of the SSP into four classes (Table 7). From this classification, 30 samples were considered as 'good' (Table 5) for irrigation and rest of them were 'excellent' for irrigation purpose.

The pH values of water samples that were collected from Baliadangi upazilla varied from 5.4 to 6.9 and mean value is 5.8 (Table 3). The mean value of all samples is 8.5. 48% of water samples containing 5.4 to 5.8 pH value and pH value of rest samples ranged from 5.9 to 6.9. The pH value of all samples indicated that these samples of water were slightly acidic. All samples were in recommended value (Table 8). Water quality for irrigation has a great impact on crop production. The important factors that control the pH solution during crop production are:

1) pre-plant substance such as dolomitic limestone put into the substance and substrate component themselves

2) the alkalinity of irrigation water.

3) the acidity or basicidy of the fertilizer used during crop production. All water samples were suitable for irrigation, according to the Table 8.

The values of total dissolved solids (TDS) of collected water samples varied from 48 to 549 mg/L and mean value was 113 mg/L (Table 3). According to Carroll (1962) and Freeze and Cherry (1979), water quality divided into four groups on the basis of TDS (Table 9). By following this classification, all samples were considered as ‘fresh’ for irrigation. Because of TDS values of all samples were less than 1000 mg/L (Table 3).

The value of Hardness for all samples was ranged from 3.58 to 182.88 mg/L and the mean value of the hardness was 90.24 mg/L (Table 3). According to McCarty (1967), water was classified into four groups on the basis of hardness (Table 10). By following this classification, maximum samples were considered as ‘soft’ (Table 5), some were ‘moderately hard’ and 3 samples (sample no. 18, 27 and 45) were ‘hard’ for irrigation.

Recommended concentration of different ions for irrigation is showed in table-8. According to this table chloride, copper, potassium, iron and zinc; all samples were under the recommended value.

Results of Sodium Adsorption Ratio (SAR) for all surface and groundwater samples were ranged from 0.25 to 1.45 meq/L (Table 4). All water samples for SAR were ‘excellent’ for irrigation indicated in Table 5, which is classified on the basis of criteria as shown in table-11.

The value of RSC for all samples was ranged from -1.7 to 0.32 meq/L and the mean value was -0.3 meq/L (Table 4). Eaton (1950) classified the irrigation water on the basis of RSC (Table 12). According to this classification all water samples were considered as ‘suitable’ for irrigation (Table 5).

Table 7. Irrigation water classification on the basis of EC and SSP (Wilcox, 1955)

Water class	Percent Sodium	Electrical Conductivity (EC) μScm^{-1}
Excellent	<20	<250
Good	20-40	250-750
Permissible	40-60	750-2,000
Doubtful	60-80	2,000-3,000

Table 8: Recommended concentration of different ions for irrigation

Element	**Recommended limit**
Bicarbonate	1.5 meq/L
Chloride (Cl)	4.0 meq/L
Copper (Cu)	0.20 mg/L
Iron (Fe)	5.00 mg/L

Element	**Recommended limit**
Manganese (Mn)	0.20 mg/L
Nitrate (NO_3)	< 5 mg/L
Potassium (K)	0-2.0 mg/L
Sulfate (SO_4)	0-20 mg/L
Zinc (Zn)	2.0 mg/L
pH	6.0-8.5

Table 9: Irrigation water classification based on TDS (Freeze and Cherry, 1979)

Water Class	Total Dissolved Solids (TDS), mg/L
Fresh water	0-1000
Brackish water	1,000-10,000
Saline water	10,000-100,000
Brine water	>100,000

Table 10: Classification of irrigation water based on hardness (Sawyer and McCarty, 1967)

Water Class	Hardness mg/L, as $CaCO_3$
Soft	0-75
Moderately hard	75-150
Hard	150-300
Very hard	>300

Table 11: Irrigation water classification based on SAR

Water Class	Sodium adsorption ratio (SAR)
Excellent	<10
Good	10-18
Fair	18-26
Poor	>26

Table 12: Irrigation water classification based on RSC (Eaton, 1950)

Suitability of water	Residual Sodium Carbonate (RSC), meq/L
Suitable	<1.25
Marginal	1.25-2.50
Unsuitable	>2.50

15. Suitability of water samples for drinking and domestic purposes

Drinking water standard on the basis of bicarbonate, calcium, chloride, copper, hardness, iron, magnesium, manganese, nitrate, phosphate, potassium, sulfate, sodium and zinc were presented in Table 13. On the basis of these limits, concentrations of all samples of water are far below the recommended limits for drinking and domestic purposes.

The pH range of our survey was varied from 5.4 to 6.9. According to the WHO, 2004, all water samples were within the safe limits for drinking purposes. Our drinking water pH level varies between 5.4 and 6.9. The safest pH level of drinking water would be 7 which is the pH level of pure water. When water has a low pH level it is called "soft water." Soft water is more acidic; with the pH between 6 and lower, it can be harmful to metals and cause stain in clothes.

The recommended concentration of TDS for drinking water was 500 mg/L. The concentration of TDS was ranged from 48 to 549 mg/L (Table 3). All samples except three samples (sample no. 18, 27 and 45) was considered as safe for drinking water. Todd (1980) reported that of the value of TDS higher than 500 mg/L, then that was considered as ‘undesirable’. So sample no. 18 was considered as undesirable for drinking purpose.

The calcium concentration of water samples were 0.27 to 1.2 meq/L. The chloride concentration of water samples were varied from 0.72 to 1.6 meq/L. All samples were within the recommended value for drinking water in case of both parameters. The concentrations of K^+ were 0.4 to 0.38 meq/L, except 3 samples all samples were suitable for drinking. The values of all water samples of Zn^{2+} were 0.01 to 0.05 meq/L. All water samples were within the recommended values. The concentrations of iron were 0.08 to 0.2 mg/L. All samples were suitable for drinking. The manganese values of water samples were 0.01 to 0.04 meq/L. From this range 47 samples were suitable for drinking. The values of water samples for sulfate were 0.04 to 0.13 meq/L. All water samples were safe to drink. According to the Table 14, no samples were suitable for drinking on the basis of magnesium concentrations (0.01 to 0.04 mg/L) of water samples. The range of sodium for all samples was from 0.34 to 0.88 meq/L. All water samples were suitable for drinking on the basis of sodium and phosphorus concentration. But the range of hardness is not suitable to drink.

In drinking water, excess concentration of some nutrients can cause health hazard. For example, Sodium should not exceed 200 mg/L. Higher concentration of sulfate in drinking water gives in associated with respiratory problems (Subba Rao, 1993).

Table 13: Recommended Concentration (mg/L) of different ions for drinking water (WHO, 2004)

Element	**Recommended limit**
Bicarbonate	11
Calcium (Ca)	75
Chloride (Cl)	250
Copper (Cu)	1
Hardness (H_T)	200-500
Iron (Fe)	0.10-0.30
Magnesium (Mg)	30-35
Manganese (Mn)	0.01-0.04
Nitrate (NO_3)	10
Phosphate (PO_4)	6
Potassium (K)	12
Sulfate (SO_4)	150
Sodium (Na)	200
Zinc (Zn)	5

16. Suitability of water samples for industrial uses

In table-15, the recommended concentration of different ions for industrial uses was presented. Based on TDS (48 to 549 mg/L), only 2% samples were suitable for brewing according to the table-14. But these concentrations of TDS were suitable for dairy (except sample no. 18) and all samples were suitable for carbonate beverage. 36 (72% samples) samples were suitable for confectionary and 45 (90% samples) samples were suitable for paper and pulp. Only 5 (10% samples) samples were suitable for the Ice manufacturing.

In case of hardness (36.58 to 182.88 mg/L), all samples were not suitable for carbonated beverage. In case of dairy only one sample (sample no. 45) is not suitable. Only one sample is suitable for laundering. But paper & pulp is suitable for 37 samples (74% samples) and 49 samples (98% samples) were suitable for tanning. 30% samples were suitable for confectionary. Only one sample was suitable for rayon manufacture and textile.

The recommended pH values for different industrial purposes were shown in table-15. The pH values of all samples were ranged from 5.4 to 6.9 (Table 3). 6 samples (12% samples) were suitable for tanning. 2% samples were suitable for brewing. All samples were not suitable for confectionary. 6 samples (12% samples) were suitable for laundering. No sample was suitable for rayon manufacture of industrial purposes.

In case of Cl^- concentration, the recommended values for different industrial uses were found in table-15. All samples were suitable for textile. No samples were suitable for brewing and all samples were suitable for carbonated beverage for industrial purposes. 7 samples (14% samples) were appropriate for dairy. No samples were suitable for sugar industrial purposes.

The suggested values for Fe^{3+} were shown in Table 14 for industrial uses. All samples were suitable for any kind of industrial uses.

The recommend Mn^{++} values for industrial uses were shown in table-14. According to these suggested values no sample was suitable for carbonated beverage, Confectionary, Ice manufacture and Laundering industry. 18% samples were proper for air-conditioning industry. No sample was suitable for brewing purposes. All samples were suitable for dairy industry. 66% water samples were suitable for paper and pulp and sugar industrial purposes. All samples were not suitable for tanning. 86% samples were suitable for textile. All samples were inappropriate for tanning industrial uses.

The suggested values of sulfate were given in table-14. According to this table all samples were suitable for carbonated beverage, 36 samples (72% samples) were suitable for textile and 6 samples (12% samples) were suitable for dairy industrial uses. All samples were inappropriate for sugar industry.

Table 14: Recommended concentration of different ions for industrial process waters

Use	**TDS mg/L**	**Hardness mg/L**	**pH**	**Cl^- Mg/L**	**$SO_4^=$ Mg/L**	**Fe^{3+} Mg/L**	**Mn^{++} Mg/L**
Air-conditioning	-	-	-	-	-	0.5	0.5
Brewing	500-1500	-	6.5-7.0	60-100	-	0.1	0.1
Carbonated beverage	850	200-250	-	250	250	0.1-0.2	0.2
Confectionary	50-100	Soft	>7	-	-	0.2	0.2
Dairy	500	180	-	30	60	0.1-0.3	0.03-0.2
Ice manufacture	170-1300	-	-	-	-	0.2	0.2
Laundering	-	0-50	6.0-6.88	-	-	0.2-1.0	0.2
Paper and Pulp	200	100	-	-	-	0.1	0.5
Rayon manufacture	-	55	7.8-8.3	-	-	-	-
Sugar	-	-	-	20	20	0.1	-
Tanning	-	50-500	6.0-8.0	-	-	0.1-0.2	0.1-0.2
Textile	-	0-50	-	100	100	0.1-1.0	0.05-1.0

These all ions and their industrial uses are present in the Figure 4 as graphically.

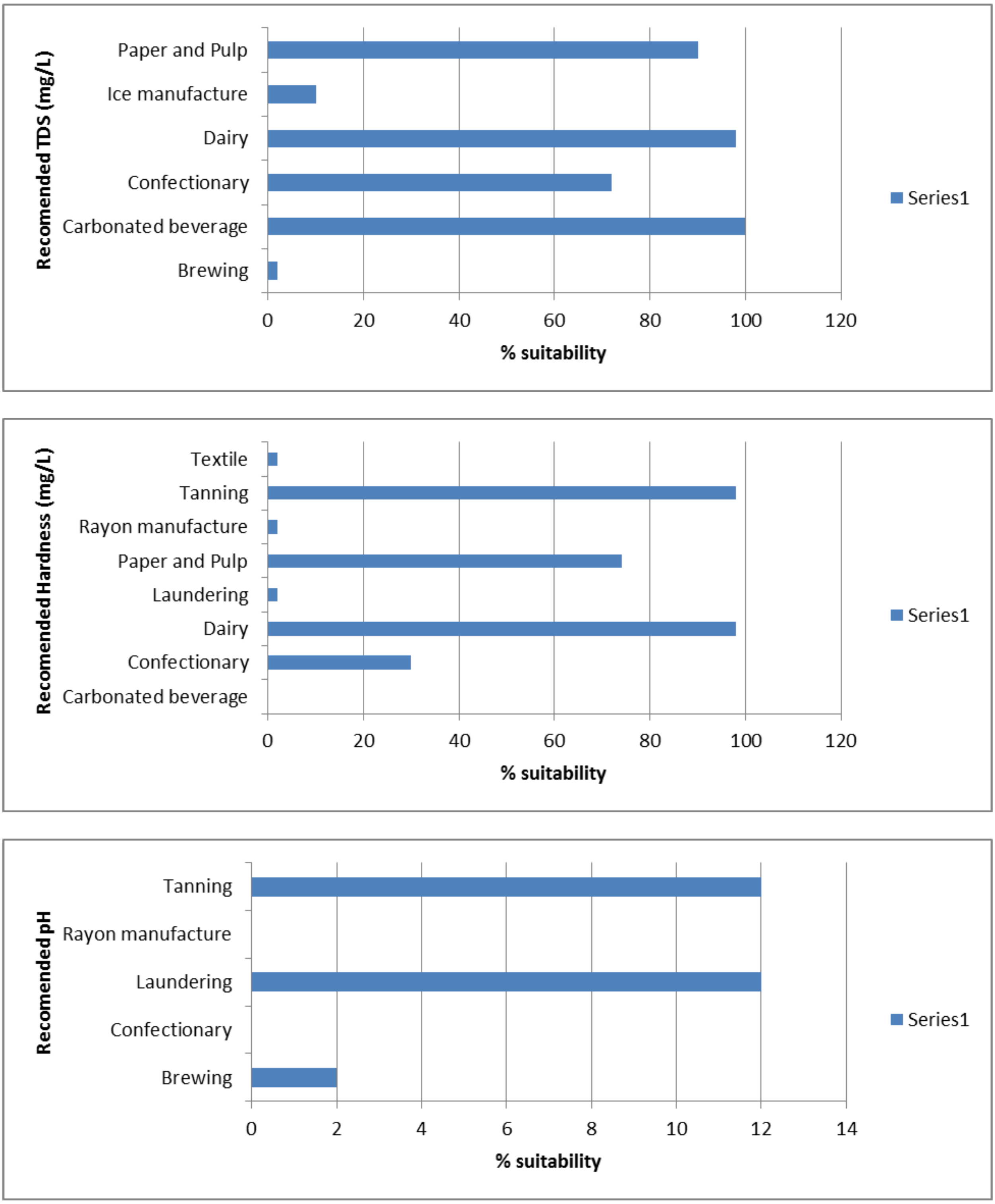


Figure 4: Relative suitability of studied water sample for various industries based on TDS, Hardness, pH, Cl^-, $SO_4^=$ and Mn^{++} concentration. In X axis, the recommended concentrations for different industries are shown according to Todd and Mays (2005).

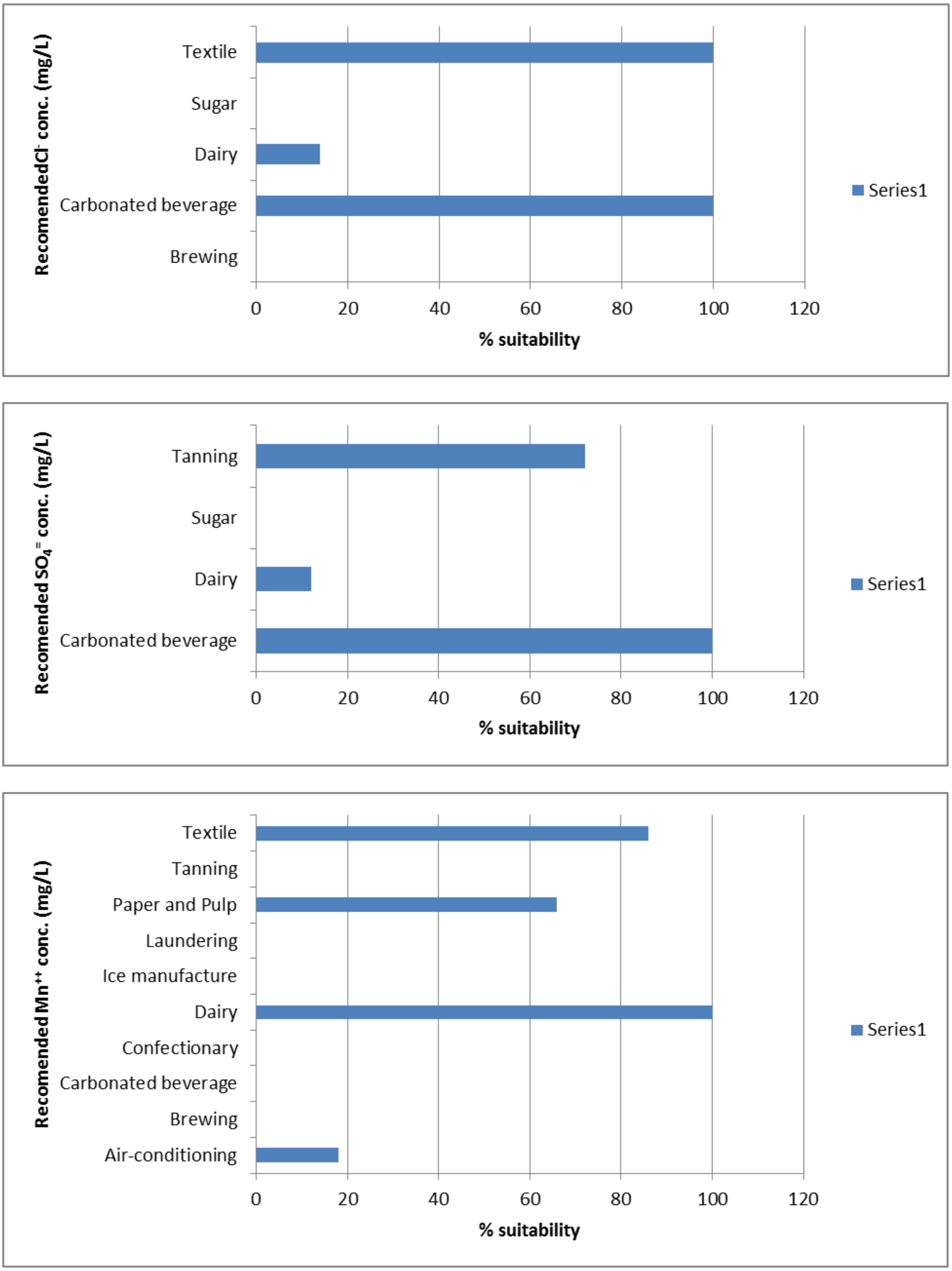


Figure 4. (Contd.)

17. Compositional relationship

In case of relationship between Na and Cl we can see that most of samples were higher than unity, some of them were lower and few were equal to one (Figure 5). The correlation co-efficient was 0.0034 (Table 15). This relationship is mainly used to know the mechanisms for acquiring salinity and saline intrusions (Jalali, 2007). All higher values were reflected the release of sodium ions from silicate weathering (Meyback, 1987). All samples were contained low concentration of Cl^-. According to Jalali (2007), dissolution of halite has no effect in the regulation of Na^+ in the ground water due to these low concentrations of Cl^-. On the other hand, Cl^- was increased due to increase of alkalis metal and this is considered as the common source for Cl^- (Datta and Tyagi, 1996). According to the Jankowski and Acworth (1997), the main reason of increasing Na^+ and Cl^- is evapotranspiration.

The compositional relationship between $Na^+ + K^+$ and $Cl^- + SO_4^{-2}$ were shown in Figure 5 and correlation co-efficient was 0.0164 (Table 15). This ratio is significant in the balance of cation and anion. The ratio of $Ca^{2+} + Mg^{2+}$ and $HCO_3^- + SO_4^{-2}$ was found in this figure. In this ratio we can see that $HCO_3^- + SO_4^{-2}$ concentration is higher than the concentration of $Ca^{2+} + Mg^{2+}$. It is possible only for the magnesium hazard. In this study area, maximum samples were contained lower concentration of magnesium. The correlation co-efficient was 0.4851 (Table 15). On the other hand, the compositional relationship between $Ca^{2+} + Mg^{2+}$ and $Cl^- + SO_4^{-2}$ was also shown in Figure 5. The correlation co-efficient was 0.1452 (Table 15). In this figure, all samples were lower than the unity. Because low concentrations of Cl^- and SO_4^{-2}. In other compositional relation that is $Na^+ + K^+$ and $HCO_3^- + SO_4^{-2}$ polled in figure 2. The R^2 value of this ratio was 0.0041 (Table 15). In this relationship, maximum samples were higher than the one. This ratio indicates the lower concentration of Na^+ and K^+ than the concentration of $HCO_3^- + SO_4^{-2}$. There were also found another ratio of $Na^+ + K^+$ and HCO_3^- in Figure 2. The correlation co-efficient was 0.0029 (Table 15). In this ratio maximum samples were higher than unity. On the other hand, the relationship between Na^+ and HCO_3^- was shown in figure 2 and R^2 was 0.0146 (Table 15). These two ions are most dominating ions in groundwater. The main sources of these ions are mineral dissolutions (Sarin et al., 1989). The relationship between HCO_3^- and Na^+ is used to identify the weathering process in groundwater (Krishna Kumar et al., 2009 and Subba Rao, 2008). When this ratio is lower than one that means silicate weathering occurs, but when this ratio is higher than one then carbonate weathering occurs. In study area maximum samples were greater than one in this ratio, that means in this area carbonate weathering occurs.

The dominate anions for groundwater are HCO_3^- and Cl^-. When the concentration of HCO_3^- is decreased due to the precipitation of salts then Cl^- anion becomes dominate in the groundwater. This precipitation of salt ($CaCO_3$) is occurred to decline in calcium concentration. The ratio of Mg^{2+}:Ca^{2+} was greater than unity in ground water samples (Figure 5). The correlation co-efficient was 0.3251 (Table 15). This ratio indicates the higher concentration of sodium ion in groundwater. The main source of major cations (Mg^{2+} and Ca^{2+}) is weathering of calcium and magnesium minerals (Krishna Kumar et al., 2009).

The ratio of $Na^+ + Mg^{2+}$ and $Na^+ + Ca^{2+}$ was shown in Figure 5. The correlation co-efficient was 0.5864 (Table 15). In this figure $Na^+ + Mg^{2+}$ is greater than $Na^{2+} + Ca^{2+}$. This figure indicates the Na hazard can be greater (Yousaf et al., 1987). Ratios of Ca^{2+}:HCO_3^-+CO_3^- and Mg^{2+}: HCO_3^-+CO_3^- were shown in figure 2 and the correlation co-efficient were shown in Table 15. In these two ratios we can see that maximum samples were higher than unity. These ratios also indicate the predominance of calcium and magnesium ions over the sodium ions in the groundwater. For this result, the ratio of Ca^{2+}+ Mg^{2+}: total cations most of water sample were almost equal or less than unity.

The correlation co-efficient was 0.7835 (Table 15). On the other hand $Na^+ + K^+$: total cations were far below the unity (Figure 5). The correlation co-efficient was 0.0041 (Table 15).But in the relationship of Ca^{2+}+ Mg^{2+} and HCO_3^- , maximum samples were lower than the unity. The correlation co-efficient was 0.4782 (Table 15). All water samples were also polled in Na^+/Cl^- vs EC in Figure 5. In this diagram we can see that all points were found to spreads vertically. This diagram indicated that ratio of sodium and chlorine can be changed with the increases of EC value. The correlation co-efficient was 0.014 (Table 15).In case of ratio of Na^+: Ca^{2+}, few of samples were found under the unity. This ratio is shown in the figure 2. That means, sodium concentration is higher than the calcium concentration. The correlation co-efficient was 0.088 (Table 15).Another ratio of Cl: Total cations also found in this Figure 5. The correlation co-efficient was 0.0034 (Table 15). In this case all samples were lower than unity. Because of very low concentration of chloride.

Table 15: Correlation co-efficient and regression equation of different ionic constituents

Different variation	Correlation co-efficient	Regression Equation
Total cations-(Na^++K^+)	0.0041 NS	y = 0.0332x + 0.8328
Total cation-(Ca^{2+}+Mg^{2+})	0.7835**	y = 0.9594x - 1.0268
Na^+-Cl^-	0.0034 NS	y = -0.0008x + 1.0353
Na^+-(HCO_3^-)	0.0146 NS	y = 1.5791x + 0.8028
(Na^++Ca^{2+})-(Na^++Mg^{2+})	0.5864 NS	y = 1.5791x + 0.8028
Ca^{2+}-HCO_3^-	0.3312**	y = 0.9779x + 0.9464
(Na^++K^+)-HCO_3^-	0.193 NS	y = 0.0688x + 1.4599
(Ca^{2+}+Mg^{2+})-HCO_3^-	0.4782**	y = 0.4242x + 0.75
(Na^++K^+)-(HCO_3^-+SO_4^{2-})	0.0041NS	y = 0.0827x + 1.5397
(Ca^{2+}+Mg^{2+})-(HCO_3^-+SO_4^{2-})	0.485**	y = 0.4289x + 0.8342
(Na^++K^+)-(Cl^-+SO_4^{2-})	0.0164 NS	y = 0.0894x + 1.0254
(Ca^{2+}+Mg^{2+})-(Cl^-+SO_4^{2-})	0.1452 NS	y = 0.1267x + 0.8775
Mg^{2+}-HCO_3^-	0.4169**	y = 0.5287x + 0.8716
Ca^{2+}-Na^+	0.0743 NS	y = -0.3326x + 0.8923
EC-(Na^+/Cl^-)	0.0682 NS	y = -0.0006x + 0.8006
Total cation-Cl^-	0.0034 NS	y = -0.0008x + 1.0353
Ca^{2+}-Mg^{2+}	0.3251**	y = 1.1832x + 0.5351

NS = Nonsignificant

**=Significant

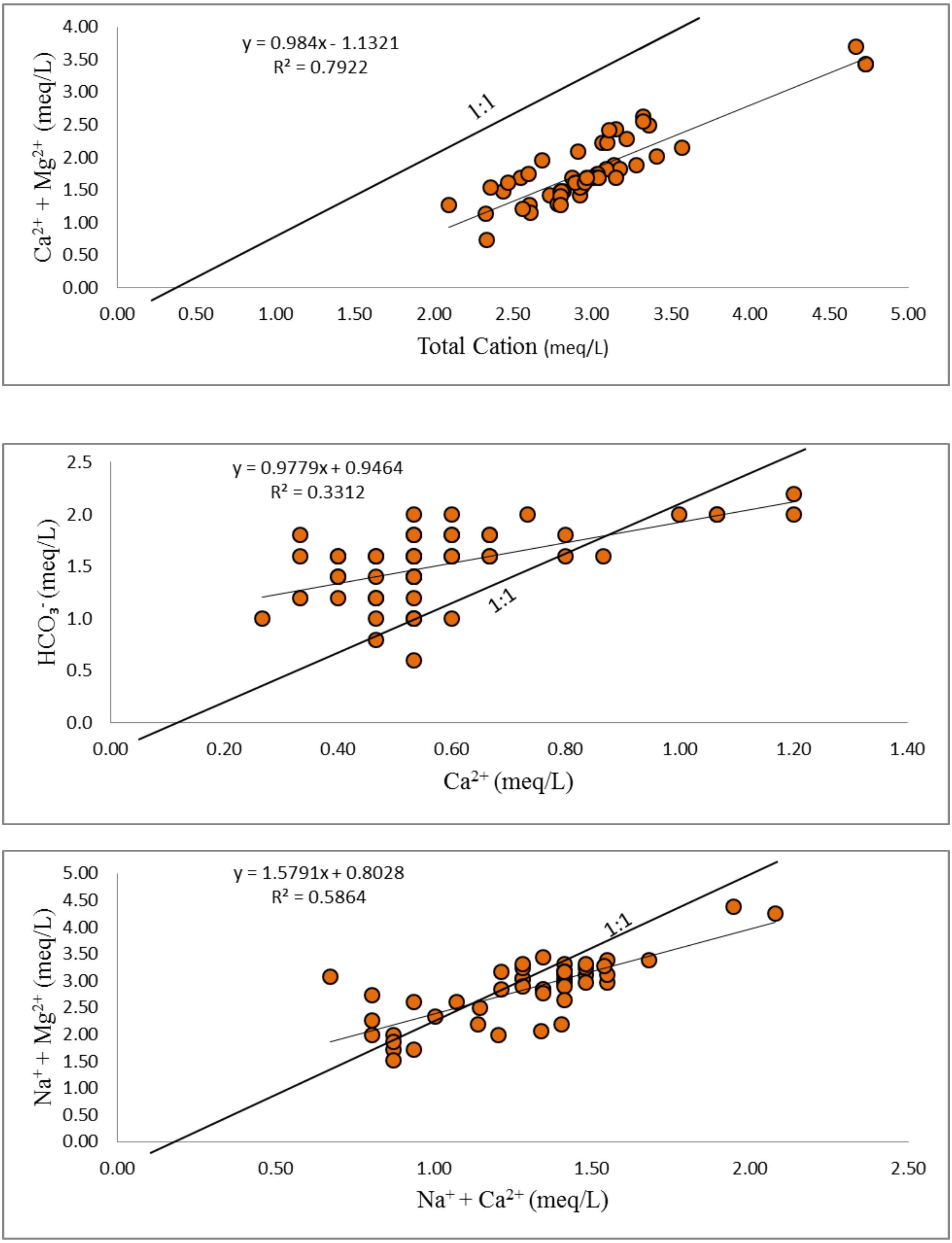


Figure 5: Ratios of the major anions and cations in groundwater from Baliadangi Upazilla, Bangladesh

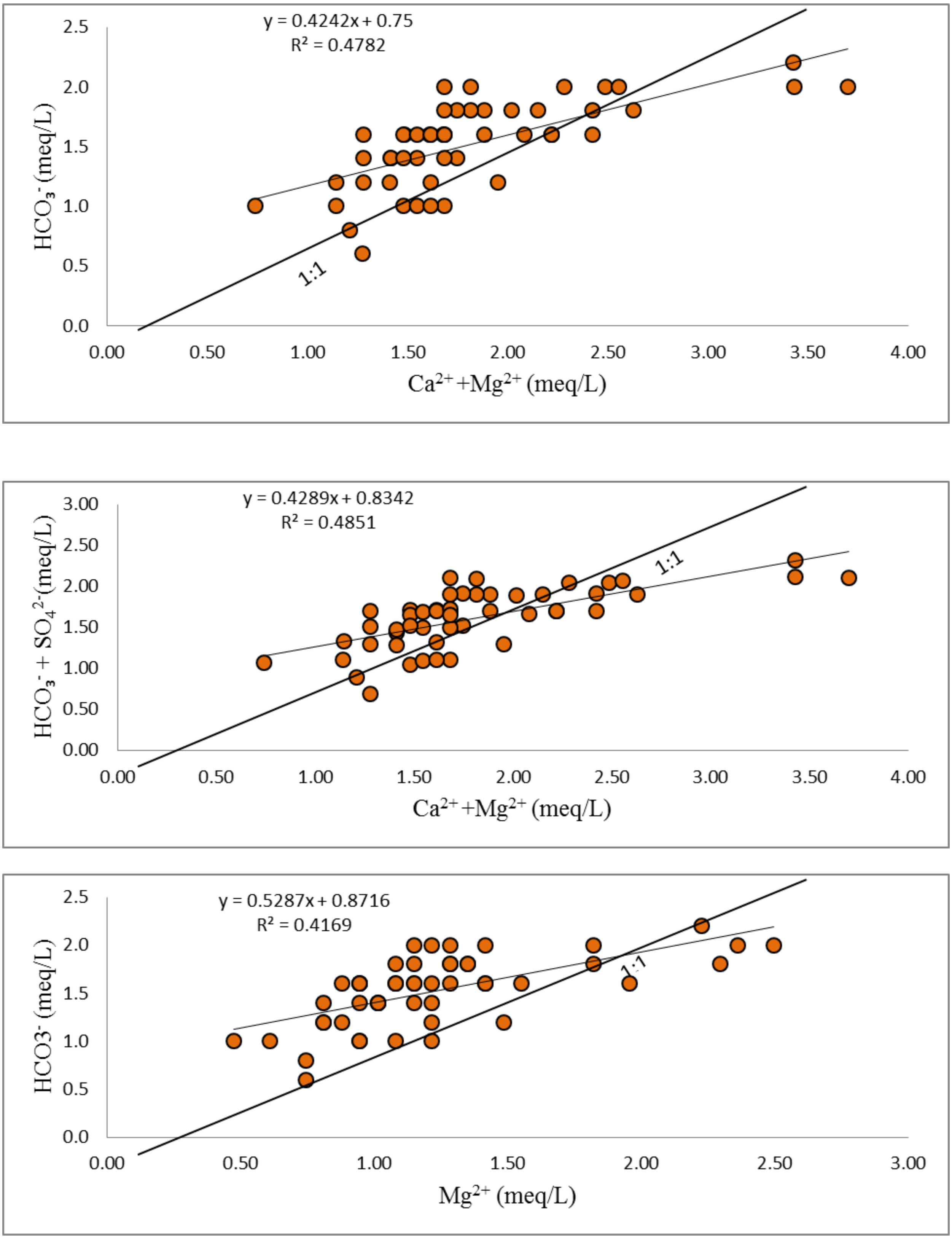


Figure 5. (Contd.)

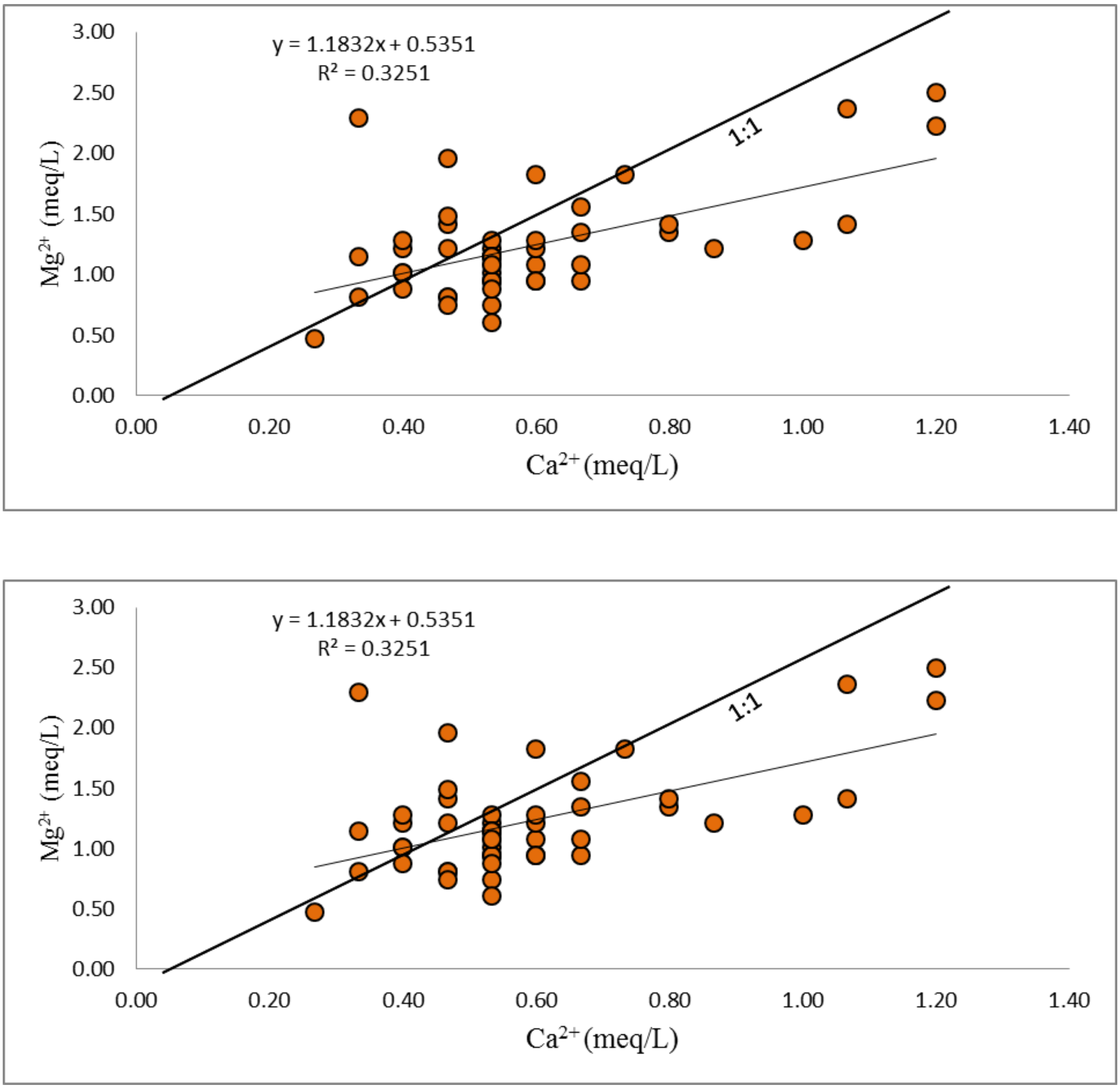


Figure 5. (Contd.)

Cation-Exchange:

Cation exchange is an important parameter of ionic concentrations in the water. According to Gimenez and Morell (1997) this parameter works as temporary buffer, when the ionic contents are changeable, causing non-steady-state conditions. The exchangeable cations on exchange sites tend to compensate for the variations of the chemical composition of waters, modifying considerably the cationic concentrations (Appelo and Postma, 1993).

The confirmation for ion exchange in the development of salinization can lead to release of sodium from clay products replacing calcium that present in ground water. A plot of Na^+ against Ca^{2+} was shown in Figure 5. There this plot shows that, the maximum date on or above 1:1 line. It happened for the excess of Na^+ over Ca^{2+}. This is occurred due to the proximity of the wells to the clay horizons. Another reason of this process of cation-exchange is higher concentration of sodium in the groundwater.

Another two important compositions are $Ca^{2+} + Mg^{2+}-HCO_3^-+ SO_4^{-2}$ and Na^+-Cl^-. These two compositions were responsible for the cation exchange. These two plots were shown in the Figure 5. From this $Ca^{2+} + Mg^{2+}-HCO_3^-+ SO_4^{-2}$ compositional relationship, we can find out the amount of calcium and magnesium gained or lost from provided gypsum, calcite and dolomite dissolution. On the other hand, Na^+-Cl^- plot reflects the amount of sodium gained or lost by chloride salt dissolution (mostly halite dissolution). These two compositions were significant, that reflects these two compositions linear with the slope of -1.

18. Correlation

The correlation among the five parameters pH, EC, SAR, SSP and RSC was studied for all water samples. There were ten combination of correlation from these five parameters. These were SAR-SSP, EC-SSP, EC-RSC, EC-SAR, pH-SSP, pH-EC, pH-SAR, pH-RSC, SSP-RSC and SAR-RSC. These correlations were shown in respectively Figure 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15. Their respective correlation co-efficient ‘R’ values were shown in Table 16. The tabulated ‘r’ was 0.267 at 1% level of significance. In this case, except SAR-SSP, SSP-RSC and SAR-RSC correlation all correlation co-efficient ‘R’ values were lower than this tabulated ‘r’ value. That means only one correlation was significant. These statistical parameters further reflect status of water in relation to their uses as irrigation, drinking and industrial purposes.

17 variations these were Total cations-(Na+K), Total cations-(Ca+Mg), Na-Cl, Na-(HCO_3+CO_3), (Na+Ca)-(Na+Mg), Ca-HCO_3, (Na+K)-HCO_3, (Ca+Mg)-HCO_3, (Na+K)-(HCO_3+SO_4), (Ca+Mg)-(HCO_3+SO_4), (Na+K)-(Cl+SO_4), (Ca+Mg)-(Cl+SO_4), Mg-HCO_3, Ca-Mg, EC-(Na/Cl), Total cations-Cl and Ca-Mg were shown in Figure 5 and there correlation co-efficient ‘R’ values were shown in Table 15. We can see that, the ‘R’ values of Total cation-(Ca^{2+}+Mg^{2+}), Ca^{2+}-HCO_3^-, (Ca^{2+}+Mg^{2+})-HCO_3^-, (Ca^{2+}+Mg^{2+})-(HCO_3^-+SO_4^{2-}), Mg^{2+}-HCO_3^-, and Ca^{2+}-Mg^{2+} were greater that the tabulated ‘r’ value (0.27) and they were significant correlation. And rest of them was lower than tabulated ‘r’ value, they were nonsignificant.

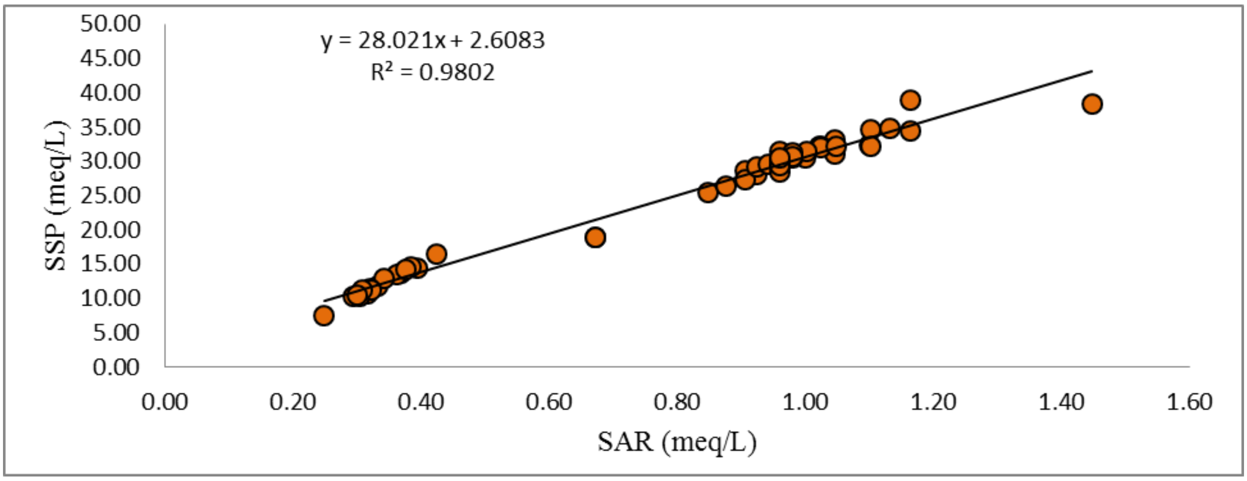


Figure 6: Relationship between SAR and SSP

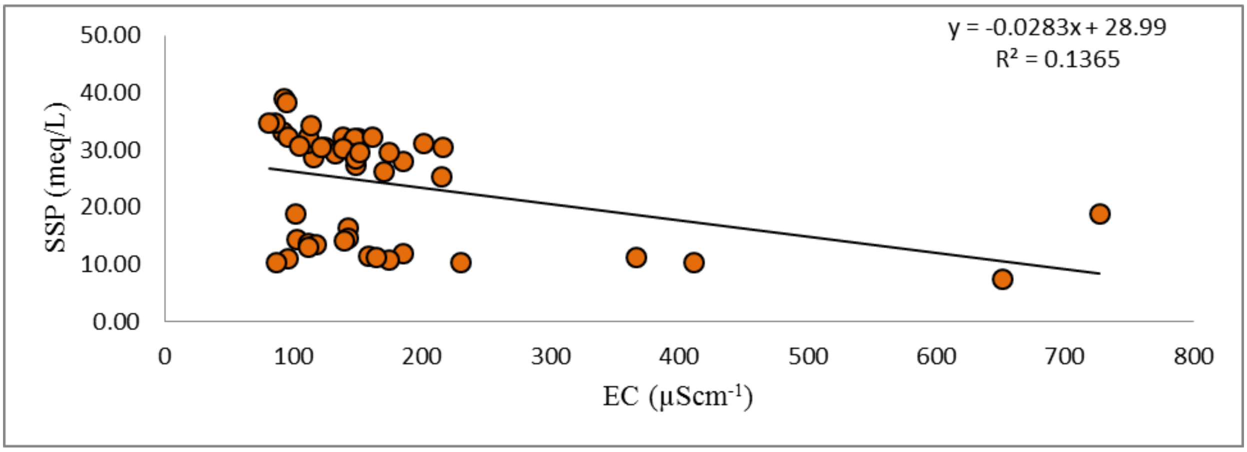


Figure 7: Relationship between EC and SSP

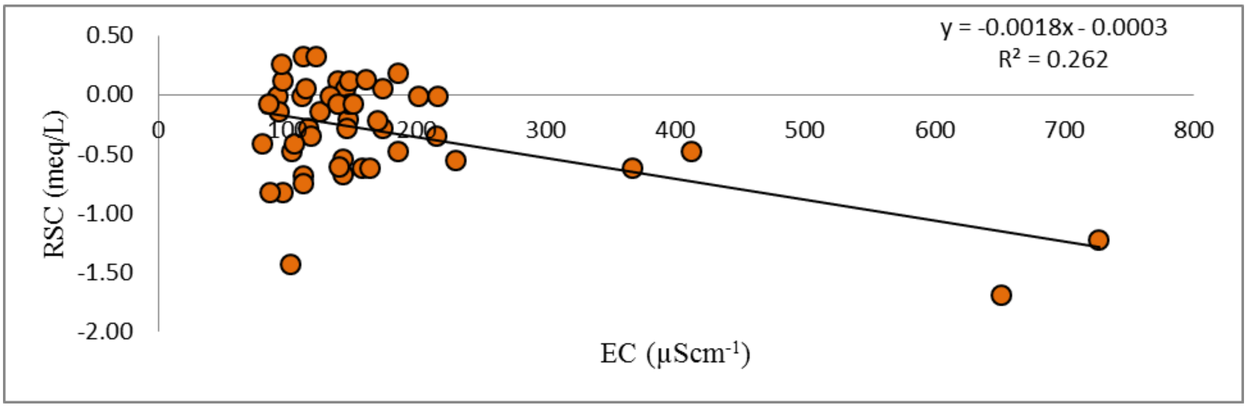


Figure 8: Relationship between EC and RSC

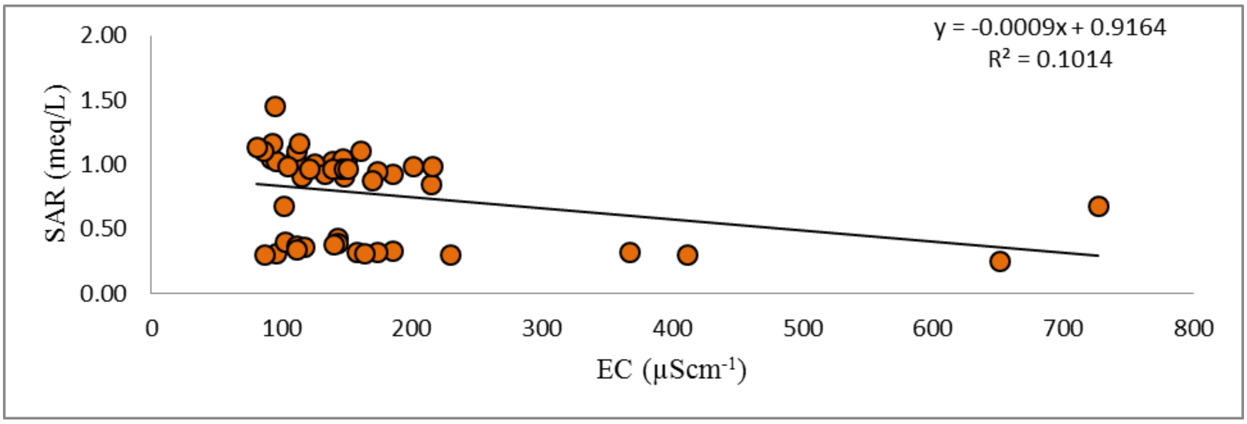


Figure 9: Relationship between EC and SAR

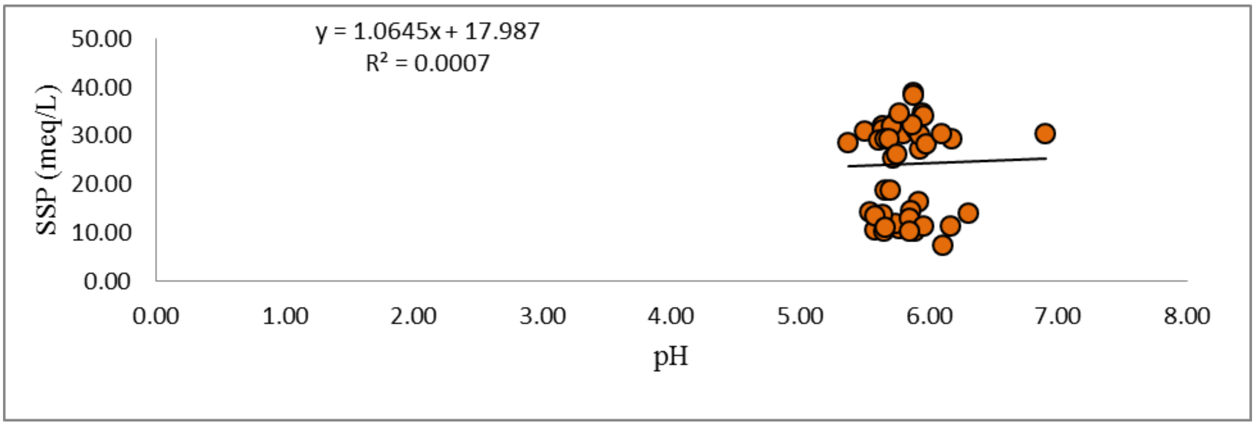


Figure 10: Relationship between P^H and SSP

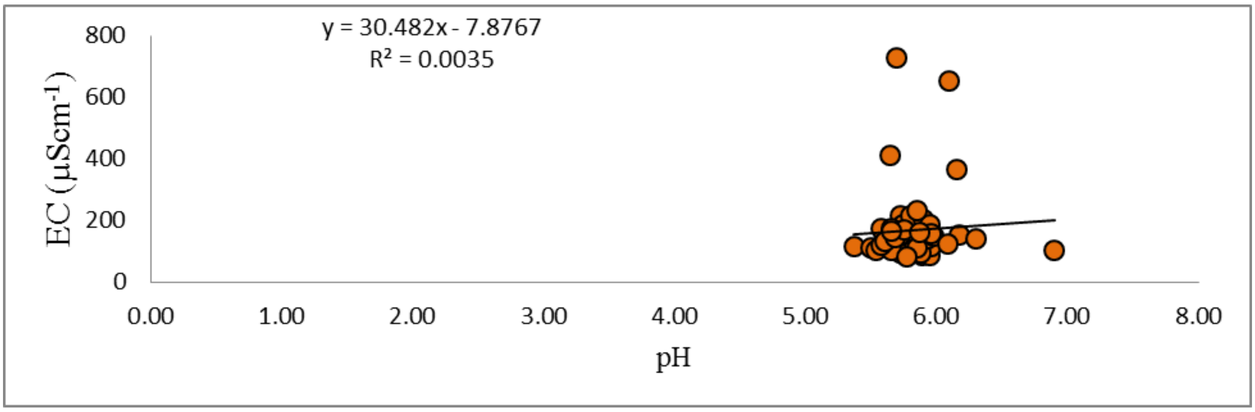


Figure 11: Relationship between P^H and EC

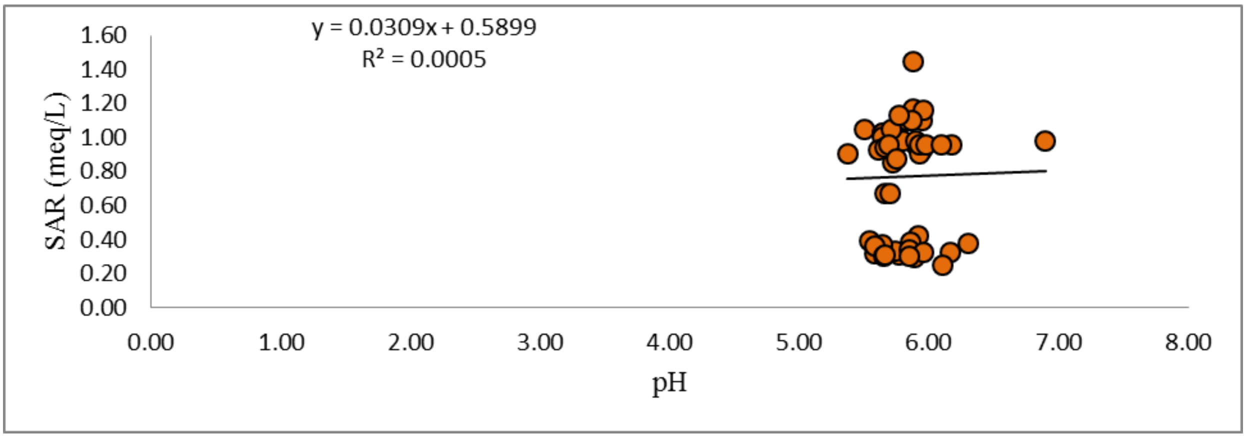


Figure 12: Relationship between P^H and SAR

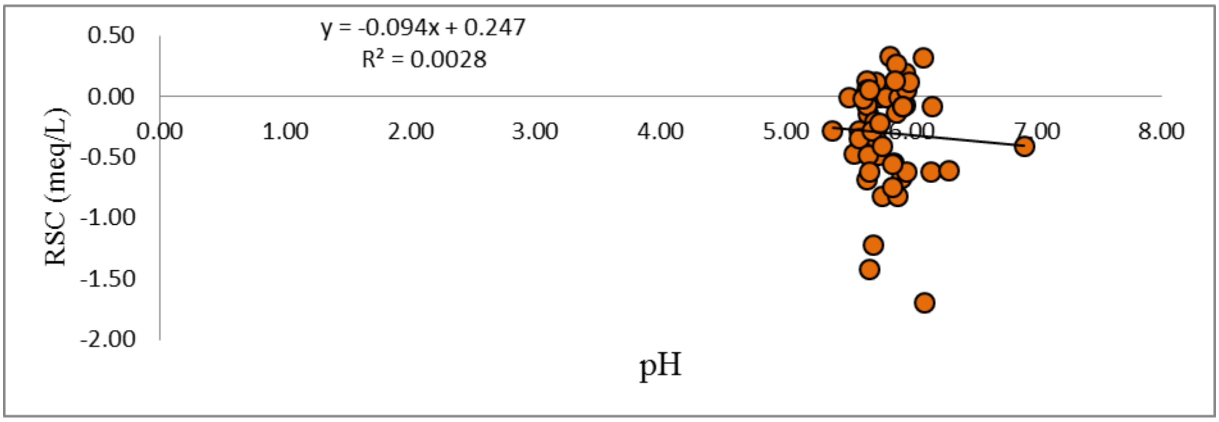


Figure 13: Relationship between pH and RSC

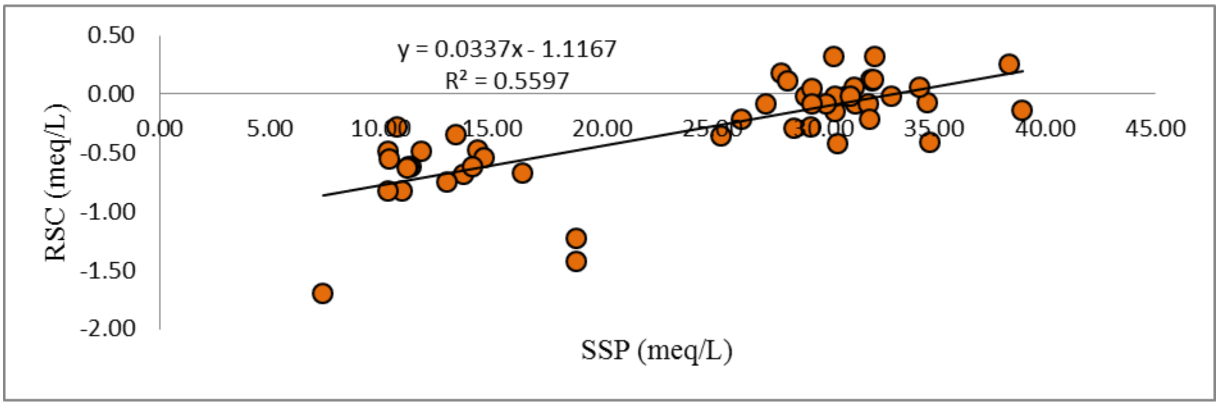


Figure 14: Relationship between SSP and RSC

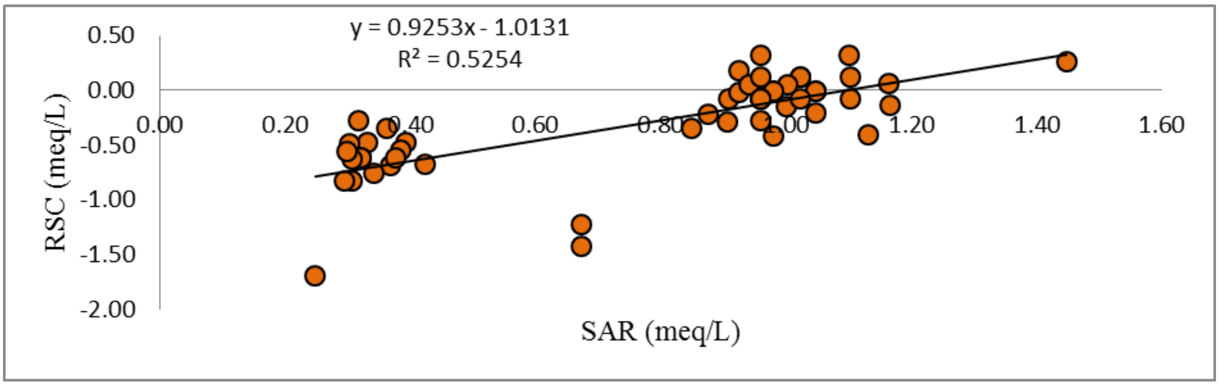


Figure 15: Relationship between SAR and RSC

Table 16: Correlation co-efficient and regression equation of different parameters

Different parameters	**Correlation co-efficient**	**Regression Equation**
SAR-SSP	0.9802**	y = 28.021x + 2.6083
EC-SSP	0.1365 NS	y = -0.0283x + 28.99
EC-RSC	0.262 NS	y = -0.0018x - 0.0003
EC-SAR	0.1014 NS	y = -0.0009x + 0.9164
pH-SSP	0.0007 NS	y = 1.0645x + 17.987
pH-EC	0.0035 NS	y = 30.482x - 7.8767
pH-SAR	0.0005 NS	y = 0.0309x + 0.5899
pH-RSC	0.003 NS	y = -0.094x + 0.247
SSP-RSC	0.559**	y = 0.0337x - 1.1167
SAR-RSC	0.525**	y = 0.9253x - 1.0131

NS= Nonsignificant

**= Significant

CHAPTER VI

SUMMARY

The location of the study area is Baliadangi Upozilla under Thakurgaon district of Bangladesh. This area is located at most northern region. Both the groundwater samples were collected in March 2014). Water samples were collected monthly from 15 deep tube wells, 18 shallow tubewells and 17 hand tube wells (Figure 1). Water samples were collected for analyzing of dissolved chemical constituents and to classify the water according to their suitability for irrigation, drinking and industrial usage. In order to assess the suitability classes for irrigation, domestic and industrial uses, we measured pH, EC, TDS, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Zn^{2+}, Cu^{2+}, Mn^{2+}, Fe^{3+}, PO_4^{3-}, $HC0_3^{2-}$, SO_4^{2-} and Cl^{-}.

The pH values of water samples were varied from 5.4 to 6.9 (Table 3). All samples were suitable for irrigation. Maximum samples were appropriate for tanning, brewing, confectionary, laundering for industrial purposes. pH level varies between 6.5 and 9.5 for drinking water and according to the WHO, 2004, all water samples were within the safe limits for drinking purposes.

The EC value of all samples varied from 81 to 727µScm^{-1}. According to Wilcox, 46 samples were ‘Excellent’ and 4 samples ‘good’ (Table 7) for irrigation.

The concentrations of TDS were ranged from 48 to 549 mg/L (Table 3). All samples except 3 samples (samples no. 18, 27 and 45) were within the recommended limits for drinking. Water samples were not suitable for the brewing and Ice manufacturing of industrial uses. According to Carroll (1962) and Freeze and Cherry (1979), all samples were considered as ‘fresh’ for irrigation on the basis of TDS.

The 50 water samples in the study area showed little more amounts of calcium and magnesium among cations and of bicarbonate among anions. The calcium concentration of water samples were 5 to 24 mg/L. All samples were within the recommended value for drinking water. In case of chloride, values of water were 26 to 57 mg/L. All samples were also within the suggested value for drinking water. All water samples were also proper suitable for irrigation. In case of Cl concentration, water samples were not suitable for brewing, textile and carbonated beverage for industrial purposes. 80 % & 55% samples were appropriate for dairy and sugar industrial purposes.

According to the Table 16 copper, potassium, and zinc; all samples were under the recommended value for irrigation and drinking. All samples were suitable for drinking on the basis of the concentration of Iron. On the other hand, all samples were suitable for irrigation. 100% samples were suitable for air-conditioning industry according the suggested value of Fe. 78% samples were proper for brewing, paper and pulp and sugar industry. 38 samples and 19 samples from 50 samples were suitable for respectively Confectionary, Ice manufacture industry and carbonated beverage. 55% samples were appropriate for dairy. 18 samples were suitable for Laundering industry. 36% and 62% samples were suitable for respectively tanning and textile industrial uses.

For the concentration of Mn^{2+}, 39 samples were suitable for drinking purposes. Maximum samples were suitable for different uses of industry on the basis of manganese values of water samples.

All water samples were safe to drink in case of sulfate concentration. According to these concentrations all samples were not suitable for carbonated beverage, textile and dairy industrial use and all samples were appropriate for sugar industry. For the irrigation, all samples were suitable. Samples were not suitable for drinking on the basis of magnesium concentrations (5.7 to 29.9 mg/L) of water samples.

All water samples were suitable for drinking on the basis of sodium and phosphorus concentration. On the basis of hardness, approximately no sample suitable for carbonated beverage, laundering, rayon manufacture and textile. 100% samples were suitable for dairy. 85% and 94% samples were suitable for respectively uses of paper and plup and tanning. But this range of hardness is not suitable to drink. According to McCarty (1967) classification, 17 samples were considered as ‘soft’ and 32 samples considered as ‘moderately hard’ and only three sample (sample no. 18, 27 and 45) was considered as ‘hard’ (Table 5) for irrigation on the basis of hardness.

The value of RSC for all samples was ranged from -1.7 to 0.32me/L. According to Eaton (1950) classification all water samples were considered as ‘suitable’ for irrigation (Table 5). All water samples for SAR were ‘excellent’ for irrigation indicated in Table 6. All water samples contained SSP value ranged from 7.39 to 38.98me/L. According to Eaton (1950), 20 samples were considered as ‘excellent’ and 30 samples were considered as ‘good’ for irrigation.

Some correlations and compositional relationships have been studied. These correlations were SAR-SSP, SSP-RSC and SAR-RSC. And compositional relationships were Total cations-(Na+K), Total cations-(Ca+Mg), Na-Cl, Na-(HCO_3+CO_3), (Na+Ca)-(Na+Mg), Ca-HCO_3, (Na+K)-HCO_3, (Ca+Mg)-HCO_3, (Na+K)-(HCO_3+SO_4), (Ca+Mg)-(HCO_3+SO_4), (Na+K)-(Cl+SO_4), (Ca+Mg)-(Cl+SO_4), Mg-HCO_3, Ca-Mg, EC-(Na/Cl), Total cations-Cl and Ca-Mg were shown in Figure 5 and there correlation co-efficient 'R' values were shown in Table 16. Except SAR-SSP, EC-SSP, EC-RSC, EC-SAR, SSP-RSC and SAR-RSC correlations all correlations were nonsignificant. On the other hand, some compositional relationships such as Total cation-(Ca^{2+}+Mg^{2+}), Ca^{2+}-HCO_3^-, (Ca^{2+}+Mg^{2+})-HCO_3^-, (Ca^{2+}+Mg^{2+})-(HCO_3^-+SO_4^{2-}), Mg^{2+}-HCO_3^-, and Ca^{2+}-Mg^{2+} were significant correlation. And rests of them were nonsignificant.

CHAPTER VII

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