EVALUATION OF GROUND WATER QUALITY OF BIROL AND BOCHAGONJ UPAZILLA IN DINAJPUR FOR IRRIGATION AND DRINKING USAGE

A THESIS

BY

TOPU KUMAR ROY

Student No: 1605556

Session: 2016-2017

Thesis Semester: July-December, 2017

MASTER OF SCIENCE (M.S.)

IN

IRRIGATION AND WATER MANAGEMENT

DEPARTMENT OF AGRICULTURAL AND INDUSTRIAL ENGINEERING

HAJEE MOHAMMED DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR

DECEMBER, 2018

EVALUATION OF GROUND WATER QUALITY OF BIROL AND BOCHAGONJ UPAZILLA IN DINAJPUR FOR IRRIGATION AND DRINKING USAGE

A THESIS

BY

TOPU KUMAR ROY

Student No: 1605556

Session: 2016-2017

Thesis Semester: July-December, 2017

Submitted to the Department of Agricultural & Industrial Engineering,

Hajee Mohammed Danesh Science and Technology University, Dinajpur
In partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE (M.S.)

IN

IRRIGATION AND WATER MANAGEMENT

DEPARTMENT OF AGRICULTURAL & INDUSTRIAL ENGINEERING

HAJEE MOHAMMED DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR

DECEMBER, 2018

EVALUATION OF GROUND WATER QUALITY OF BIROL AND BOCHAGONJ UPAZILLA IN DINAJPUR FOR IRRIGATION AND DRINKING USAGE

A THESIS

BY

TOPU KUMAR ROY

Student No: 1605556

Session: 2016-2017

Thesis Semester: July-December, 2017

Approved as to style and contents by

____

(**Dr. Md. Mofizul Islam**)
Associate Professor
Supervisor

____

(**Professor Dr. Mohammad Shiddiqur Rahman**)
Co-supervisor

____

(**Professor Dr. Md. Kamal Uddin Sarker**)

Chairman
Examination Committee
And
Chairman
Department of Agricultural & Industrial Engineering
Hajee Mohammad Danesh Science and Technology University, Dinajpur

December, 2018

DEDICATED

TO

MY BELOVED PARENTS

AND

HONORABLE TEACHERS

ACKNOWLEDGEMENT

All admirations and praises are solely due to Almighty God whose endless kindness mercy absolutely enabled the author to pursue study in Irrigation and Water Management discipline and to complete M.S. course and this research work successfully for the degree of M.S. in Irrigation and Water Management. The author expresses sincere appreciations, deep and sincere gratitude and profound indebtedness to reverend research supervisor **Dr. Md. Mofizul Islam**, Associate Professor, Department of Agricultural & Industrial Engineering (AIE), Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur for his valuable suggestions, scholastic guidance, constructive instructions, affectionate feelings and inspirations throughout the period of the research work and during the preparation of this thesis.

From the core of heart, the author humbly desires to express deepest and profound gratitude and immense indebtedness to the co-supervisor **Professor Dr. Mohammad Shiddiqur Rahman**, Department of Agricultural & Industrial Engineering (AIE), Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur for his critical advises and valuable comments as well as constructive criticisms during the research period and in the preparation of the dissertation. The author is happy to express sincere gratitude to teachers **Professor Dr. Md. Kamal Uddin Sarker,** Chairman, Department of Agricultural & Industrial Engineering (AIE), Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur for their cooperation and inspirations during the research work. The author humbly avails the opportunity of conveying heartiest respect and thankfulness to honorable teachers of the Department of Agricultural & Industrial Engineering (AIE), HSTU, for their encouragements, inspirations, active cooperation, valuable suggestions and providing research facility during the period of the study.

The author is also indebted to all laboratory and office staffs of the Department of Agricultural & Industrial Engineering and Department of Agricultural Chemistry, HSTU, Dinajpur, who directly or indirectly helped to complete this work.

Last but not least the author express heartfelt gratitude to beloved parents, other family members, friends who always sacrificed and all sorts of support their causes of happiness for higher study and constant inspirations throughout academic careers.

The Author

December 2018

ABSTRACT

A laboratory experiment was performed to determine the chemical constituents of groundwater for irrigation and drinking uses in the selected site of Birol and Bochagonj Upazila under Dinajpur district of Bangladesh. Thirty six and eighteen water samples of groundwater source were collected from different locations of Birol and Bochagonj Upazila, respectively for the determination of chemical constituents. The research work was accomplished to assess the extent of water quality and to predict the suitability and acceptability for drinking and irrigation usage. Groundwater samples collected from selected areas were classified by analyzing chemical constituents present therein. Several parameters like Ca, Mg, HCO_3, Fe, Mn, pH, EC, TDS, SAR, SSP, H_T, permeability index and Kelly's ratio were considered for the classification. In the study areas, the water contained an appreciable amount of Ca, Mg, Na, K. Fe, Mn, Zn, Cu and SO_4, which concentrations were found within safe limit for drinking and irrigating crops. The pH value of all the water samples indicating slightly acidic to slightly alkaline and found `suitable' for irrigation and drinking. On the combination basis of EC and SAR, all samples were low salinity and low alkali hazard. All the samples were graded as 'fresh water' based on TDS and "excellent" based on SSP, collected in Birol and Bochagonj upazilla. As regards to hardness, 12 samples were 'Soft' and 24 samples were 'Moderately Hard'for irrigation but 27 samples were 'Highest Desirable' and 9 samples were 'Desirable' for drinking in Birol upazilla and for Bochagonj upazilla, all samples were 'moderately hard' for irrigation but 12 samples were 'Highest Desirable' and 6 samples were 'Desirable' for drinking. All the waters under test were suitable and might be recommended for drinking and irrigating agricultural crop in the study area. The present investigation indicated that the analysis of groundwater is important for proper understanding of the irrigation and drinking. It is suggested that drinking and irrigation water should be analyzed systematically for understanding the impact of dissolved ions on the quality crops and soil health management in the entire area.

CONTENTS

CONTENTS (Contd.)

CONTENTS (Contd.)

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF APPENDICES (Contd.)

CHAPTER I

INTRODUCTION

Water is the fluid of life not only for human beings but also for any living organism. Water is abundant on the planet as a whole, but fresh potable water is not always available at the right place in the right quantity for human or ecosystem use. The main sources of water in Bangladesh are surface waters in rivers, reservoirs, lakes, canals and ponds, and the ground water in deep and shallow aquifer (Ahmed and Rahman, 2000). Ground water is the major source of drinking and other domestic water uses in many countries including Bangladesh. It has long been utilized as a readily accessible and stable source of water supply for domestic, industrial and agricultural use throughout the world (Keishiro, 2006).

In the global water resources, about 97.2% is salt water mainly in oceans, and only 2.8% is available as freshwater. Out of 2.8%, about 2.2% is available as surface water and 0.6% as ground water (Raghunath, 1987). At present one fifth of all the water used in the world is obtained from ground water sources. Agriculture is the greatest uses of water accounting for 80% of all consumption.The total irrigated area is about 3986235 ha of which (73-74%) areas is irrigated by ground water (BBS, 1997). In dry season (Jan-April), irrigation from the surface water is not economically feasible for most of the areas of river or small perenial streams.Thus ground water becomes the only dependable source of water supply for irrigation. Water quality for irrigation is an utmost important for successful crop production as it contains different ions in varying concentrations. If low quality of water is used for irrigation, toxic elements may accumulate in the soils and deteriorates soil properties. Therefore, the necessity for the assessment of suitability of ground water resources for drinking and irrigation purposes is becoming increasingly important and is demonstrated by the relatively large number of recent studies in this field (Peiyue *et al.* 2011; Tadesse *et al.* 2009).

There are several factors such as ions, salts, heavy metals, toxic elements, fertilizers, pesticides, insecticides and industrial wastages etc. that affect water quality and make the water quality poor. Using this poor quality water, it might deteriorate soil properties, crops yield and quality (Sarker *et al.* 2000). Alfalfa yield decreased by irrigating with poor quality water was reported by Prunty *et al.* (1991). High concentration of Na, B, Cl and HCO_3 ions of water affects directly the soils and crop yield (Sarker *et al.* 2000; Sarker *et al.* 2009). Osmotic effects of excessive salinity cause adverse soil physical properties and reduce crop growth. Salts from the irrigation water accumulate in the soil profile and cause soil dispersion and surface seal development during irrigation, thus decreasing infiltration rate and amount (Sarker, 2001).

Water generally contains different species of cations and anions in varying amounts. The principal soluble ions are Ca, Mg, Na, and K as cations and Cl, SO_4, CO_3 and HCO_3 as anions. Besides these, Cu, PO_4, Fe, Mn, Zn, As, B, Si and F are present in small amounts. Out of soluble constituents Ca, Mg, Fe, Na, Cl, HCO_3, SO_4 and B are of prime importance in determining the quality and suitability of irrigation water, especially for rice. Certain soluble ions at relatively high concentrations have a direct toxic effect on sensitive crops. The toxic elements are B, Na, Cl and Li. Specific water may be suitable for irrigation but may not be suitable for drinking and industrial uses due to presence of some other ions at toxic level. Most toxic elements for drinking water are As, Cd, Cr, Cl, Pb, Hg, Fe and Zn. The quality of water is generally judged by its total salts concentrations, relative proportion of cations or sodium absorption ratio (SAR) and the contents of HCO_3. The concentrations of some important chemical constituents of water are necessary to assess their suitability for irrigation, drinking and industrial uses.

Ground water seems to be pure and free from suspended materials in comparison to surface water, yet many compound and/or ions in varying amounts may be present in dissolved and/or ionic forms. If low quality water is used for drinking, domestic and beneficial uses, ionic toxicity as well as health hazards may occur. Sometimes, those substances are found at an objectionable level in ground water and considered as contaminated. When these waters are used in various irrigation, drinking and industrial purposes, they deteriorate the quality of the products. For the production of different products, there is a different limit of various variables such as pH, Total Dissolved Solids (TDS), Hardness (H_T), temperature and some ionic constituents. Besides these, chlorine and sulfate are the important variables to determine the toxicity and suitability of the water for industrial usage (Raghunath, 1987).

Proper utilization and overall management of ground water resources are important from the view point of it's after effects and economic viability, especially where huge volume of water is to be extracted from underground storage for large scale utilization. It's judicial utilization depends on reliable information of the static water level. Unplanned extraction from underground reservoir may lead to ground water over draft which may cause a number of long-term adverse effects including the irreparable geo-technical problem of land subsidence (Mojid, 1993).

Some studies on the assessment of water quality in some areas of Bangladesh namely Birganj, Dinajpur sadar, Dimla, Chirirbandar, Noakhali, Madhupur, Trishal, Sherpur, Meherpur, Shahjadpur upazila, etc has been conducted. Most of the chemical analysis of these studies included pH, EC, Ca, Mg, Na, K, HCO_3, Cl, Fe, Mn, Cu and Zn. But a little attention has been given to the concentration of micronutrients, toxic elements and static water level.

In the study area, there are different water sources in which deep tube well was mainly applied for irrigation. In cropping sequences; rice, vegetable and Rabi crops were also found to be cultivated. Farmers apply irrigation water from ground water sources without testing its quality. But there is no organization to assess the extent of water toxicity systematically at field level. Keeping all these facts in mind, this area was selected to evaluate the toxicity levels and static water level of ground water.

Objectives:

An attempt has been made to conduct a research work with the following objectives:

1. To assess the degree of ionic toxicity of ground water sources.
2. To categorize ground waters on the basis of standard criteria.
3. To predict the suitability and acceptability of ground water for irrigation uses.

CHAPTER II

REVIEW OF LITERATURE

Water is a universal solvent and contains variable quantities of inorganic and organic substances. Sometimes, suspended and colloidal materials are also found in it. It is necessary to determine the quality of water and its possible effects on soil properties due to long term irrigation and it's suitability for drinking and industrial usage. Few research works have been conducted on this perspective at home and abroad. But systematic research work on the Dinajpur is limited. An attempt has been made in this chapter to review the pertinent research information related to water quality assessment and static water level. Some relevant research reports are mention here under the following heads:

2.1 pH

The pH of ground water collected from Eastern Surma Kushiara flood plain and neighbouring region of Sylhet division varied from 5.27 to 7.99 (Ahsan, 2004).The pH values of ground water collected from Kushtia and Chuadanga district ranged between 6.87 to 7.43 (Azad, 2004). The pH of ground water collected from Pabna sadar upazilla under Pabna district varied from 7.50 to 8.20 reflecting acidic to alkaline in nature (Arefin, 2002). The pH of ground water collected from Sherpur upazilla under Bogra district varied from 4.20 to 8.80 reflect in acidic to alkaline properties (Rahman, 2000). Sen *et al.,* (2000) found that the pH of water sources at Tongi were within the range of 6.69 to 7.63.

The pH of ground and surface waters of Meherpur ranged from 7.80 to 8.10 and all waters under test were not problematic for irrigating agricultural crops (Quddus and Zaman, 1996). Ground water pH of Phulbari thana under Mymensingh district was within the range of 8.10 to 8.30 (Shahidullah, 1995). In ground water samples collected from Gazipur recorded the pH ranging from 7.25 to 8.62 (Quayum, 1995).

The pH of ground and surface water of Nilphamari district was 6.81 to 7.81 indicated slightly acidic to slightly alkaline as per Luna (2010). Groundwater pH in Gaibandha aquifers varied from 6.73 to 8.66 (Jesmin, 2000). Ground and surface water pH of Matiranga thana in Khagrachari district ranged from 4.02 to 7.54 indicating acidic to slightly alkaline (Helaluddin, 1996).

2.2 Electrical conductivity and salinity

The electrical conductivity (EC) from Eastern Surma Kushiara flood plain and neighbouring region of Sylhet division were found 19.57 to 1655.40 µS cm^{-1} (Ahsan, 2004). The EC of 85 ground water samples collected from Kushtia and Chuadanga districts were found to range from 412 to 1331 μScm^{-1} (Azad, 2004). The EC value of 46 ground water samples collected from Pabna sadar upazilla were found from 0.47 to 0.90 dS cm^{-1} (Arefin, 2002). The EC of 50 ground water samples collected from Sherpur upazilla under Bogra district were found to range from 442.80 to 670.80 μScm^{-1} (Rahman, 2001). Sen *et al.* (2000) carried out an experiment to determine water quality of irrigation at Tongi aquifer under the district of Gazipur and observed that the EC of surface and ground water ranged from 185 to 992 μScm^{-1} and the EC of ground water collected from Muktagacha ranged from 246 to 416 µS cm^{-1} (Hossain and Ahmed, 1999). Alamgir *et al.* (1999) examined ground water samples of Madhupur tract and indicated that EC values ranged from 230 to 350 µS cm^{-1} where all the ground water samples under test were graded as low to medium salinity class. Another investigation was earned out by Rahman and Zaman (1995) at Shahjadpur Thana under Sirajgonj and stated that the EC of some selected rivers and ground waters used for irrigation was within the range of 500 to 834 μScm^{-1}. The EC values of 15 ground water samples collected from Pangsha Thana of Rajbari district varied from 240 to 670 μscm^{-1} (Zaman and Mohiuddin, 1995). Gupta (1984) revealed that groundwater quality deteriorated with increasing the soil depth and the EC value varied from 4 to 74 μscm^{-1} at 13 to 38m depth and also from 31 to 448 dsm^{-1} at 38 to 210 m depth.

2.3 Total dissolved solids

The total dissolved solids (TDS) of ground water of Eastern Surma Kushiara flood plain and neighbouring regions of Sylhet division varied from 13.87 to 1036.88 mg L^{-1} (Ahsan, 2004). The TDS of Kushtia and Chuadanga districts ranged from 247.78 to 870.45 mg L^{-1} (Azad, 2004). The total dissolved solids of ground water of Pabna sadar upazila under Pabna district ranged from 336.26 to 671.89 mg L^{-1} (Arefin, 2002). The total dissolved solids of ground water of Sherpur under Bogra district ranged from 194.85 to 458.48 mg L^{-1} (Rahman, 2001). The TDS of some surface and ground water of Tongi under Gazipur district ranged from 123 to 675 mg L^{-1} (Sen *et al.*, 2000). The values of TDS of ground water in Sherpur sadar under Sherpur district ranged within the limit of 112 to 358 mg L^{-1} (Hoque, 2000). Quddus and Zaman (1996) cited that the TDS were within the range of 282 to 462 mg L^{-1} in irrigation water of both surface and ground water sources of Meherpur Sadar under the district of Meherpur.

The TDS of irrigation water collected from sadar thana under Gazipur district ranged from 70 to 260 mg L^{-1} (Quayum, 1995). Zaman and Majid (1995) stated that the ground waters of Madhupur thana under Tangail district contained TDS ranging from 100 to 600 mg L^{-1} showing freshwater in quality.

2.4 Cations

2.4.1 Calcium, magnesium, sodium and potassium

Roy *et al.*, (2012) reported that Ca content in Comilla *was* from 0.70 to 7.41 meq L^{-1}. The major cations basically Ca, Mg, Na and K collected in ground water samples from Lakshmipur and Noakhali district ranged from 1.37 to 35.60, 6.44 to 38.21, 1.3 to 55.78 and 9.1 to 90.66 mg L^{-1}, respectively (Uddin, 2005). The concentration of Calcium (Ca), Magnesium (Mg), Sodium (Na) and Potassium (K) in ground water samples collected from Eastern Surma Kushiara flood plain and neighbouring regions of Sylhet division ranged from 0.42 to 61.7, 0.017 to 41.0, 0.7 to 228 and 0.7 to 130 mg L^{-1}, respectively (Ahsan, 2004). Ca, Mg, Na and K contents in ground water of Pabna sadar upazila ranged from 0.80 to 3.80, 1.50 to 4.30, 0.02 to 0.07 and 0.06 to 0.14 meL^{-1}, respectively (Arefin, 2002) and those of Sherpur upazila under Bogra district ranged from 0.50 to 2.50, 0.80 to 3.60, 0.10 to 1.36 and trace to 0.22 meq L^{-1}, respectively (Rahman, 2001). Sen *et al.*, (2000) observed that the concentrations of Ca, Mg, Na and K in Tongi aquifers ranged from 0.50 to 3.21, 0.70 to 5.13. 0.20 to 2.28 and 0.12 to 0.59 meq L^{-1}, respectively. Quddus and Zaman (1996) reported that Ca, Mg, Na and K contents in surface and ground water of Meherpur ranged from 2.06 to 2.80, 1.01 to 1.60, 0.28 to 0.68 and 0.12 to 0.32 meq L^{-1}, respectively.

Shahidullah (1995) reported that the concentrations of Ca, Mg, Na and K in ground water of Phulphur thana under Mymensingh district ranged from 1.40 to 2.65, 0.65 to 1.08. 0.23 to 1.40 and 0.04 to 0.26 meq L^{-1}, respectively and of ground water samples collected from some villages of Madhupur thana under Tangail district varied from 0.72 to 3.12, 0.78 to 3.12, 0.10 to 0.80 and 0.14 to 0.58 meq L^{-1}, respectively (Zaman and Majid, 1995). Quayum (1995) showed that the ground water collected from Gazipur sadar thana contained Ca, Mg, Na and K within the range of 0.55 to 1.65, 0.04, 0.43 to 1.00 and 0.02 to 0.05 meq L^{-1}, respectively. Mitra and Gupta (1999) observed that during monsoon season, Ca, Mg, Na and K contents in tubewell water in vegetable growing area around Kolkata were 8.00, 3.40, 1.30 and 0.50 meq L^{-1} while in winter season the concentrations of those cations were 9.00, 4.20, 1.60 and 0.90 meq L^{-1}, respectively. Pucci *et al.* (1992) carried out an experiment on confixing unit effects on water quality in the New Jersey Coastal Plain and stated that the concentrations of Ca and Mg ranged from 1.70 to 666.00 mg L^{-1} and 0.30 to 140.00 mg L^{-1}, respectively.

2.4.2 Zinc

The concentration of Zinc (Zn) in collected ground water samples of Eastern Surma and Kushiara Flood plain and neighbouring regions of Sylhet division ranged from 0.002 to 0.02 mg L^{-1} (Ahsan, 2004), and in Kushtia and Chuadanga districts it varied from trace to 0.05 mg L^{-1} (Azad, 2004). Quddus and Zaman (1996) reported that the concentrations of Zn in surface and ground water of some villages in Meherpur sadar varied from traces to 0.1 mg L^{-1}.

The content of Zn in ground waters of Gazipur sadar thana varied from trace to 0.05 mg L^{-1} (Quayum, 1995). Rahman and Zaman (1995) studied the river and ground water to assess the quality for irrigation purposes and observed that Zn concentration varied from 0.023 to 0.045 mg L^{-1}. Mohiuddin (1995) showed that the collected irrigation water samples of Pangsha thana of Rajbari district contained the range of Zn was 0.02 to 0.05 mg L^{-1}. The concentration of Zn in ground waters of Phulbari thana under Mymensingh district was in the range of 0.01 to 0.03 mg L^{-1} (Shahidullah, 1995).

2.4.3 Iron

The concentration of Fe in ground water samples collected from Eastern Surma Kushiara flood plain and neighbouring region of Sylhet division varied from 0.05 to 61.0 mg L^{-1} (Ahsan, 2004), and in ground water samples of Kustia and Chuadanga districts ranged from 0.07 to 8.32 mg L^{-1} (Azad, 2004). Iron concentration in ground water of Pabna sadar upazila varied from 0.028 to 0.488 mg L^{-1} (Arefin, 2002), in Sherpur aquifers under Bogra district it varied from 0.07 to1.25 mg L^{-1} (Rahman, 2000). Sen *et al.*,(2000) reported that concentrations of Fe in surface and ground water collected from Torigi aquifers ranged from trace to 0.09 mg L^{-1}.

The concentration of Fe in ground water of Phulpur thana under Mymensingh district was within the range of 0.10 to 1.30 mg L^{-1} (Shahidullah, 1995). Quayam (1995) reported that Fe^{-1}. The irrigation water samples of Pangsha thana of Rajbari contained Fe within the range of 0.10 to 2.00 mgL^{-1} (Mohiuddin, 1995). Rahman (1993) reported that the surface and ground water of Shahzadpur thana in Sirajgonj district contained Fe within the range of 0.10 to 0.42 mg L^{-1} and iron was dominant in ground water compared to surface water. Quddus (1993) cited that the concentration of Fe in surface and ground water of Meherpur sadar thana ranged from traces to 0.05 mg L^{-1}.

2.4.4 Manganese

The concentration of Mn in collected ground water samples of Eastern Surma and Kushiara flood plain and neighbouring regions of Sylhet livision ranged from 0.015 to 3.97 mg L^{-1} (Ahsan, 2004), and in Kushtia and Chuadanga districts it varied from trace to 0.18 mg L^{-1} (Azad, 2004). Manganese concentration in ground water of Pabna sadar upazila varied from 0.008 to 0.403 mg L^{-1} (Arefin, 2002), in Sherpur upazila under Bogara district it ranged from 0.01 to 0.81 mg L^{-1} (Rahman, 2001).

The concentrations of Mn in surface and ground water collected from Tongi aquifers ranged from traceto 0.30 mg L^{-1} (Sen *et al.*, 2000). The concentration of Mn in groundwaler of Muktagacha thana ranged from 0.02 to 0.86 50 µg L^{-1} with the average value of 0.29 50 µg L^{-1} (Hossain and Ahmed, 1999).

Quayum (1995) reported that Mn content in ground water of Gazipur sadar thana varied from trace to 0.20 mg L^{-1} and Hahidullah (1995) found that the concentrations of Mn in ground water of Phulpur thana under Mymensingh district was within the range of 0.02 to 0.05 mg L^{-1}. The collected irrigation waters of Pangsha Thana of Rajbari district contained Mn within the range 0.01 to 0.07 mg L^{-1} (Mohiuddin, 1995). In Meherpur Sadar thana it ranged from trace to 0.20 mg L^{-1} (Quddus, 1993).

Zaman *et al.*, (2000) conducted a study at three upazillas (Bagmara, Mahadebpur and Nachoul) in Barind area and observed that the mean values of Mn in groundwaters were 0.11, 0.134 and 0.0478 mg L^{-1}, respectively. Helaluddin (1996) stated that Mn content in surface and groundwater in Khagrachari district varied from trace to 0.70 mg L^{-1}.

2.5 Anions

2.5.1 Sulphate

The concentration of sulphate (SO_4) in Eastern Surma Kushiara flood plain and neighbouring region of Sylhet division ranged from 0.01 to 18.00 mg L^{-1} (Ahsan, 2004). Azad (2004) mentioned that ground water in Kushtia and Chuadanga districts contained SO_4 within the range of 0.02 to 40.4 mg L^{-1}. The concentration of SO_4 in ground water of Panba sadar upazila ranged from 0.14 to 5.58 mg L^{-1} (Arefin, 2002). Rahman (2001) mentioned that the collected ground water samples of Sherpur upazila under Bogra district contained SO_4 within the range of trace to 10.30 mg L^{-1}.The surface and ground water of Tongi under Gazipur district contained SO_4 within the range of trace to 11.00 mg L^{-1} (Sen *et al.,* 2000). Zaman and Majid (1995) stated that the concentrations of SO_4 in ground water in some villages of Madhupur under Tangail district ranged from 0.12 to 2.16 meq L^{-1} (Rahman and Zaman, 1995). The contents of SO_4 in surface and ground water in some village of Meherpur sadar under Meherpur district varied from trace to 7.20 meq L^{-1} (Quddus and Zaman, 1996).

2.5.2 Phosphate

Phosphate content of ground water samples of Eastern Surma Kushiara flood plain and neighbouring regions of Sylhet division aquifers varied from 0.041 to 12.00 mg L^{-1} (Ahsan, 2004). The contents of PO_4 collected ground waters samples of Kushtia and Chuadanga districts ranged from 0.31 to 7.66 mg L^{-1} (Azad, 2004). The concentration of PO_4 in ground water of Pabna sadar upazila ranged from trace to 0.19 mg L^{-1} (Arefin, 2002). The concentration of PO_4 in surface and ground water collected from Tongi varied from trace to 0.05 mg L^{-1} (Sen *et al.,* 2000).

The content of PO_4 in surface and ground water samples collected from Bhaluka upazila under Mymensingh district ranged from trace to 0.47 mg L^{-1} (Nizam, 2000) and that of Muktagacha aquifers ranged from 0.10 to 1.40 mg $L^{-1}$with the mean value of 0.85 mg L^{-1}(Hossain and Ahmed, 1999).An experiment was earned out by Zaman and Majid (1995) to evaluate the ground water pollution at Rajbari districtand showed that the PO_4 concentration in all collected water samples ranged from0.02to 0.09 mg L^{-1}. The PO_4 content of surface, shallow and deep tubewell water of Meherpur sadar under Meherpur district ranged from 0.12 to 0.32 mg L^{-1} (Quddus and Zaman, 1996). Phosphate content of groundwaters collected from Bagmara, Mahadebpur and Nachoul upazilas varied from trace to 0.07, trace to 0.22 and 0.03 to 0.45 mg L^{-1}, respectively (Zaman, 2000).

2.5.3 Carbonate and Bicarbonate

The concentration of CO_3 in Eastern Surma Kushiara flood plain and neighbouring region of Sylhet division was not detectable and the concentration of HCO_3 ranged from 8.5 to 569.1 mg L^{-1} (Ahsan, 2004), and In Kushtia and Chuadanga districts, the amount of CO_3 in all the ground water samples varied from trace to 25.8 mg L^{-1} and HCO_3 concentration was within the range of 115.33 to 475.96 mg L^{-1} (Azad, 2004), in Pabna sadar upazila CO_3 was not detectable and the concentration of HCO_3 ranged from 3.50 to 7.00 meq L^{-1} (Arefm, 2002). In Madhupur Tract, the concentration of CO3 in water ranged from trace to 2.00 mg L^{-1} and HCO_3 content varied from 0.50 to 8.00 meq L^{-1} (Nizam, 2000). Sen *et al.,* (2000) found that in ground water of Tongi under Gazipur district the concentration HCO_3 varied from 0.80 to 6.20 meq L^{-1}.

Ali (1997) assessed the ground water quality of high Barind Tract and showed that HCO_3 content of those waters varied from 2.00 to 5.40 meq L^{-1}. All the samples contained HCO_3 and CO_3 within the range of 0.60 to 0.85 meq L^{-1} (Razzaque, 1995). Zaman and Majid (1995) found that ground water of Meherpur Sadar under Meherpur district contained CO_3 and HCO_3 within the range of 0.04 to 0.04 and 0.80 to 2.52 meq L^{-1}, respectively in Pangshathana under Rajbari district these ranged from 0.16 to 1.12 and 2.24 to 3.52 meq L^{-1}, respectively (Zaman and Mohiuddin, 1995).

2.5.4 Chloride

The concentration of Cl in groundwatcr of Eastern Surma Kushiara flood plain and neighbouring region of Sylhet division ranged from 0.40 to 156.7 mg L^{-1} (Ahsan, 2004), and Azad (2004) reported that the concentration of Cl in Kushtia and Chuadanga districts aquifers varied from 5.30 to 80.50 mg L^{-1}. The concentration of Cl in ground water of Pabna sadar upszila ranged from 0.80 to 1.40 meq L^{-1} (Arefin, 2002). Rahman (2001) mentioned that the collected ground water samples of Sherpur upazila under Bogra district contained Cl within the range of 0.40 to 2.40 meq L^{-1}. Surface and ground water samples in Tongi under Gazipur district contained Cl within the limit of 0.80 to 4.80 meq L^{-1} (Sen *et al.,* 2000). Nizam (2000) sated that Cl content in all ground and surface waters of Madhupur Tract ranged from 0.2 to 2.6 meq L^{-1} and in Muktagacha aquifers it varied from 0.20 to 0.70 meq L^{-1} (Hossain and Ahmed, 1999). The Cl in irrigation water collected from Meherpur sadar it varied from 0.75 to 0.95 meq L^{-1} (Quddus and Zaman, 1996) and in Pangsha thana under Rajbari district it ranged from 0.24 to 2.25 meq L^{-1} (Zaman and Mohiuddin, 1995). Mitra and Gupta (1999) stated that Cl content in tubewell water used for irrigation duringboth monsoon and winter seasons were 45.60 and 55.20 mg L^{-1}, respectively.

2.6 Sodium adsorption ratio (SAR)

The computed sodium adsorption ratio (SAR) of ground water of Lakshmipur and Noakhali district ranged from 0.40 to 4.20 (Uddin, 2005). The computed sodium adsorption ratio (SAR) of ground water from Eastern Surma Kushiara flood plain and neighbouring region of Sylhet division ranged within 0.082 to 35.79 (Ahsan, 2004), and in Kushtia and Chuadanga district it ranged from 0.08 to 1.19% (Azad, 2004). The SAR of ground water of Pabna sadar upazila ranged from 0.38 to 1.05 with the mean value of 0.74 (Arefin, 2002), that of Sherpur upazila in Bogra district it ranged from 0.22 to 0.90 (Rahman, 2001) and in Sherpur sadar under Sherpur district ranged from 0.07 to 2.69 (Hoque, 2000), and Ahmed (1999) observed that the SAR of ground water of Muktagacha thana under Mymensingh district varied from 0.35 to 4.31.The SAR of ground water of Nachoul thana at high Barind Tract ranged from 0.36 to. 2.70 Ali (1997). Quddus and Zaman (1996) analyzed waters collected from some villages of Meherpur sadar under Meheipur district and stated that the SAR ranged from 0.21 to 0.49. The SAR of water samples of Gazipur sadar varied from 0.50 to 0.94 as reported by Quayum (1995).

The SAR values of surface and ground waters collected from Shahzadpur thana under Sirajgonj district varied from 0.56 to 0.85 (Rahman and Zaman, 1995). SAR values of the irrigation waters of Madhupur under Tangail district were categorized as low alkalinity hazard (S1) (Zaman and Majid, 1995).

2.7 Soluble sodium percentage (SSP)

Soluble sodium percentage (SSP) values in ground water of Lakshmipur and Noakhali district ranged from 17.03 to 90.92% (Uddin, 2005). The soluble sodium percentage (SSP) values in ground water of Eastern Surma Kushiara flood plain and neighbouring region of Sylhet division were within the range of 6.43 to 98.61% (Ahsan, 2004), that of

Kushtia and Chuadanga districts ranged from 4.38 to 28.98% (Azad, 2004) and in Pabna sadar upazila ranged from 11.85 to 28.85% (Arefin, 2002).

Ali (1997) analyzed ground water of Nachoul upazila at High Barind Tract and found that the SSP of those waters varied from 17.00 to 51.56%. Quddus and Zaman (1996) showed that the SSP of those waters was within the limit of 8.14 to 14.70% and all water was excellent in class. Quayum (1995) found that the values of SSP ranged from 18.31 to 40.95% in ground water of Gazipur sadar under the district of Gazipur. The SSP of ground water of Shahzadpur thana under Sirajgonj district were within the limit of 13.18 to 21.93% (Rahman and Zaman, 1995).

SSP values of ground water of Phulpur thana under Mymensingh district ranged from 6.81 to 28.99%, (Shahidullah, 1995). The SSP of ground water of Madhupur thana under Tangail district varied from 2.14 to 31.50% (Zaman and Majid, 1995). Another study was conducted by Zaman and Mohiuddin (1995) and the SSP of Pangsha thana under Rajbari district fluctuated from 14.91 to 46.67% and all waters under test were graded as 'excellent', ‘good’ and permissible classes.

2.8 Residual sodium carbonate (RSC)

The residual sodium carbonate (RSC) values of ground water collected from Lakshmipur and Noakhali district ranged from -1.21 to 3.13 meq L^{-1} (Uddin, 2005). The residual sodium carbonate (RSC) values of ground water collected from Eastern Surma Kushiara flood plain and neighbouring regions of Sylhet division fluctuated between -1.002 to 7.5 meq L^{-1} (Ahsan, 2004) and that of Kushtia and Chuadanga districts varied from -6.799 to -0.204 meq L^{-1} (Azad, 2004) and of Pabna sadar upazila ranged from 1.80 to 0.10 meq L^{-1} (Arefin, 2002).

The RSC values of ground water samples of Sherpur upazila in Bogra district were found between -0.10 to 2.40 meq L^{-1} (Rahman, 2001) that of Sherpur sadar under Sherpur district varied from 1.10 to -0.10 and 0.00 to 1.90 meq L^{-1} (Haque, 2000). Nizam (2000) stated that the RSC values of surface and ground water collected from Madhupur Tract fluctuated between -0.30 to 5.8 meq L^{-1}. Sen *et al.*, (2000) observed that ground and surface water samples in Tongi aquifers contained RSC within the limit of trace to 11.00 meq L^{-1}.

The value of RSC of ground water of Narayangonj aquifers fluctuated between 0.64 to 2.93 meq $L^{-1}$with the mean value of-1.84 meq L^{-1} (Sarker, 1997). Zaman and Mohiuddin (1995) observed that RSC values were below 1.25 meq L^{-1} and the RSC value of ground water samples from Shahzadpur thana, Sirajgonj district were negative which meant that all samples were free from residual sodium carbonate and were suitable for irrigation (Rahman and Zaman, 1995). The concentration of RSC in groundwater samples from Avinashi, Pollachi and Palladam in Tamil Nadu varied from 5.0 to 7.5 meq L^{-1} (Latha *et al*, 2002).

2.9 Hardness

The hardness (H_T) of ground water samples in Lakshmipur and Noakhali district ranged from 29.83 to 217.13 mg L^{-1} (Uddin, 2005). The hardness (H_T) of ground water samples in Eastern Surma Kushiara flood plain and neighbouring regions of Sylhet division fluctuated between 3.71 to 322.35 mg L^{-1} (Ahsan, 2004), and the hardness in ground water of Pabna sadar upazila ranged from 183.08 to 376.72 mg L^{-1} (Arefin, 2002).

Rahman (2001) mentioned that $H_T$values ranged from 84.9 to 265.9 mg L^{-1} in ground water of Sherpur upazila in Bogra district. The hardness of ground and surface waters collected from Bhaluka upazila under Mymensingh district varied from 29.94 to 304.39 mg L^{-1} (Nizam, 2000).

The ground water of Pangsha thana under Rajbari district were in moderately hard and 'hard' classes (Zaman and Mohiuddin, 1995). Quddus and Zaman (1996) stated that some surface and ground water used for irrigation at Meherpur sadar under Meherpur district were rated as 'hard' in quality. Rahman and Zaman (1995) observed that H_T varied from 159.83 to 324.20 mg L^{-1}. The ground waters samples collected from Gazipur sadar under Gazipur district were in 'soft' class (Quayum, 1995). Helaluddin (1996) studied 88 water samples of surface and ground sources collected from the Khagrachari Hill district and revealed that the H_T of pond and well waters varied from 2.93 to 46.72 and 1.27 to 16.90 mg L^{-1}, respectively.

CHAPTER III

MATERIALS AND METHODS

Water quality is an important factor in using water for various purposes because its quality bears importance in successful crop production. The chemical analyses of ground water samples are necessary to assess the extent of ground water pollution caused by the higher concentration of dissolved constituents. An attempt has been taken to analyze ground water samples collected from 12 unions of Birol upazila and 6 unions of Bochagonj upazila under Dinajpur district and the chemical analyses include the estimation of pH, electrical conductivity (EC), total dissolved solids (TDS) and major ionic constituents like Ca, Mg, K, Na, Fe, Mn, Zn, Cu, P, SO_4, CO_3 and HCO_3.

3.1 Collection and preparation of ground water samples

3.1.1 Site

Ground water sampling sites were selected from different places under Birol upazila and Bochagonj upazila in Dinajpur district.

3.1.2 Collection of water samples

The first consideration for assessment of ionic toxicity of water is obtaining a sample or series of representative samples. Thirty six samples were collected during irrigation time. All the water samples were collected from different deep tubewells used for the study purposes. All sources of water have widely used as irrigation for the production of major agricultural crops such as cereals, pulses, fiber, spices and vegetable crops. The sites of water sampling for different sources of waters were shown in Figure 1, Figure 2 and Figure 3. The information of different water samples collected for analysis was mentioned in Appendix I and Appendix II. Water samples were collected in liter plastic bottles. These bottles were cleaned and washed with tap water followed by distilled water. Before sampling, containers were again rinsed 3 to 4 times with water to be sampled. The water carried to the laboratory of the Department of Agricultural Chemistry, HSTU, Dinajpur for testing. The samples were analyses as quickly as possible on arrival at the laboratory.

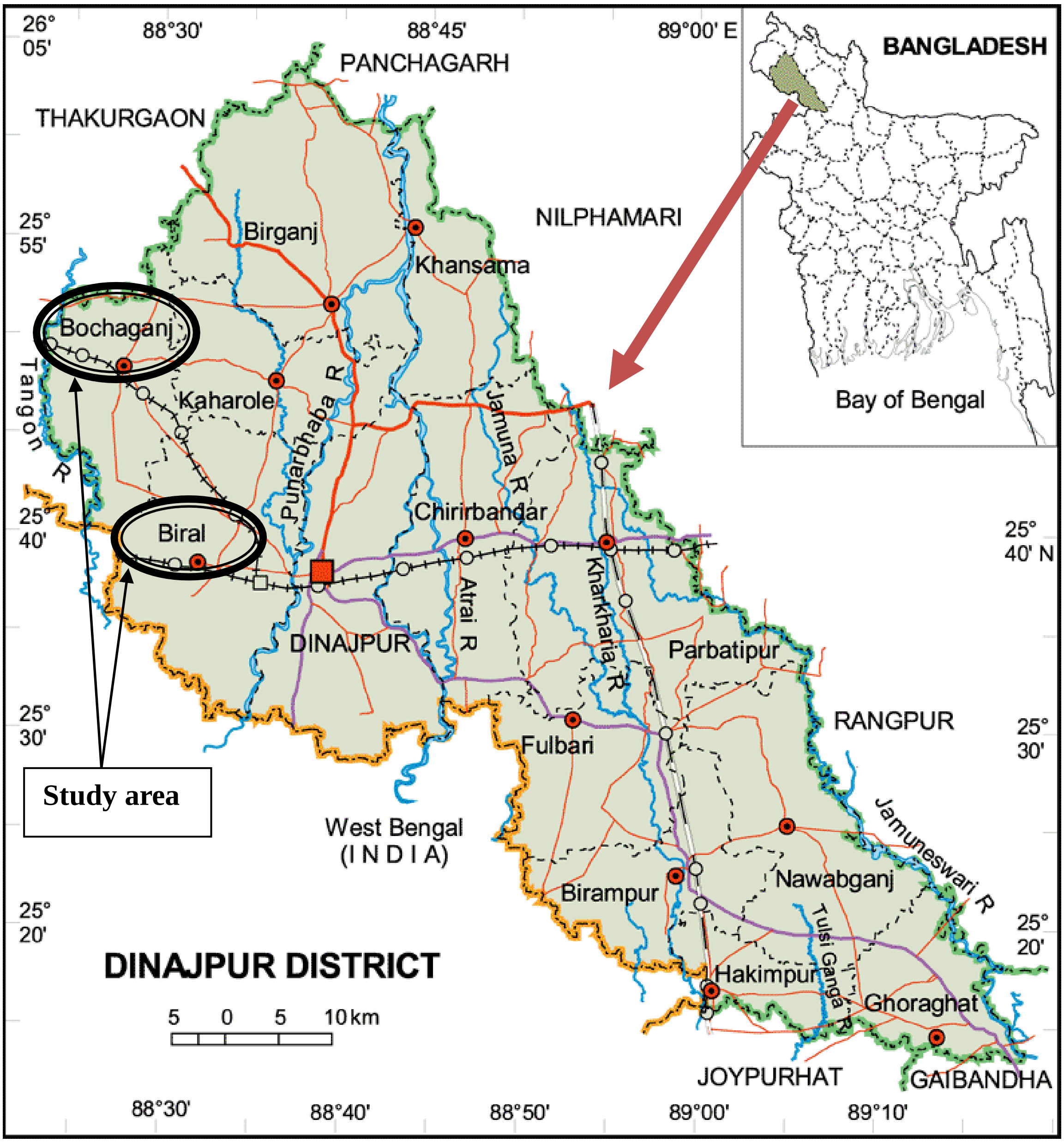


Figure 1: Map of the Dinajpur indicating the sampling sites along with the Bangladesh locating study area.

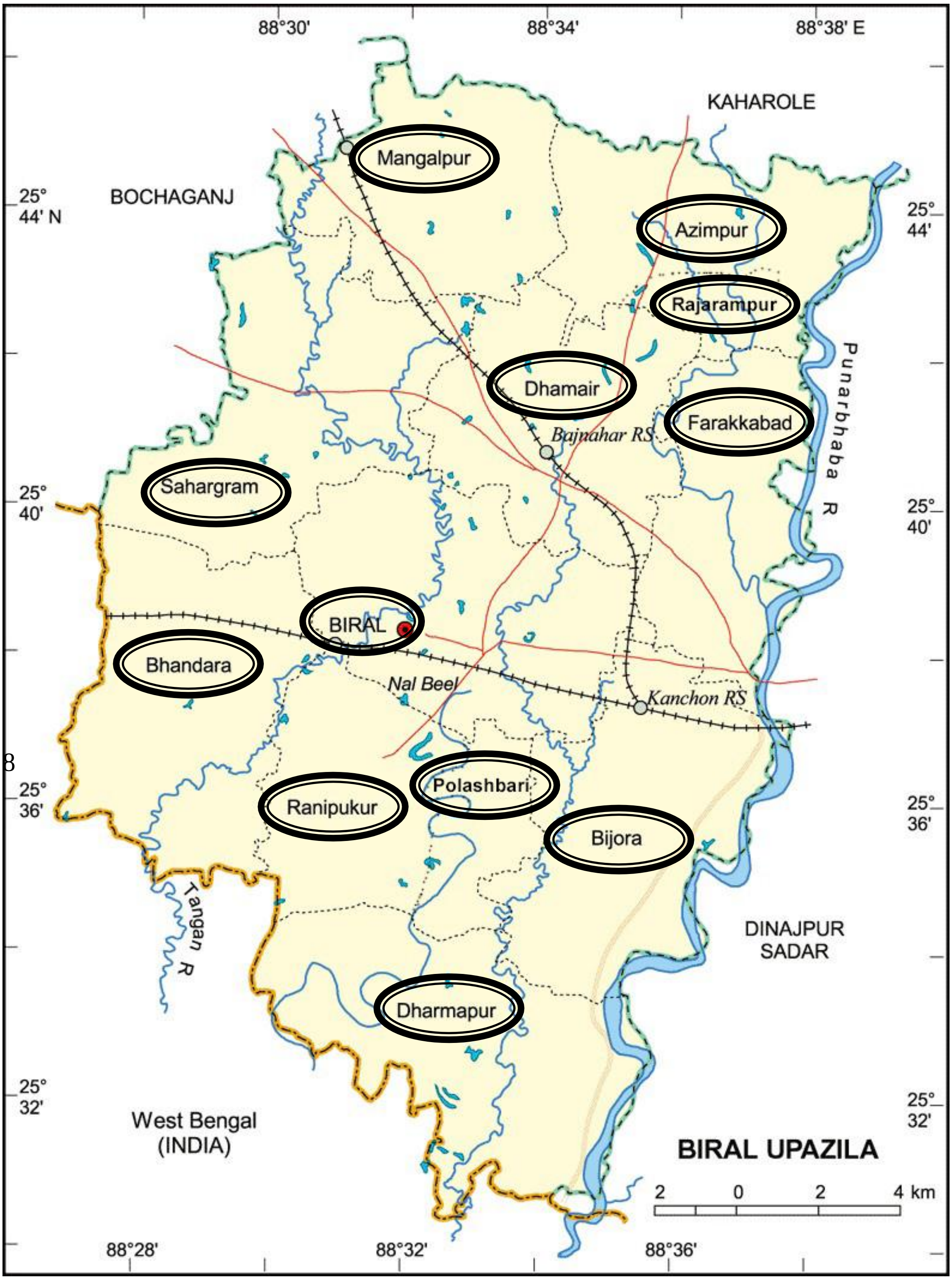


Figure 2: Map of the Birol upazila indicating the sampling sites along with the Bangladesh locating study area.

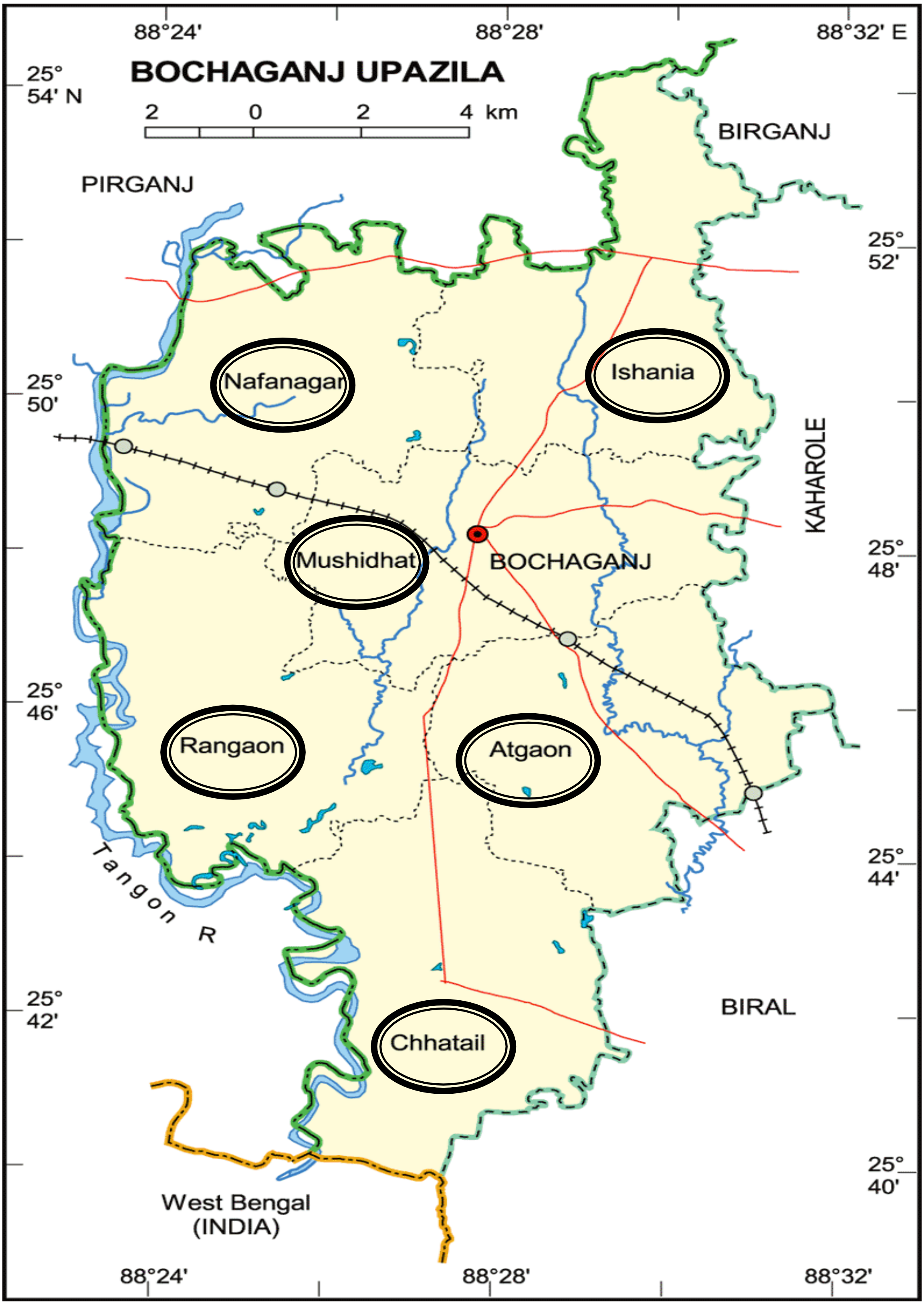


Figure 3: Map of the Bochagonj upazila indicating the sampling sites along with the Bangladesh locating study area.

3.2 Notes on Analytical Methods of Water Analysis

The major chemical constituents or compounds both ionic and nonionic forms which all essentially can take part in water pollution. The major chemical constituents or salient features considered for analyses were as follows:

A. Hydrogen ion concentration (pH)

B. Electrical conductivity (EC)

C. Total dissolved solids (TDS)

D. Ionic constituents, i) Calcium (Ca)

ii) Magnesium (Mg)

iii) Potassium (K)

iv) Sodium (Na)

v) Iron (Fe)

Vi) Manganese (Mn)

vii) Zinc (Zn)

viii) Copper (Cu)

ix) Phosphorus (P)

x) Bicarbonate (HCO_3)

xi) Chloride (Cl)

xii) Sulphate (SO_4)

E. Sodium adsorption ratio (SAR)

F. Soluble sodium percentage (SSP)

G. Residual sodium carbonate (RSC)

H. Total hardness and alkalinity.

I. Permiability index (PI)

J. Kelly's ratio (KR)

3.2.1 pH

The pH of water sample were determined electrometrically following the procedure mentioned by Ghosh *et al.* (1983) using pH meters (Hanna instrument-211 model) in the laboratory of Agricultural Chemistry Department, Hajee Mohammad Danesh Science and Technology University, Dinajpur.

3.2.2 Electrical conductivity (EC)

The electrical conductivity of a system actually represents the concentration of total dissolved solids (TDS) or total salinity in water excluding the amount of silica. The EC of collected water samples was determined by conductivity bridge (Harna instrument-HI8033 model) as outlined by Ghosh *et al.* (1983) in the laboratory of the Department of Soil Science, Hajee Mohammad Danesh Science and Technology University, Dinajpur.

3.2.3 Total dissolved solids (TDS)

Total dissolved solids (TDS) 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).

3.2.4 Carbonate and bicarbonate

Carbonate and bicarbonates of water samples were determined by acidimetric method of titration using phenolphthalein indicator ($C_{20}H_{14}O_4$) for carbonate. With dilute sulphuric acid, carbonate forms colourless and bicarbonate forms rose red colour complex at the end of titration. The carbonate and bicarbonates were estimated titrimetrically after Chopra and Kanwar (1980) and Ghose *et al.* (1983). The reactions are mentioned below:

$$Na_2CO_3 + H_2SO_4 \longrightarrow NaHCO_3 + Na_2SO_4$$

$$NaHCO_3 + H_2SO_4 \longrightarrow Na_2SO_4 + H_2O + CO_2$$

3.2.5 Nitrate nitrogen

Nitrate was determined by phenoldisulphonic acid method with the help of a spectrophotometer (Hitechi-U-2800) set at 420 nm wavelength. The water sample was evaporated to dryness over a water bath and after cooling, the yellow colour was developed by the reaction between nitrate and phenoldisulphonic acid in presence of ammonia (Ghosh *et al.*, 1983).

3.2.6 Phosphorus

Phosphorus was determined colorimtrically from water samples using stannous chloride as reducing agent (Clesceri *et al.*, 1989). This method involved the formation of molybdophosphoric acid which was reduced to the intensity complex molybdenum blue by stannous chloride. The colour intensity was read at 660 nm wavelength with a spectrophotometer (Hitechi-U-2800) within 15 minutes after stannous chloride addition following the procedure outlined by Olsen *et al.*, (1954). The principal hypothetical reaction is as follows:

$$H_3PO_4 + 12\ H_2MoO_4 \longrightarrow H_3P\ (Mo_3O_{10})_4 + 12H_2O$$

3.2.7 Sulphate sulphur

Sulphate was estimated turbidimetrically with the help of spectrophotometer. Turbidimetric reagent ($BaCl_2.2H_2O$) was added in a definite volume of sample. Sulphate ion reacted with barium chloride to form barium sulphate. Reading was taken in spectrophotometer (Hitachi-U-2800) after 30 minutes of $BaCl_2$ addition al 425 nm wavelength following the methods of Wolf (1982).

3.2.8 Calcium

Complexometric titration was used for estimating the calcium from the water samples using disodium ethylene diamine tetraacetate ($Na_2H_2C_{10}H_{12}O_{28}N_2.2H_2O$) as a chelating agent. This analytical method was carried on eliminating possible interfering ions such as Fe, Mn, Cu, Zn, Ni and PO_4 adding respective masking agents at pH 12 in presence of calcon indicator ($C_{20}H_{13}N_2NaO_5S$). Sodium hydroxide (NaOH) was first added to the water samples for the precipitation of magnesium as insoluble magnesium hydroxide [$Mg(OH)_2$]. Potassium ferrocyanide [$K_4Fe(CN)_6.3H_2O$], hydroxylamine-hydrochloride

($NH_2OH.HCl$) and triethano lamime ($C_6H_{15}NO_3$) were added to eliminate this interference of various non-target ions (Page *et al*., 1982).

3.2.9 Magnesium

Magnesium was analysed by complexometric method of titration using disodium ethylene diamine tetraacetate ($Na_2H_2C_{10}H_{12}O_{28}N_2.2H_2O$) as a chelating agent. This analytical method was practiced for eliminating possible interfering non-target ions in presence of Erichrome Black T indicator ($C_{20}H_{12}N_3NaO_7S$) with adjusting the required pH 10. To determine magnesium alone, calcium was first precipitated from water samples as calcium tumgastate ($CaWO_4$) with sodium tungastate solution ($Na_2WO_4.2H_2O$). Potassium ferrocyanide [$K_4Fe\ (CN)\ _6.3H_2O$], hydroxylamine-hydrochloride ($NH_2OH.HCl$) and triethanolamine ($C_6H_{15}NO_3$) were also added to eliminate the competition of various ions (Fe, Mn, Cu, Zn and PO_4) by the EDTA molecule in the raction after Page *et al.* (1982).

3.2.10 Sodium and potassium

Sodium and potassium were determined with the help of a flame emission spectrophotometer by using sodium and potassium filters respectively. The sample was aspirated into a gas flame and excitation was carried out in a carefully controlled and reproducible conditions. The air pressure was fixed at 10 psi. The desired spectral line was isolated using interference filters. The intensity of light at 589 nm and at 768 nm is approximately proportional to the concentration of the elements sodium and potassium respectively. The percent emission was recorded following the methods outlined by Golterman (1971) and Ghosh *et al.* (1983).

3.2.11 Zinc, copper, iron and manganese

Zinc, copper, iron and manganese were analysed by atomic absorption spectrophotometer (AAS Chemito-203) at the wavelengths of 213.8 nm, 324.8 nm, 248.3 nm and 279.5 nm respectively in the laboratory of Soil Chemistry Division, Bangladesh Agricultural Research Institute (BARI) following the procedure by Clesceri *et al.,* (1989).

3.3 Evaluation of Water Quality

Whether a ground or surface water of a given quality is suitable for a particular purpose depends on the criteria or standards of acceptable quality for that specific use. Quality limits the water supplies for drinking, industrial and irrigation because of its extensive development for these purposes. The following formulae related to the irrigation water classes rating were computed from the data obtained by chemical analyses of water samples. The equations were-

a) Sodium Adsorption Ratio (SAR)

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

b) Soluble Sodium Percentage (SSP)

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

c) Residual Sodium Carbonate (RSC)

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

d) Hardness or Total Hardness (H_T)

$H_T = 2.5 \times Ca^{2+} + 4.1 \times Mg^{2+}$

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

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

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

Where, concentrations of ionic constituents for calculating all parameters except hardness in mg L^{-1}.

CHAPTER IV

RESULTS AND DISCUSSION

The ionic concentration of Ca, Mg, Na, K, Fe, Mn, Zn, Cu, P, SO_4 and HCO_3, were present in variable quantities in the collected ground water samples. The advantage of water testing is initially judged from the nature and extent of its relationship with soil and crop. Rating of waters on the basis of chemical analyses is usually done after USEPA (United States Environmental Protection Agency) standards. These criteria are followed world wide by the scientists working on water quality. Different leading organizations also follow USEPA criteria such as FAO, UNICEF and USDA etc. The experimental findings described in the foregoing chapter are described and discussed here in the light and of relevant research reports wherever applicable. The concentration of major ions (Ca, Mg, Na, K, Fe, SO_4, HCO_3 and Cl) was presented in Fig. 4 and Fig. 5 where the vertical bar diagrams presented major ionic concentrations. The major ground water quality determining indices (pH, EC, TDS, SSP and H_T) was presented in Fig. 6 and Fig. 7 where the vertical bar diagrams presented majorground water quality determining indices.

The obtained result are described and discussed under following headings:

4.1 Ground water rating for irrigation

4.1.1 pH

The pH value of water sample of Birol upazilla was within the range of 6.91 to 7.78 while the average value was 7.39 (Appendix IX) and the pH value of water sample of Bochagonj upazilla 6.56 to7.72 while the average value was 7.31 (Appendix X). Out of 36 samples, the pH of 30 samples (83.33 %) were found from 6.91 to 7.39 and the rest 6 samples (16.67%) water varied 7.40 to 7.78 for Birol upazilla butout of 18 samples, the pH of 9 samples (50 %) were found from 6.96 to 7.31 and the rest 9 samples (50%) water varied 7.31 to 7.72 for Bochagonj upazilla. The pH of water varied from 6.91 to 7.78 and 6.96 to 7.72 for Birol and Bochagonj upazilla, respectively indicated that the water were slightly acidic to alkaline. Out of 36 samples of Birol upazilla, 8 samples were below pH 7 and out of 18 samples of Bochagonj upazilla, 2 samples were below pH 7 and slightly acidic in nature and might be due to the presence of lower concentration of Ca, Mg, Na and HCO_3. These water samples would be suitable for acid loving crops. The remaining 28 samples for Birol upazilla and 16 samples for Bochagonj upazilla under the study showed higher pH values above 7were slightly alkaline in nature and this might be due to the presence of higher amount of Ca, Mg, Na and HCO_3. Ayers and Westcot (1985) mentioned that normal pH range of irrigation usually varied from 6.0 to 8.5. It indicated that pH of all water samples of both upazilla under test were within the normal range and this water might not be harmful for soils and crops. Similar observations were also reported by Quayum (1995) and Razzaque (1995).

4.1.2 Electrical Conductivity (EC)

The electrical conductivity (EC) of all water samples was within the limit of 200 to 264 $\mu S\ cm^{-1}$ with the mean value of 232.833 $\mu S\ cm^{-1}$ (Appendix IX) and 190 to 248 $\mu S\ cm^{-1}$ with the mean value of 216.833 $\mu S\ cm^{-1}$ (Appendix X) in Birol and Bochagonj upazilla, respectively. The EC value of 17 samples (47.22%) were less than the mean value and rest 19 samples (52.78 %) were higher than the average valuefor Birol upazilla and EC value of 9 samples (50%) were less than the mean value and rest 9 samples (50 %) were higher than the average value for Bochagonj upazilla. The highest amount (264 $\mu S\ cm^{-1}$) and the lowest amount (200 $\mu S\ cm^{-1}$) were obtained from the sample no. 20 and 16 respectively of Birol upazilla and for Bochagonj upazilla, the highest amount (248 $\mu S\ cm^{-1}$) and the lowest amount (190 $\mu S\ cm^{-1}$) were obtained from the sample no. 5 and 15 respectively. According to the Richards (1968) as illustrated in Figure 3, all the ground waters under test were rated as ‘medium salinity’ (C2). Therefore, ground water of such quality can be used for irrigation purpose without harmful effects on soils and crops but moderate leaching will be required.

4.1.3 Total dissolved solids (TDS)

The amount of total dissolved solids (TDS) in ground water samples of the investigated area varied from 101 to 180 mg L^{-1} with mean value of 123.25 mg L^{-1} (Appendix IX) and varied from 100 to 122 mg L^{-1} with mean value of 111.11 mg L^{-1} (Appendix X) in Birol and Bochagonj upazilla, respectively. Out of the 36 samples of Birol upazilla, about 69.44 % TDS values (25 samples) were found bellow the mean value and the remaining 30.56% (11 samples) were found above the average value but out of the 18 samples of Bochagonj upazilla, about 55.56 % TDS values (10 samples) were found bellow the mean value and the remaining 44.44% (8 samples) were found above the average value. The highest and the lowest TDS values (101 mg L^{-1}) and (180 $\mu S\ cm^{-1}$)

were obtained from the sample no. 20 and 33, respectively of Birol upazilla and for Bochagonj upazilla, the highest and the lowest TDS values (100 mg L^{-1}) and (122 mg L^{-1}) were obtained from the sample no. 5 and 9, respectively. Sufficient qualities of bicarbonate, sulphates and chloride are of Ca, Mg and Na caused high TDS values (Karanth, 1994). According to Freeze and Cherry (1979) as reported in Appendix V, all the ground water's under investigation contained less than 1,000 mg L^{-1} TDS and were classified 'fresh water' in quality. These waters would not affect the osmotic pressure of soil solution and cell sap of the plants when applied to soil as irrigation water.

Table 1: Temerature, pH, EC and TDS of ground water samples of different unions in Birol

Name of Upazila	Temp.	pH	EC µS cm^{-1}	TDS mg L^{-1}
Rajarampur	22.5	7.02	248	122
Azimpur	22.6	7.07	246	126
Mangalpur	22.4	7.18	243	128
Shahorgram	22.6	7.30	244	124
Farakkabad	22.5	7.04	226	116
Dharmapur	22.6	7.10	208	109
Bijora	22.6	7.56	249	174
Dhamoir	22.5	7.58	246	127
Bhandara	22.4	7.20	222	114
Ranipukur	22.6	7.04	226	116
Birol	22.5	7.02	214	110
Polashbari	22.6	7.06	227	117

Table 2: Temerature, pH, EC and TDS of ground water samples of different unions in Bochagonj

Name of Upazila	Temp.	pH	EC µS cm^{-1}	TDS mg L^{-1}
Nafanagor	22.4	7.66	236	118
Eshania	22.5	6.99	243	120
Murshidahat	22.4	7.21	198	102
Atgao	22.6	7.24	218	112
Chatol	22.5	7.35	207	111
Rongao	22.6	7.41	201	106

4.1.4 Ionic constituents

In present study, major ions like Ca, Mg, K, Na, CO_3, and HCO_3 were dominant quantities but the remaining detected ions were also recorded in minor amounts. The estimated amounts of these ions present in all the samples in relation to irrigation water quality have been described and discussed as follows:

4.1.4.1 Calcium (Ca)

The concentration of Ca was found within the range of 10.87 to 19.31 mgL^{-1} with the mean value of 16.039 mg L^{-1} (Appendix XI) and 15.35 to 18.90 mg L^{-1} with the mean value of 17.393 mg L^{-1} (Appendix XII) in Birol and Bochagonj upazilla, respectively. Out of 36 samples of Birol upazilla, 18 samples (50%) were found below the mean value and the rest 18 samples (50%) were above the mean value but out of the 18 samples of Bochagonj upazilla, 8 samples (44.44%) were found below the mean value and the rest 10 samples (55.56%) were above the mean value. The highest and the lowest concentration of Ca (19.31 mg L^{-1}) and (10.87 mg L^{-1}) was observed at sample no.2 and 14, respectively of Birol upazilla and for Bochagonj upazilla, the highest and the lowest concentration of Ca (18.90 mg L^{-1}) and (15.35 mg L^{-1}) were obtained from the sample no. 12 and 16, respectively. The concentration of Ca content in ground water was largely dependent on the solubility of $CaCO_3$, $CaSO_4$ and rarely on $CaCl_2$ (Karanth, 1994). Irrigation water containing less than the 20 meq L^{-1} Ca was suitable For Irrigating crops plants (Ayers and Westcot, 1985). On the basis of Ca content, the entire water samples can safely be used for irrigation and would not affect the soils.

4.1.4.2 Magnesium (Mg)

The concentration of Mg was found within the range of 7.98 to 19.44 mg L^{-1} with the mean value of 12.42 mg L^{-1} (Appendix XI) and 13.33 to 16.53 mg L^{-1} with the mean value of 14.613 mg L^{-1} (Appendix XII) in Birol and Bochagonj upazilla, respectively. Out of 36 samples of Birol upazilla, 17 samples (47.22%) were found below the mean value and the rest 19 samples (52.78%) were above the mean value but out of the 18 samples of Bochagonj upazilla, 10 samples (55.56%) were found below the mean value and the rest 8 samples (44.44%) were above the mean value. The highest and the lowest concentration of Mg (19.44 mg L^{-1}) and (7.98 mg L^{-1}) was observed at sample no.19 and 28 respectively of Birol upazilla and for Bochagonj upazilla, the highest and the lowest concentration of Mg (16.53 mg L^{-1}) and (13.33 mg L^{-1}) were obtained from the sample no. 10 and 14, respectively. According to the Ayers and Westcot (1985), all the irrigation water was within the safety limit. The area of this study, all the ground water samples were 'suitable' for irrigation with respect of Mg content.

4.1.4.3 Sodium (Na)

The concentration of Na in different water samples were within the range of 2.20 to 4.01 mg L^{-1} with the mean value of 2.879 mg L^{-1} (Appendix XI) and 2.42 to 3.75 mg L^{-1} with the mean value of 2.694 mg L^{-1} (Appendix XII) in Birol and Bochagonj upazilla, respectively. Out of 36 samples of Birol upazilla, 24 samples (66.67%) were found below the mean value and the rest 12 samples (33.33%) were above the mean value but out of the 18 samples of Bochagonj upazilla, 15 samples (83.33%) were found below the mean value and the rest 3 samples (16.67%) were above the mean value. The highest and the lowest concentration of Na (4.01 mg L^{-1}) and (2.20 mg L^{-1}) was observed at sample no.3 and33 respectively of Birol upazilla and for Bochagonj upazilla, the highest and the lowest concentration of Na (3.75 mg L^{-1}) and (2.42 mg L^{-1}) were obtained from the sample no. 1 and 14, respectively.The recorded Na content in all the ground water samples under test was far below this specified limit (Ayers and Westcot, 1985). Hence, as per Na content, all the waters of the study area can safely be applied for long-term irrigation without the harmful effects on soils and crops.

4.1.4.4 Potassium (K)

The concentration of K in the collected water samples was within the range from of 2.44 to 7.75 mg L^{-1} with the mean value of 43.341 mg L^{-1} (Appendix XI) and 2.08 to 5.02 mg L^{-1} with the mean value of 3.652 mg L^{-1} (Appendix XII) in Birol and Bochagonj upazilla, respectively. Out of 36 samples of Birol upazilla, 21 samples (58.33%) were found below the mean value and the rest 15 samples (41.67%) were above the mean value but out of the 18 samples of Bochagonj upazilla, 10 samples (55.56%) were found below the mean value and the rest 8 samples (44.44%) were above the mean value. The highest and the lowest concentration of K (7.75 mg L^{-1}) and (2.44 mg L^{-1}) was observed at sample no. 2 and 32, respectively of Birol upazilla and for Bochagonj upazilla, the highest and the lowest concentration of K (5.02 mg L^{-1}) and (3.08 mg L^{-1}) were obtained from the sample no. 4 and 1 respectively. The presence of higher quantity of K in some ground water samples might be due to the presence of some potash bearing minerals like sylvite

(KCl) and nitre (KNO_3) in the aquifers (Karanth, 1994). The detected quantity of K in all the colleted ground water samples had no significant influence on water quality for irrigation. The presence of higher K content in the ground water might have beneficial effect as it acts as an essential nutrient element for plant growth and development.

4.1.4.5 Iron (Fe)

The concentration of Fe in the collected water samples was within the range from of 0.22 to 0.46 mg L^{-1} with the mean value of 0.282 mg L^{-1} (Appendix XI) and 0.26 to 0.62 mg L^{-1} with the mean value of 0.391 mg L^{-1} (Appendix XII) in Birol and Bochagonj upazilla, respectively. Out of 36 samples of Birol upazilla, 23 samples (63.89%) were found below the mean value and the rest 13 samples (36.11%) were above the mean value but out of the 18 samples of Bochagonj upazilla, 9 samples (50%) were found below the mean value and the rest 9 samples (50%) were above the mean value. The highest and the lowest concentration of Fe (0.46 mg L^{-1}) and (0.22 mg L^{-1}) was observed at sample no.16 and4 respectively of Birol upazilla and for Bochagonj upazilla, the highest and the lowest concentration of Fe (0.62 mg L^{-1}) and (0.26 mg L^{-1}) were obtained from the sample no. 7 and 15, respectively. The recorded iron concentration of all ground water samples was far below the acceptable limit in Appendix III.

4.1.4.6 Zinc (Zn)

The concentration of Zn in the collected water samples was within the range from of 0.032 to 0.068 mg L^{-1} with the mean value of 0.0049 mg L^{-1} (Appendix XI) and 0.038 to 0.077 mg L^{-1} with the mean value of 0.058 mg L^{-1} (Appendix XII) in Birol and Bochagonj upazilla, respectively. Out of 36 samples of Birol upazilla, 21 samples (58.33%) were found below the mean value and the rest 15 samples (41.67%) were above the mean value but out of the 18 samples of Bochagonj upazilla, 9 samples (50%) were found below the mean value and the rest 9 samples (50%) were above the mean value. The highest and the lowest concentration of Zn (0.068 mg L^{-1}) and (0.032 mg L^{-1}) was observed at sample no. 22 and19 respectively of Birol upazilla and for Bochagonj upazilla, the highest and the lowest concentration of Zn (0.077 mg L^{-1}) and (0.038 mg L^{-1}) were obtained from the sample no. 1 and 5, respectively. According to Ayers and Westcot (1985), the acceptable limit of zinc in irrigation water is less than 2.0 mg L^{-1}. On the basis of this limit, all the water under investigation was not toxic or problematic for continuous irrigation. The more Zn concentration in ground water is suitable for crop growth as it helps in many enzymatic reactions.

4.1.4.7 Copper (Cu)

The concentration of Cu in the collected water samples was within the range from of 0.065 to 0.089 mg L^{-1} with the mean value of 0.072 mg L^{-1} (Appendix XI) and 0.047 to 0.088 mg L^{-1} with the mean value of 0.067 mg L^{-1} (Appendix XII) in Birol and Bochagonj upazilla, respectively. Out of 36 samples of Birol upazilla, 10 samples (27.78%) were found below the mean value and the rest 26 samples (72.22%) were above the mean value but out of the 18 samples of Bochagonj upazilla, 10 samples (55.56%) were found below the mean value and the rest 8 samples (44.44%) were above the mean value. The highest and the lowest concentration of Cu (0.089 mg L^{-1}) and (0.065 mg L^{-1}) was observed at sample no.16 and5 respectively of Birol upazilla and for Bochagonj upazilla, the highest and the lowest concentration of Cu (0.088 mg L^{-1}) and (0.047 mg L^{-1}) were obtained from the sample no. 4 and 18, respectively. According to Ayers and Westcot (1985), the acceptable limit of Cu in irrigation water is less than 0.20 mg L^{-1}. On the basis of this limit, all the water under investigation was not problematic for continuous irrigation.

4.1.4.8 Manganese (Mn)

The concentration of Mn in different water samples were within the range of 0.024 to 0.066 mg L^{-1} with the mean value of 0.041 mg L^{-1} (Appendix XI) and 0.006 to 0.033 mg L^{-1} with the mean value of 0.019 mg L^{-1} (Appendix XII) in Birol and Bochagonj upazilla, respectively. Out of 36 samples of Birol upazilla, 14 samples (38.89%) were found below the mean value and the rest 22 samples (61.11%) were above the mean value but out of the 18 samples of Bochagonj upazilla, 9 samples (50%) were found below the mean value and the rest 9 samples (50%) were above the mean value. The highest and the lowest concentration of Mn (0.066 mg L^{-1}) and (0.024 mg L^{-1}) was observed at sample no.1 and 17, respectively of Birol upazilla and for Bochagonj upazilla, the highest and the lowest concentration of Mn (0.033 mg L^{-1}) and (0.006 mg L^{-1}) were obtained from the sample no. 7 and 2, respectively. According to Ayers and Westcot (1985), the maximum recommended content of Mn for water used for irrigation is 0.20 mg L^{-1}. On the basis of Mn content, all the waters but one under test was not toxic for long-term irrigation.

The cationic concentrations of water samples for both Birol and Bochagonj upazila analyzed were in the descending order of magnitude as:

Ca > Mg > K > Na > Cu > Zn > Mn > Fe

Table 3: Cationic constituents of the collected ground water samples of different unions in Birol

Name of Upazila	Ca^{2+} mg L^{-1}	Mg^{2+} mg L^{-1}	Na^{+} mg L^{-1}	K^{+} mg L^{-1}	Zn^{2+} mg L^{-1}	Cu^{2+} mg L^{-1}	Fe^{2+} mg L^{-1}	Mn^{2+} mg L^{-1}
Rajarampur	19.16	14.34	3.86	7.59	0.037	0.075	0.24	0.065
Azimpur	17.51	13.55	3.61	3.59	0.044	0.065	0.23	0.044
Mangalpur	17.24	13.52	3.64	7.28	0.054	0.086	0.25	0.062
Shahorgram	16.28	14.27	2.51	5.06	0.064	0.080	0.37	0.040
Farakkabad	11.09	8.96	2.49	3.62	0.045	0.073	0.33	0.043
Dharmapur	11.19	8.12	2.45	2.47	0.045	0.087	0.44	0.026
Bijora	21.54	19.34	3.66	3.77	0.033	0.083	0.26	0.025
Dhamoir	22.34	17.41	2.51	3.65	0.066	0.066	0.23	0.036
Bhandara	14.14	11.48	2.52	5.01	0.065	0.067	0.24	0.044
Ranipukur	11.81	7.82	2.51	2.96	0.056	0.075	0.28	0.043
Birol	14.19	8.85	2.32	2.56	0.046	0.080	0.17	0.018
Polashbari	15.92	12.44	2.44	5.01	0.038	0.082	0.38	0.047

Table 4: Cationic constituents of the collected ground water samples of different unions in Bochagonj

Name of Upazila	Ca^{2+} mg L^{-1}	Mg^{2+} mg L^{-1}	Na^{+} mg L^{-1}	K^{+} mg L^{-1}	Zn^{2+} mg L^{-1}	Cu^{2+} mg L^{-1}	Fe^{2+} mg L^{-1}	Mn^{2+} mg L^{-1}
Nafanagor	18.63	15.33	3.63	1.54	0.073	0.064	0.31	0.009
Eshania	17.41	13.52	2.51	4.18	0.041	0.076	0.41	0.019
Murshidahat	16.42	14.35	2.50	4.06	0.064	0.071	0.59	0.030
Atgao	18.57	16.44	2.52	3.65	0.056	0.073	0.38	0.016
Chatol	17.75	13.43	2.50	3.64	0.061	0.061	0.34	0.024
Rongao	15.56	14.7	2.48	3.62	0.052	0.055	0.43	0.013

4.1.4.9 Sulphate (SO_4)

The concentration of SO_4 in different water samples were within the range of 0.359 to 4.220 mg L^{-1} with the mean value of 1.570 mg L^{-1} (Appendix XIII) and0.265 to 1.940 mg L^{-1} with the mean value of 0.851 mg L^{-1} (Appendix XIV) in Birol and Bochagonj upazilla, respectively. Out of 36 samples of Birol upazilla, 19 samples (52.78%) were found below the mean value and the rest 17 samples (47.22%) were above the mean value but out of the 18 samples of Bochagonj upazilla, 12 samples (66.67%) were found below the mean value and the rest 6 samples (33.33%) were above the mean value. The highest and the lowest concentration of SO_4 (4.220 mg L^{-1}) and (0.359 mg L^{-1}) was observed at sample no.7 and 5 respectively of Birol upazilla and for Bochagonj upazilla, the highest and the lowest concentration of SO_4 (1.940 mg L^{-1}) and (0.265 mg L^{-1}) were obtained from the sample no. 10 and 17 respectively. According to Ayers and Westcot (1985), the acceptable limit of SO_4 for irrigation water is less than 20 mg L^{-1}. On the basis of this limit, all the waters under investigation were not problematic for irrigation without any toxic effect on soils and crops grown in the area of this study.

4.1.4.10 Phosphorus (PO_4)

The concentration of PO_4 in different water samples were within the range of 0.421 to 1.283 mg L^{-1} with the mean value of 0.680 mg L^{-1} (Appendix XIII) and0.588 to 1.162 mg L^{-1} with the mean value of 0.839 mg L^{-1} (Appendix XIV)in Birol and Bochagonj upazilla, respectively. Out of 36 samples of Birol upazilla, 24 samples (66.67%) were found below the mean value and the rest 12 samples (33.33%) were above the mean value but out of the 18 samples of Bochagonj upazilla, 9 samples (50%) were found below the mean value and the rest 9 samples (50%) were above the mean value. The highest and the lowest concentration of PO_4 (1.283 mg L^{-1}) and (0.421 mg L^{-1}) was observed at sample no.1 and 30, respectively of Birol upazilla and for Bochagonj upazilla, the highest and the lowest concentration of PO_4 (01.162 mg L^{-1}) and (0.588 mg L^{-1}) were obtained from the sample no. 13 and 6 respectively. Appendix X showed the SO_4^- content of collected goundwater samples in Birol Upazilla. The status of PO_4 of all tested ground water samples were found within the recommended limit as per Ayers and Westcot (1985).

4.1.4.11 Bicarbonate (HCO_3)

The concentration of HCO_3 in different water samples were within the range of 0.60 to 43.30 mg L^{-1} with the mean value of 1.88 mg L^{-1} (Appendix XIII) and0.90 to 1.80 mg L^{-1} with the mean value of 1.41 mg L^{-1} (Appendix XIV) in Birol and Bochagonj upazilla, respectively. Out of 36 samples of Birol upazilla, 18 samples (50%) were found below the mean value and the rest 18 samples (50%) were above the mean value but out of the 18 samples of Bochagonj upazilla, 10 samples (55.56%) were found below the mean value and the rest 8 samples (44.44%) were above the mean value. The highest and the lowest concentration of HCO_3 (3.30 mg L^{-1}) and (0.60 mg L^{-1}) was observed at sample no. 32 and 28, respectively of Birol upazilla and for Bochagonj upazilla, the highest and the lowest concentration of HCO_3 (1.80 mg L^{-1}) and (0.90 mg L^{-1}) were obtained from the sample no. 1 and 14 respectively.

4.1.4.11 Chloride (Cl)

The concentration of Cl in different water samples were within the range of 11.988 to 21.128 mg L^{-1} with the mean value of 15.944 mg L^{-1} (Appendix XIII) and 13.464 to 23.584 mg L^{-1} with the mean value of 19.237 mg L^{-1} (Appendix XIV) in Birol and Bochagonj upazilla, respectively. Out of 36 samples of Birol upazilla, 19 samples (52.78%) were found below the mean value and the rest 17 samples (47.22%) were above the mean value but out of the 18 samples of Bochagonj upazilla, 6 samples (33.33%) were found below the mean value and the rest 12 samples (66.67%) were above the mean value. The highest and the lowest concentration of Cl (21.128 mg L^{-1}) and (11.988 mg L^{-1}) was observed at sample no.10 and 23 respectively of Birol upazilla and for Bochagonj upazilla, the highest and the lowest concentration of Cl (23.584 mg L^{-1}) and (13.464 mg L^{-1}) were obtained from the sample no. 8 and 6 respectively. Chloride content was recorded comparatively higher among the ionic constituents. According to WHO (1971), the acceptable limit of Cl for irrigation water is less than 200 mg L^{-1}. On the basis of this limit, all the waters under investigation were not problematic for irrigation without any toxic effect on soils and crops grown in the area of this study.

Table 5: Anionic constituents of the collected ground water samples of different unions in Birol

Name of Upazila	SO_4^- mg L^{-1}	PO_4^- mg L^{-1}	HCO_3^- mg L^{-1}	Cl^- mg L^{-1}
Rajarampur	0.611	1.260	2.0	19.482
Azimpur	0.369	0.911	2.8	13.420
Mangalpur	4.088	0.603	3.1	12.597
Shahorgram	0.780	0.646	2.3	19.980
Farakkabad	2.133	0.604	1.2	12.408
Dharmapur	0.677	0.794	1.1	12.646
Bijora	2.524	0.682	2.2	17.568
Dhamoir	2.787	0.568	1.4	12.030
Bhandara	0.831	0.663	1.3	20.255
Ranipukur	1.377	0.431	0.7	141.129
Birol	1.396	0.467	3.1	12.828
Polashbari	1.749	0.522	1.4	15.331

Table 6: Anionic constituents of the collected ground water samples of different unions in Bochagonj

Name of Upazila	SO_4^- mg L^{-1}	PO_4^- mg L^{-1}	HCO_3^- mg L^{-1}	Cl^- mg L^{-1}
Nafanagor	1.517	0.902	1.6	19.758
Eshania	0.588	0.608	1.3	20.028
Murshidahat	0.464	0.636	1.4	22.643
Atgao	1.895	1.005	1.5	18.80
Chatol	0.376	1.083	1.1	13.963
Rongao	0.266	0.796	1.4	20.227

The anionic concentrations of water samples ofor both Birol and Bochagonj upazila analyzed were in the descending order of magnitude as:

$Cl > SO_4 > HCO_3 > PO_4$

4.2 Ground water Quality Determining Indices

4.2.1 Sodium adsorption ratio (SAR)

Appendix XV and Appendix XVI showed the computed SAR of collected goundwater samples in Birol and Bochagonj Upazilla. The computed sodium adsorption ratio (SAR) of ground water samples was within of 0.552 to 0.984 mg L^{-1} with the mean value of 0.768 mg L^{-1} (Appendix XV) and 0.580 to 0.906 mg L^{-1} with the mean value of 0.673 mg L^{-1} (Appendix XVI) in Birol and Bochagonj upazilla, respectively. Out of 36 samples of Birol upazilla, 17 samples (47.22%) were found below the mean value and the rest 19 samples (52.78%) were above the mean value but out of the 18 samples of Bochagonj upazilla, 15 samples (83.33%) were found below the mean value and the rest 3 samples (16.67%) were above the mean value. The highest and the lowest value of SAR (0.984 mg L^{-1}) and (0.552 mg L^{-1}) was observed at sample no.3 and 24 respectively of Birol upazilla and for Bochagonj upazilla, the highest and the lowest value of SAR (0.906 mg L^{-1}) and (0.580 mg L^{-1}) were obtained from the sample no. 1 and 12 respectively. On the basis of SAR, Todd (1980) categorized irrigation waters into 4 groups as shown in Appendix VI. Considering this classification, all the ground waters were 'Excellent' for Birol upazilla (Appendix XVII and Appendix XX) and Bochagonj upazilla (Appendix XIX and Appendix XXI) for both irrigation and drinking purpose. The present investigation expressed that a good proportion of Ca and existed in waters which was ‘suitable’ for good structure and tilth condition of soil also would improve the soil permeability. The irrigation water with SAR less than 10 might not be harmful for agricultural crops (Todd, 1980). All the ground waters samples used for irrigation were also classified on the basis of alkalinity hazard as diagrammatically in Figure 4 (Richards, 1968). According to this classification, all samples were rated as ‘low’ alkalinity hazard (S_1) class for irrigation as per SAR (Figure 4).

4.2.2 Soluble sodium percentage (SSP)

Appendix XV and Appendix XVI showed the computed SSP of collected goundwater samples in Birol and Bochagonj Upazilla. The soluble sodium percentage (SSP) ofground water samples was within of 5.333 to 9.996 mgL^{-1} with the mean value of 8.132 mg L^{-1} (Appendix XV) and 5.816 to 9.236 mg L^{-1} with the mean value of 6.914 mg L^{-1} (Appendix XVI) in Birol and Bochagonj upazilla, respectively. Out of 36 samples of Birol upazilla, 16 samples (44.44%) were found below the mean value and the rest 20 samples (55.56%) were above the mean value but out of the 18 samples of Bochagonj upazilla, 15 samples (83.33%) were found below the mean value and the rest 3 samples (16.67%) were above the mean value. The highest and the lowest value of SSP (9.996 mg L^{-1}) and (5.333 mg L^{-1}) was observed at sample no.16 and 24, respectively of Birol upazilla and for Bochagonj upazilla, the highest and the lowest value of SSP (9.236 mg L^{-1}) and (5.186 mg L^{-1}) were obtained from the sample no. 1 and 12 respectively. According to the water classification proposed by Wilcox (1955), all the collected water samples were classified as ‘excellent’ for Birol upazilla (Appendix XVII) and for Bochagonj upazilla (Appendix XIX) (SSP<20%) as reported in Appendix IV. In the study area, ground waters might safely be applied for irrigating agricultural crops.

4.2.3 Totalhardness (H_T)

Appendix XV and Appendix XVI showed the computed H_T of collected goundwater samples in Birol and Bochagonj Upazilla. The total hardness (H_T) of water samples was within the range of 60.880 to 133.028 mg L^{-1} with the mean value of 91.381 mgL^{-1} (Appendix XV) and 98.268 to 114.665 mg L^{-1} with the mean value of 103.468 mg L^{-1} (Appendix XVI) in Birol and Bochagonj upazilla, respectively. Out of 36 samples of Birol upazilla, 17 samples (47.22%) were found below the mean value and the rest 19 samples (52.78%) were above the mean value but out of the 18 samples of Bochagonj upazilla, 12 samples (66.67%) were found below the mean value and the rest 6 samples

(33.33%) were above the mean value. The highest and the lowest value of H_T (133.028 mg L^{-1}) and (60.880 mg L^{-1}) was observed at sample no.21 and 18, respectively of Birol upazilla and for Bochagonj upazilla, the highest and the lowest value of H_T (114.665 mg L^{-1}) and (98.268 mg L^{-1}) were obtained from the sample no. 12 and 17 respectively. Sawyer and McCarty (1967) classified irrigation water into 4 classes based on hardness as mentioned in Appendix VII. According to this classification, 24 samples were 'moderately hard', and 12 samples were 'soft'for Birol upazilla (Appendix XVII and Appendix XX) but for Bochagonj upazilla, all samples are 'moderately hard' (Appendix XIX and Appendix XXI). Hardness resulted due to presence of appreciable amount of divalent cations like Ca and Mg (Todd, 1980).

4.2.4 Permeability Index and

Appendix XV and Appendix XVI showed the computed value of Permeability Index (PI) of collected goundwater samples in Birol and Bochagonj Upazilla. The range of the value of Permeability Index (PI) for all water samples varied from 0.085 to 0.165 mg L^{-1} with the mean value of 0.138 mg L^{-1} (Appendix XV) and 0.095 to 0.134 mg L^{-1} with the mean value of 0.111 mg L^{-1} (Appendix XVI) in Birol and Bochagonj upazilla, respectively. Out of 36 samples of Birol upazilla, 16 samples (44.44%) were found below the mean value and the rest 20 samples (55.56%) were above the mean value but out of the 18 samples of Bochagonj upazilla, 11 samples (61.11%) were found below the mean value and the rest 7 samples (38.89%) were above the mean value. The highest and the lowest value of PI (0.165 mg L^{-1}) and (0.085 mg L^{-1}) was observed at sample no.31 and 24 respectively of Birol upazilla and for Bochagonj upazilla, the highest and the lowest value of PI (0.134 mg L^{-1}) and (0.095 mg L^{-1}) were obtained from the sample no. 7 and 11 respectively. Permeability Problem (PI) 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, PI, H_T etc. also the indicators of permeability problem.

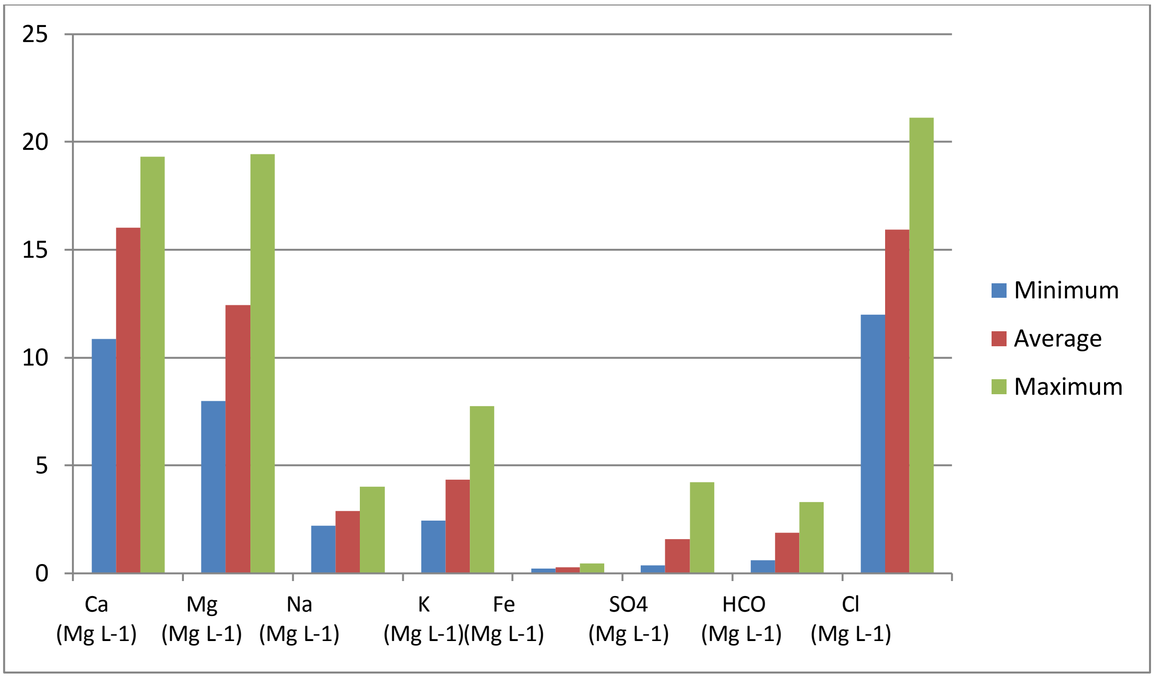


Figure 4: Different ions of water sample for Birol Upazila

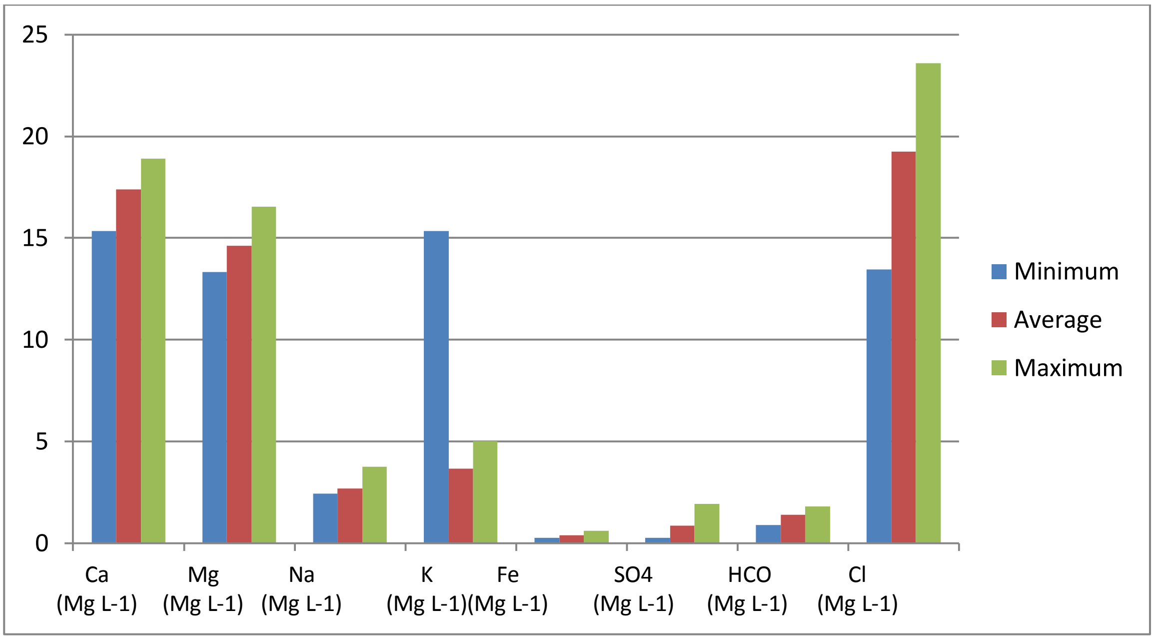


Figure 5: Different ions of water sample for Bochaganj Upazila

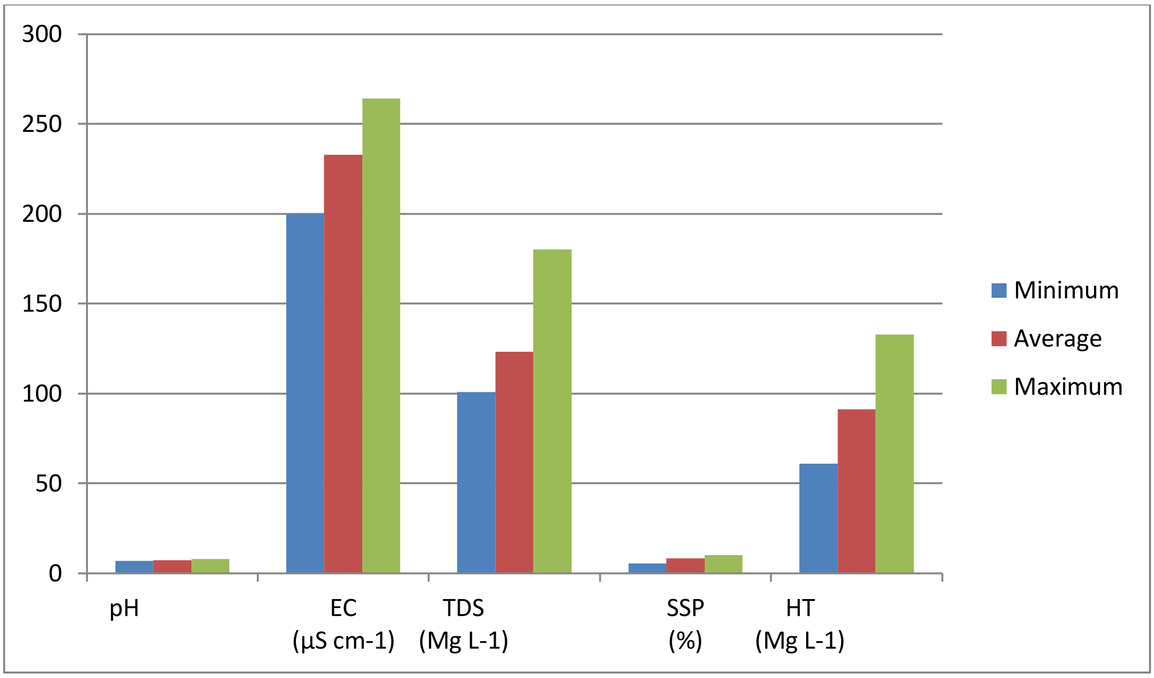


Figure 6: Different perameter of water sample for Birol Upazila

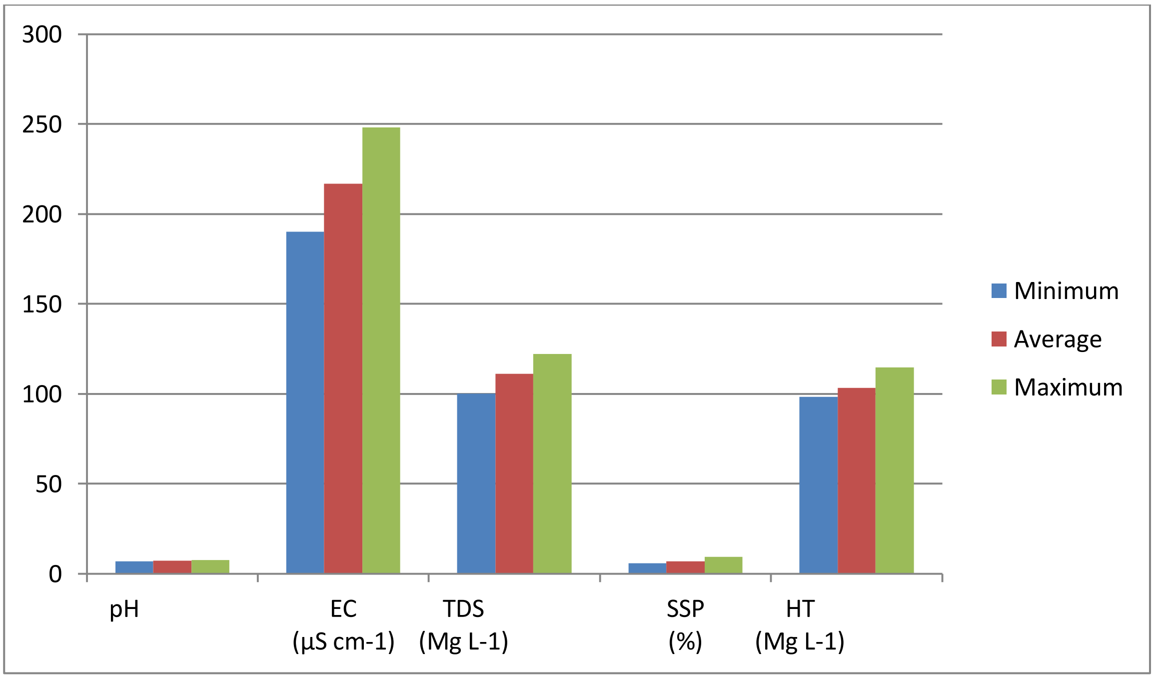


Figure 7: Different perameter of water sample for Bochaganj Upazila

4.2.5 Potential Salinity

Appendix XV and Appendix XVI showed the computed value of Permeability Salinity (PS) of collected goundwater samples in Birol and Bochagonj Upazilla. The range of the value of Permeability Salinity (PS) for all water samples varied from 5.693 to 83.266 mg L^{-1} with the mean value of 29.733 mg L^{-1} (Appendix XV) and 13.647 to 23.826 mg L^{-1} with the mean value of 19.662 mg L^{-1} (Appendix XVI) in Birol and Bochagonj upazilla, respectively. Out of 36 samples of Birol upazilla, 19 samples (52.78%) were found below the mean value and the rest 17 samples (47.22%) were above the mean value but out of the 18 samples of Bochagonj upazilla, 7 samples (38.89%) were found below the mean value and the rest 11 samples (61.11%) were above the mean value. The highest and the lowest value of Permeability Salinity (PS) (83.266 mg L^{-1}) and (5.693 mg L^{-1}) was observed at sample no. 6 and 7 respectively of Birol upazilla and for Bochagonj upazilla, the highest and the lowest value of Permeability Salinity (PS) (0.134 mg L^{-1}) and (0.095 mg L^{-1}) were obtained from the sample no. 1 and 12 respectively. Therefore, according to Permeability Salinity (PS), all of the water samples were suitable for irrigation.

4.2.6 Kelly's Ratio

Kelly's ratio (KR) represents the alkali hazards of water and is calculated by this equation, where all the concentrations were expressed in mg L^{-1}. Kelly's ratio is used to find whether ground water is suitable for irrigation or not. Sodium measured against calcium and magnesium was considered by Kelly (1951) for calculating Kelly's ratio. Ground water having Kelly's ratio more than one (1) is generally considered as unfit for irrigation. The range of the value of Kelly's ratio for all water samples varied from 0.062 to 0.129 mg L^{-1} with the mean value of 0.104 mg L^{-1} (Appendix XV) and 0.069 to 0.109 mg L^{-1} with the mean value of 0.084 mg L^{-1} (Appendix XVI) in Birol and Bochagonj upazilla, respectively. Out of 36 samples of Birol upazilla, 18 samples (50%) were found below the mean value and the rest 18 samples (50%) were above the mean value but out of the 18 samples of Bochagonj upazilla, 15 samples (83.33%) were found below the mean value and the rest 3 samples (16.67%) were above the mean value. The highest and the lowest value of Kelly's ratio (0.129 mg L^{-1}) and (0.062 mg L^{-1}) was observed at sample no. 16 and 24 respectively of Birol upazilla and for Bochagonj upazilla, the highest and the lowest value of Kelly's ratio (0.109 mg L^{-1}) and (0.069 mg L^{-1}) were obtained from the sample no. 1 and 12 respectively. Therefore, according to Kelly's ratio, all of the water samples were suitable for irrigation.

Table 7: SAR, H_T, SSP, PI and Kelly's ratio of ground water samples of different unions in Birol

Name of Upazila	SAR	SSP %	H_T mg L^{-1}	PI	PS mg L^{-1}	Kelly's ratio
Rajarampur	0.943	8.504	106.729	0.141	64.752	0.115
Azimpur	0.918	9.356	99.321	0.153	72.478	0.116
Mangalpur	0.928	8.635	98.540	0.157	6.169	0.118
Shahorgram	0.644	6.504	99.229	0.121	51.273	0.082
Farakkabad	0.787	9.350	64.474	0.159	11.639	0.124
Dharmapur	0.788	9.864	61.280	0.160	37.357	0.126
Bijora	0.809	7.520	133.144	0.106	16.097	0.089
Dhamoir	0.564	5.433	127.217	0.087	8.646	0.063
Bhandara	0.705	7.526	82.431	0.130	48.805	0.098
Ranipukur	0.799	9.968	61.614	0.057	34.609	0.127
Birol	0.683	8.213	71.768	0.160	18.430	0.101
Polashbari	0.647	6.708	90.820	0.117	17.543	0.086

Table 8: SAR, H_T, SSP, PI and Kelly's ratio of ground water samples of different unions in Bochagonj

Name of Upazila	SAR	SSP %	H_T mg L^{-1}	PI	PS mg L^{-1}	Kelly's ratio
Nafanagor	0.880	8.960	109.447	0.131	20.517	0.106
Eshania	0.639	6.474	98.995	0.109	20.322	0.081
Murshidahat	0.639	6.644	99.888	0.110	22.875	0.081
Atgao	0.602	6.039	113.838	0.100	19.748	0.072
Chatol	0.634	6.632	99.466	0.106	14.151	0.080
Rongao	0.639	6.732	99.172	0.112	20.360	0.082

4.3 Water quality rating and suitability of ground waters for drinking and irrigation usage

The pH values of all samples varied from 6.91 to 7.78 with the mean value of 7.39 (Appendix IX) and 6.96 to 7.72 with the mean value of 7.31 (Appendix X) in Birol and Bochagonj upazilla, respectively. Out of 36 samples of Birol upazilla, 30 samples (83.33%) were found below the mean value and the rest 6 samples (30.56%) were above the mean value but out of the 18 samples of Bochagonj upazilla, 9 samples (50%) were found below the mean value and the rest 9 samples (50%) were above the mean value. The highest and the lowest value of pH (7.78) and (6.91) was observed at sample no. 22

and 5 respectively of Birol upazilla and for Bochagonj upazilla, the highest and the lowest value of pH (6.96) and (7.72) were obtained from the sample no. 1 and 4, respectively. The pH value of all samples indicated that these samples were slightly acidic to neutral or slightly alkaline in nature. Almost all the water sampleswere 'Highest Desirable' within the recommended value for drinking by WHO as reported in Appendix III. Water quality for irrigation has a great impact on crop production. The important factor 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 basicity of the fertilizer used during crop production.

The EC value of all samples varied from 200 to 264 µS cm^{-1} with mean value of 232.833 µS cm^{-1} (Appendix IX) and 190 to 248 µS cm^{-1} with mean value of 216.833 µS cm^{-1} (Appendix X) in Birol and Bochagonj upazilla, respectively. Out of 36 samples of Birol upazilla, 17 samples (47.22%) were found below the mean value and the rest 19 samples (52.78%) were above the mean value but out of the 18 samples of Bochagonj upazilla, 9 samples (50%) were found below the mean value and the rest 9 samples (50%) were above the mean value. The highest and the lowest value of EC (264 µS cm^{-1}) and (200 µS cm^{-1}) was observed at sample no.20 and 16 respectively of Birol upazilla and for Bochagonj upazilla, the highest and the lowest value of EC (248 µS cm^{-1}) and (190 µS cm^{-1}) were obtained from the sample no. 5 and 15, respectively. Wilcox (1955) classified water quality into five groups on the basis of EC value (Appendix IV). According to this classification, 33 samples were 'Excellent', and samples were 'Good' for Birol upazilla (Appendix XVII) but for Bochagonj upazilla, all samples are 'Excellent' (Appendix XIX). Higher concentration of EC indicated higher concentration of dissolved constituents that may affect the irrigation water quality.

The values of total dissolved solids (TDS) of collected water samples varied from 101 mg L^{-1} to 180 mg L^{-1} with mean value of 123.25 mg L^{-1} (Appendix IX) and 100 mg L^{-1} to 122 mg L^{-1} with mean value of 111.11 mg L^{-1} (Appendix X) in Birol and Bochagonj upazilla, respectively. Out of 36 samples of Birol upazilla, 25 samples (69.44%) were found below the mean value and the rest 11 samples (30.56%) were above the mean value but out of the 18 samples of Bochagonj upazilla, 10 samples (55.56%) were found below the mean value and the rest 8 samples (44.44%) were above the mean value. The highest and the lowest value of TDS (180 mg L^{-1}) and (101 mg L^{-1}) was observed at sample no. 20 and 33, respectively of Birol upazilla and for Bochagonj upazilla, the highest and the lowest value of TDS (122 mg L^{-1}) and (100 mg L^{-1}) were obtained from the sample no. 5 and 9 respectively. According to Carroll (1962) and Freeze and Cherry (1979), water quality divided into four groups on the basis of TDS (Appendix V). By As per this suitability rating, all the collected ground water samples were considered as 'Fresh Water' for irrigation purpose and 'Highest Desirable' for drinking purpose in both Birol and Bochagonj upazilla. Because TDS values of all water samples were less than 1000 mg L^{-1} (Appendix IX) and (Appendix X) for Birol and Bochagonj upazilla, respectively.

Table 9: Quality classification and suitability assessment of water samples for irrigation of different unions in Birol Upazila

Name of Upazila	Water class based on					Alkinity and Salinity Hazard
	EC	TDS	SAR	SSP	HT	
Rajarampur	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
Azimpur	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
Mangalpur	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
Shahorgram	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
Farakkabad	Excellent	Fresh Water	Excellent	Excellent	Soft	C_1S_1
Dharmapur	Excellent	Fresh Water	Excellent	Excellent	Soft	C_1S_1
Bijora	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
Dhamoir	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
Bhandara	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
Ranipukur	Excellent	Fresh Water	Excellent	Excellent	Soft	C_1S_1
Birol	Excellent	Fresh Water	Excellent	Excellent	Soft	C_1S_1
Polashbari	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1

Legend: C_1= Low salinity and S_1= Low alkalinity

Table 10: Quality classification and suitability assessment of water samples for irrigation of different unions in Bochagonj Upazila

Name of upazila	Water class based on					Alkinity and Salinity Hazard
	EC	TDS	SAR	SSP	HT	
Nafanagor	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
Eshania	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
Murshidahat	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
Atgao	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
Chatol	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
Rongao	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1

Legend: C_1= Low salinity and S_1= Low alkalinity

Table 11: Quality classification and suitability assessment of water samples for drinking of different unions in Birol Upazila

Name of upazila	Water class based on									
	Ca	Mg	Zn	Cu	Fe	Mn	SO_4	pH	TDS	HT
Rajarampur	HD	HD	HD	D	D	HD	HD	HD	HD	D
Azimpur	HD	HD	HD	D	D	HD	HD	HD	HD	D
Mangalpur	HD	HD	HD	D	D	HD	HD	HD	HD	D
Shahorgram	HD	HD	HD	D	D	HD	HD	HD	HD	HD
Farakkabad	HD	HD	HD	D	D	HD	HD	HD	HD	HD
Dharmapur	HD	HD	HD	D	D	HD	HD	HD	HD	HD
Bijora	HD	HD	HD	D	D	HD	HD	HD	HD	HD
Dhamoir	HD	HD	HD	D	D	HD	HD	HD	HD	HD
Bhandara	HD	HD	HD	D	D	HD	HD	HD	HD	HD
Ranipukur	HD	HD	HD	D	D	HD	HD	HD	HD	HD
Birol	HD	HD	HD	D	D	HD	HD	HD	HD	HD
Polashbari	HD	HD	HD	D	D	HD	HD	HD	HD	HD

Legend: HD= Highest Desirable and D= Desirable

Table 12: Quality classification and suitability assessment of water samples for drinking of different unions in Bochagonj Upazila

Name of upazila	Water class based on									
	Ca	Mg	Zn	Cu	Fe	Mn	SO_4	pH	TDS	HT
Nafanagor	HD	HD	HD	D	D	HD	HD	HD	HD	D
Eshania	HD	HD	HD	D	D	HD	HD	HD	HD	D
Murshidahat	HD	HD	HD	D	D	HD	HD	HD	HD	D
Atgao	HD	HD	HD	D	D	HD	HD	HD	HD	HD
Chatol	HD	HD	HD	D	D	HD	HD	HD	HD	HD
Rongao	HD	HD	HD	D	D	HD	HD	HD	HD	HD

Legend: HD= Highest Desirable and D= Desirable

CHAPTER V

CONCLUSION AND RECOMMENDATION

The concentrations of cations and anions under study were within the safe limit for irrigation and drinking usage in Birol and Bochagonj upazila under Dinajpur district. The pH values were within the range of 6.91 to 7.78 and 6.96 to 7.72 in Birol and Bochagonj upazilla, respectively all indicating the slightly acidic to slightly alkaline. The EC value of all samples varied from 200 to 264 µS cm^{-1} and 190 to 248 µS cm^{-1} and the SAR values ranged from within of 0.552 to 0.984 mg L^{-1} and 0.580 to 0.906 mg L^{-1} in Birol and Bochagonj upazilla, respectively. On the combination basis of EC and SAR, all samples were graded as ‘low salinity’ (C_1) and ‘low alkali’ (S_1) class, combinedly expressed as C_1S_1 for all water samples. All the samples were graded as ‘fresh water’ collected in both Birol and Bochagonj upazilain respect to TDS because all waters contained TDS less than 1000 mgL^{-1}. Water samples were “excellent” based on SSP, in Birol and Bochagonj upazilla. As regards to hardness, 12 samples were ‘Soft’ and 24 samples were ‘Moderately Hard’ for irrigation but 27 samples were ‘Highest Desirable’ and 9 samples were ‘Desirable’ for drinking in Birol upazilla and for Bochagonj upazilla, all samples were ‘moderately hard’ for irrigation but 12 samples were ‘Highest Desirable’ and 6 samples were ‘Desirable’ for drinking.

Recommendations:

Based on this study, the following recommendations may be made:

1. The ground water samples of Birol and Bochagonj upazila under Dinajpur district had no health hazard effect and good for irrigation, drinking and domestic uses.

2. In addition to the chemical quality of water, biological and radiological qualities should also be assessed in future for the efficient management of water use for specific purpose.

3. The chemical constituents of ground water should be taken into consideration for fertilizer recommendation as it contains reasonable quantity of Ca, Mg, K, Na, Cl, HCO_3, SO_4, PO_4 and some micronutricnts.

REFERENCES

Ahmed, M. F. and Rahman, M. M. 2000. Water Supply and Sanitation: Rural and low income urban communities, ITN-Bangladesh. *Center for water supply and waste management, BUET, Dhaka, Bangladesh*.

Ahmed, M., Talukder, M.S.U. and Majid, M.A. 1993. Quality of groundwater for irrigation in Muktagacha area. Journal of the Institution of Engineers, Bangladesh. 21(3): 91-98.

Ahsan, M. N. 2004. Assessment of groundwater quality at Eastern Surma Kushiar floodplain and neighboring regions in Sylhet division. M.S. Thesis, Department of Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh.

Alamgir, M., Biswas, S.K., Robbani, G., Chakraborty, K.L., Mannaf, A. and Chowdhury, D.A. 1999. Groundwater quality of the Madhupur Tract. Bangladesh Journal of Science and Technology 1 (1): 47-52.

Ali, M.K. 1997. Groundwater pollution and its impact on the soil of Nachoul at High Barind Tract. M.S. Thesis, Department of Agricultural Chemistry. Bangladesh Agricultural University, Mymensingh.

Arefin, M.S. 2002. Water quality assessment for irrigation, livestock, poultry, aquaculture and industrial usage in Pabna. M.S. Thesis, Department of Agriculture Chemistry, Bangladesh Agricultural University, Mymensingh.

Ayers, R.S. and Westcot, D.W. 1985. Water Quality for Agriculture. FAO Irrigation and Drainage Paper 29 (Rcv. 1): 40-96.

Azad, A. K. 2004. Ionic toxicity assessment of groundwater sources in Kushtia and Chuadanga. M.S. Thesis, Department of Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh.

Chopra, S.L. and Kanwar, J.S. 1980. Analytical Agricultural Chemistry. Kalyani Publishers, Ludhiana, New Delhi. pp. 148-289.

Ghosh, A.B., Bajaj, J.C., Hasan, R. and Singh, D. 1983. Soil and Water Testing Methods. A Laboratory Manual, Division of Soil Science and Agricultural Chemistry, IARI, New Delhi-1100012. pp. 1-48.

Golterman, H.L. and Clymo, R.S. 1971. Methods for Chemical Analysis of Fresh Waters. IBP Handbook No. 8. Blackwell Scientific Publications. Oxford and Edenbourgh. pp. 41-46.

Helaluddin, S.M. 1996. Toxicity assessment of ground and surface waters in different aquifers of Khagrachari. M.S. Thesis, Department of Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh.

Hoque, S.M. 2000. Water toxicity assessment of different sources in Old Brahmaputra Floodplain. M.S. Thesis, Departments of Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh.

Hossain, M. and Ahmed, M. 1999. Groundwater quality of Muktagacha aquifer for irrigation. Bangladesh Journal of Agricultural Research. 24(1): 141-152.

Jesmin, M.S. 2000. Pollution studies on groundwater for irrigation, drinking and industrial usage in Gaibandha aquifers. M.S. Thesis, Department of Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh.

Karanth, K.R. 1994. Ground water Assessment Development and Management. TATA McGraw-Hill Publishing Company Limited. New Delhi, pp. 217-273.

Latha, M.R., Indirani, R., Sheeba, S. and Francis, H.J. 2002. Groundwater quality of Coimbatore district, Tamil Nadu. Journal of Ecobiology, 14:3, 217-221.

Luna, M.A.A. 2010. Water quality assessment for irrigated agriculture in Nilphamari District. MS Thesis. Department of Agricultural Chemisty, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh

Michael, A.M. 1978. Irrigation: Theory and Practice. Vikas Pub. House Pvt. Ltd. pp. 448-452.

Mitra, A. and Gupta S.K. 1999. Effect of sewage water irrigation on essential plant nutrient and pollutant element status in vegetable growing area around Calcutta. Journal of the Indian Society of Soil Science 47(1): 99-105.

Mohiuddin, A.K. 1995. Change in soil physical-chemical properties under long-term groundwater irrigation at Pangsha thana of Rajbari District. M.S. Thesis, Department of Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh.

Nizam, M.U. 2000. Copper, manganese, iron, zinc and arsenic toxicity detection in water sources of Madhupur Tract. M.S. Thesis, Department of Agricultural Chemistry. Bangladesh Agricultural University, Mymensingh.

Pucci, A.A.J.; Ehlke, T.A. and Owens, J.P. 1992. Confining unit effects on water quality in the New Jersey Coastal Plan. Groundwater. 30: 415-427.

Quayum, A. 1995. Impact of groundwatcr on the Grey Terrace soils of Gazipur. M.S. Thesis, Department of Agricultural Chemistry. Bangladesh Agricultural University, Mymensingh.

Quddus, K.G. and Zaman, M.W. 1996. Irrigation water quality in some selected villages of Meherpur in Bangladesh. Bangladesh Journal of Agricultural Sciences. 23(2): 51-57.

Raghunath, H.M. 1987. Groundwater. 2nd Edition. Wiley Eastern Ltd. New Delhi. pp. 344-369.

Rahman, M.M. 1993. Irrigation water quality and its impact on the physio-chemical parameters of Shahzadpur soil. M.Sc. (Ag.) Thesis, Department of Agricultural Chemistry. Bangladesh Agricultural ' University, Mymensingh.

Rahman, M.M. and Zaman, M.W. 1995. Quality assessment of river and groundwater for irrigation at Shahzadpur in Bangladesh. Progressive Agriculture. 6(2): 98-69.

Rahman, T.M.A. 2001. Comparative studies of groundwater quality for irrigation and drinking in Bogra Aquifers. M.S. Thesis, Department of Agricultural Chemistry. Bangladesh Agricultural University, Mymensingh.

Rahnan, M.S. 2000. An appraisal of surface and groundwater pollution in Lower Atrai Basin. M.S. Thesis, Department of Agricultural Chemistry. Bangladesh Agricultural University, Mymensingh.

Razzaque, M.A. 1995. Assessment of ionic toxicity in water sources and their long-term effect of soil properties. M.S. Thesis, Department of Agricultural Chemistry. Bangladesh Agricultural University, Mymensingh.

Roy P.K., Roy S.R, Roy B., Sarkar M., and Sarker B.C. 2012. Assessment of arsenic contamination and technique for arsenic free water of arsenic affected area in Bangladesh. Int. J. Sustain. Agril. Tech. 8(8): 30-37.

Sarker, B.C. 1997. Pollution assessment of surface and groundwater in Narayagonj aquifers. M.S. Thesis, Department of Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh.

Sarker, B.C. 2001. Water quality assessment for agriculture: sodium and chloride toxicity. Bangladesh J. Agril. Res. 26(1): 15-26.

Sarker, B.C., Hara, M. and Zaman, M.W. 2000. Suitability assessment of natural water in relation to irrigation and soil properties. Soil Sci. Plant Nutr. 46(4): 773-786.

Sen, R., Rahman, M.M. and Zaman, M.W. 2000. Groundwater and surface water quality for irrigation in some selected sites of Tongi in Gazipur district. Bangladesh Journal of Agricultural Research. 25(4): 593-601.

Shahidullah, S.M. 1995. Quality of groundwater and its long-term effect of the properties of Old Brahmaputra Floodplain Soils of Phulphr. M.Sc. (Ag). Thesis, Department of Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh.

Todd, D.K. 1980. Groundwater Hydrology. 2nd Edition. John-Wiley and Sons. Inc., New York 10016. pp. 267-315.

Uddin, M. S. 2005. A baseline study on the groundwater quality of lakshmipur and Noakhali districts. M. S. thesis, Department of Agricultural Chemistry, BAU, and Mymensingh.

UNDP (United Nations Development Program) 1987. The groundwater resources and its availability for development. Master Plan Organization, Ministry of Irrigation, Water Development and Flood Control, Government of the People's Republic of Bangladesh. Technical report No. 5. pp. 4-46.

USEPA (United States Environmental Protection Agency). 1975. Federal Register. 40 (248): 59566-59588.

Wilcox, L.V. 1955. Classification and use of irrigation water. United States Department of Agriculture Circular No. 969. Washington D.C. p. 19.

Zaman, M.W. 2000. Environmental impacts of groundwater abstraction in Barind area. Component-B: Water Quality and Agro-ecology. Paper presented at the Annual workshop of ARMP contract Research project, BARC, Dhaka, 3 April, 2000.

Zaman, M.W. and Majid, M.A. 1995. Irrigation water quality of Madhupur in Bangladesh. Progressive Agriculture. 6(2): 103-108.

Zaman, M.W. and Mohiuddin, A.K. 1995. Assessment of groundwater at some parts of Rajbari district in Bangladesh. Bangladesh Journal of Environmental Science. 1: 46-57.

Zaman, M.W. and Rahman, M.M. 1996. Ionic toxicity of industrial process waters in some selected sites of Sirajgonj in Bangladesh. Bangladesh Journal of Environmental Science 2: 27-34.

APPENDICES

Appendix I: Information regarding water sampling

Sl. No.	Source	Location (Birol)		Depth	Date of collection
		Union	Village		
1	Deep Tubewell	Rajarampur	Hasila	200 ft	13/03/18
2	Deep Tubewell	Rajarampur	Rajarampur	200 ft	13/03/18
3	Deep Tubewell	Rajarampur	Maljhar	200 ft	13/03/18
4	Deep Tubewell	Azimpur	Rajuria	205 ft	13/03/18
5	Deep Tubewell	Azimpur	Ajitpur	205 ft	13/03/18
6	Deep Tubewell	Azimpur	Vabki	205 ft	13/03/18
7	Deep Tubewell	Mangalpur	Gouripur	210 ft	13/03/18
8	Deep Tubewell	Mangalpur	Rudrapur	210 ft	13/03/18
9	Deep Tubewell	Mangalpur	SHikarpur	210 ft	13/03/18
10	Deep Tubewell	Shahorgram	Narapur	205 ft	13/03/18
11	Deep Tubewell	Shahorgram	Fulbari	205 ft	13/03/18
12	Deep Tubewell	Shahorgram	Shibpur	205 ft	13/03/18
13	Deep Tubewell	Farakkabad	Kanchan	215 ft	13/03/18
14	Deep Tubewell	Farakkabad	Tegera	215 ft	13/03/18
15	Deep Tubewell	Farakkabad	Taiyabpur	215 ft	13/03/18
16	Deep Tubewell	Dharmapur	Kaliyagong	220 ft	13/03/18
17	Deep Tubewell	Dharmapur	Dharmapur	220 ft	13/03/18
18	Deep Tubewell	Dharmapur	Enayetpur	220 ft	13/03/18
19	Deep Tubewell	Bijora	Chakerhat	210 ft	14/03/18
20	Deep Tubewell	Bijora	Choumuni	210 ft	14/03/18
21	Deep Tubewell	Bijora	Bijora	210 ft	14/03/18
22	Deep Tubewell	Dhamoir	Kashidanga	205 ft	14/03/18
23	Deep Tubewell	Dhamoir	Dhukurjhari	205 ft	14/03/18
24	Deep Tubewell	Dhamoir	Dhamoir	205 ft	14/03/18
25	Deep Tubewell	Bhandara	Rampur	215 ft	14/03/18
26	Deep Tubewell	Bhandara	Boro Tilain	215 ft	14/03/18
27	Deep Tubewell	Bhandara	Vandra	215 ft	14/03/18
28	Deep Tubewell	Ranipukur	Ranipukur	210 ft	14/03/18
29	Deep Tubewell	Ranipukur	Puriya	210 ft	14/03/18
30	Deep Tubewell	Ranipukur	Dharmapur	210 ft	14/03/18
31	Deep Tubewell	Birol	Moklespur	220 ft	14/03/18
32	Deep Tubewell	Birol	Madhobpur	220 ft	14/03/18
33	Deep Tubewell	Birol	Shankarpur	220 ft	14/03/18
34	Deep Tubewell	Polashbari	Formanpur	205 ft	14/03/18
35	Deep Tubewell	Polashbari	Polashbari	205 ft	14/03/18
36	Deep Tubewell	Polashbari	Horipur	205 ft	14/03/18

Appendix II: Information regarding water sampling

Sl.No.	Source	Location (Bochagonj)		Depth	Date of collection
		Union	Village		
1	Deep Tubewell	Nafanagor	Doulodpur	210 ft	22/02/18
2	Deep Tubewell	Nafanagor	Sultanpur	210 ft	22/02/18
3	Deep Tubewell	Nafanagor	Nafanagor	210 ft	22/02/18
4	Deep Tubewell	Eshania	Vorra	205 ft	22/02/18
5	Deep Tubewell	Eshania	Boiragihat	205 ft	22/02/18
6	Deep Tubewell	Eshania	Bokultola	205 ft	22/02/18
7	Deep Tubewell	Murshidahat	Ramdaspara	220 ft	22/02/18
8	Deep Tubewell	Murshidahat	Krisnapur	220 ft	22/02/18
9	Deep Tubewell	Murshidahat	Lokkhonia	220 ft	22/02/18
10	Deep Tubewell	Atgao	Madhodpur	210 ft	22/02/18
11	Deep Tubewell	Atgao	Bondhugao	210 ft	22/02/18
12	Deep Tubewell	Atgao	Nehelgao	210 ft	22/02/18
13	Deep Tubewell	Chatol	Rampur	220 ft	22/02/18
14	Deep Tubewell	Chatol	Maherpur	220 ft	22/02/18
15	Deep Tubewell	Chatol	Anora	220 ft	22/02/18
16	Deep Tubewell	Rongao	Mobarakpur	205 ft	22/02/18
17	Deep Tubewell	Rongao	Condipur	205 ft	22/02/18
18	Deep Tubewell	Rongao	Basudebpur	205 ft	22/02/18

Appendix III: Standards for chemical quality of drinking water (WHO, 1971)

Chemical	Highest Desirerable	Maximum Permissible
pH	7.0-8.5	6.5-9.2
TDS (mg/L)	500	1500
H_T (mg/L)	100	500
Calcium (mg/L)	75	200
Magnesium (mg/L)	<30 if $\mathbf{SO_4^-}$ is 250 mg/L upto 150 mg/L if $\mathbf{SO_4^-}$ is <250 mg/L	150
Iron (mg/L)	0.05	1.5
Manganese (mg/L)	0.1	1
Zinc (mg/L)	5	15
Chloride (mg/L)	200	600
Sulphate (mg/L)	200	400
Nitrate (mg/L)	-	45*
Copper (mg/L)	0.05	1.5

Appendix IV: Irrigation water classification on the basis of EC and SSP (Wilcox, 1955)

Water class	Percent sodium	Electrical conductance (EC) $\mu S\ cm^{-1}$
Excellent	<20	<250
Good	20-40	250-750
Permissible	40-60	750-2000
Doubtful	60-80	2000-3000
Unsuitable	>80	>3000

Appendix V: Irrigation water classification based on TDS (Freeze and Cherry, 1979)

Water class	Total dissolved solids (TDS) mgL^{-1}
Fresh water	0-1,000
Brackish water	1,000-10,000
Saline water	10,000-100,000
Brine water	>100,000

Appendix VI: Irrigation water classification based on SAR (Todd, 1980)

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

Appendix VII: Classification of irrigation water based on hardness (Sawyer and McCarty, 1967)

Water class	Hardness mg L^{-1}, as $CaCO_3$
Soft	0-75
Moderately hard	75-150
Hard	150-300
Very hard	>300

Appendix VIII: Acceptable range In drinking water

Parameter	Symbol	Unit	Standard	Remarks
pH	pH	-	6.5-8.5	<6.5and>8.5 not permissible
Alkalinity	-	mg/L	400	>400mg/L not permissible
Phosphate	PO_4^-	mg/L	6	>6mg/L not permissible
Sulphate	SO_4^-	mg/L	400	>400mg/L not permissible
Ammonium	NH_4^+	mg/L	1.5	>1.5mg/L not permissible
Arsenic	As	mg/L	0.05	>0.05mg/L not permissible
Conductivity	-	µS/cm	500	>500mg/L not permissible
Faecal Coliform	-	n/100ml	0	Should be nil

Appendix IX: Temerature, pH, EC and TDS of ground water samples of Birol

Serial no.	Temp.	pH	EC µS cm^{-1}	TDS mg L^{-1}
1	22.5	6.98	248	124
2	22.5	7.14	250	120
3	22.5	6.96	245	122
4	22.6	7.17	250	125
5	22.6	6.91	243	122
6	22.6	7.15	245	130
7	22.4	7.08	248	132
8	22.4	7.26	241	130
9	22.4	7.21	238	121
10	22.6	7.25	245	130
11	22.6	7.29	242	121
12	22.6	7.37	243	120
13	22.5	6.92	212	115
14	22.5	7.06	234	117
15	22.5	7.14	230	116
16	22.4	6.99	200	105
17	22.4	7.18	214	106
18	22.4	7.15	208	114
19	22.6	7.49	242	170
20	22.6	7.58	264	180
21	22.6	7.62	240	170
22	22.5	7.78	248	125
23	22.5	7.42	245	129
24	22.5	7.55	244	126
25	22.4	7.18	222	115
26	22.4	7.32	226	112
27	22.4	7.12	218	113
28	22.6	7.15	219	114
29	22.6	6.95	230	118
30	22.6	7.04	228	115
31	22.5	6.98	214	117
32	22.5	6.99	212	112
33	22.5	7.04	215	101
34	22.6	7.04	221	121
35	22.6	7.05	223	112
36	22.6	7.11	235	117
Mean	22.52	7.39	232.833	123.25
Minimum	22.4	6.91	200	101
Maximum	22.6	7.78	264	180

Appendix X: Temerature, pH, EC and TDS of ground water samples of Bochagonj

Serial no.	Temp.	pH	EC µS cm^{-1}	TDS mg L^{-1}
1	22.4	7.72	240	120
2	22.4	7.62	236	117
3	22.4	7.64	230	115
4	22.5	6.96	240	120
5	22.5	6.98	248	122
6	22.5	7.05	241	118
7	22.4	7.24	199	102
8	22.4	7.22	200	103
9	22.4	7.19	195	100
10	22.6	7.24	222	111
11	22.6	7.21	205	110
12	22.6	7.27	225	115
13	22.5	7.32	220	112
14	22.5	7.38	210	109
15	22.5	7.35	190	110
16	22.6	7.44	198	105
17	22.6	7.38	203	106
18	22.6	7.42	201	105
Mean	22.5	7.313	216.833	111.111
Minimum	22.4	6.96	190	100
Maximum	22.6	7.72	248	122

Appendix XI: Cationic constituents of the collected ground water samples of Birol

Serial no.	Ca^{2+} mg L^{-1}	Mg^{2+} mg L^{-1}	Na^{+} mg L^{-1}	K^{+} mg L^{-1}	Zn^{2+} mg L^{-1}	Cu^{2+} mg L^{-1}	Fe^{2+} mg L^{-1}	Mn^{2+} mg L^{-1}
1	19.24	14.58	3.75	7.50	0.038	0.076	0.27	0.066
2	19.31	14.18	3.82	7.75	0.036	0.074	0.24	0.064
3	18.94	14.28	4.01	7.54	0.037	0.075	0.23	0.065
4	17.54	13.61	3.25	3.75	0.045	0.066	0.22	0.046
5	17.65	13.23	3.75	3.77	0.044	0.065	0.23	0.042
6	17.33	13.81	3.85	3.25	0.043	0.064	0.25	0.044
7	17.43	13.61	3.75	7.50	0.056	0.088	0.26	0.063
8	16.98	13.52	3.50	6.98	0.052	0.085	0.26	0.062
9	17.32	13.43	3.67	7.37	0.054	0.085	0.24	0.061
10	16.24	14.25	2.55	5.08	0.063	0.081	0.39	0.041
11	16.13	14.35	2.45	4.95	0.064	0.081	0.37	0.042
12	16.48	14.22	2.55	5.15	0.065	0.080	0.35	0.039
13	11.22	8.75	2.56	3.75	0.043	0.074	0.33	0.043
14	10.87	9.12	2.48	3.58	0.045	0.072	0.34	0.044
15	11.18	9.02	2.44	3.55	0.047	0.073	0.32	0.042
16	11.24	8.21	2.51	2.53	0.044	0.089	0.46	0.029
17	11.18	8.11	2.38	2.45	0.047	0.087	0.43	0.024
18	11.15	8.05	2.46	2.44	0.044	0.085	0.43	0.026
19	21.65	19.44	3.75	3.75	0.032	0.085	0.28	0.027
20	21.46	19.25	3.66	3.82	0.034	0.083	0.26	0.024
21	21.51	19.33	3.57	3.58	0.033	0.081	0.25	0.025
22	22.25	17.45	2.52	3.75	0.068	0.065	0.23	0.038
23	22.35	17.53	2.57	3.58	0.066	0.067	0.24	0.035
24	22.42	17.24	2.46	3.62	0.064	0.066	0.22	0.036
25	14.43	11.66	2.55	5.07	0.064	0.069	0.24	0.046
26	14.02	11.35	2.58	5.00	0.064	0.067	0.23	0.042
27	13.97	11.44	2.45	4.95	0.067	0.065	0.25	0.044
28	11.85	7.98	2.54	2.57	0.059	0.076	0.29	0.044
29	12.17	8.12	2.58	2.50	0.054	0.075	0.27	0.042
30	11.41	7.38	2.39	2.48	0.055	0.074	0.28	0.043
31	14.43	8.75	2.50	2.58	0.047	0.082	0.17	0.018
32	13.89	8.89	2.26	2.44	0.045	0.079	0.18	0.017
33	14.26	8.91	2.20	2.66	0.046	0.081	0.16	0.019
34	16.03	12.64	2.50	5.00	0.038	0.083	0.40	0.048
35	15.76	12.36	2.45	4.97	0.037	0.080	0.38	0.045
36	15.99	12.32	2.37	5.08	0.039	0.083	0.37	0.048
Mean	16.036	12.420	2.879	4.341	0.049	0.072	0.282	0.041
Min.	10.87	7.98	2.20	2.44	0.032	0.065	0.22	0.024
Max.	19.31	17.53	4.01	7.75	0.068	0.089	0.46	0.066

Appendix XII: Cationic constituents of the collected ground water samples of Bochagonj

Serial no.	Ca^{2+} mg L^{-1}	Mg^{2+} mg L^{-1}	Na^{+} mg L^{-1}	K^{+} mg L^{-1}	Zn^{2+} mg L^{-1}	Cu^{2+} mg L^{-1}	Fe^{2+} mg L^{-1}	Mn^{2+} mg L^{-1}
1	18.75	15.51	3.75	2.08	0.077	0.072	0.35	0.011
2	18.59	15.13	3.54	2.55	0.068	0.061	0.28	0.006
3	18.56	15.36	3.60	2.72	0.076	0.059	0.32	0.012
4	17.64	13.62	2.52	5.02	0.042	0.088	0.47	0.024
5	17.26	13.53	2.48	4.82	0.038	0.068	0.42	0.021
6	17.35	13.43	2.55	4.75	0.045	0.072	0.36	0.014
7	16.25	14.46	2.56	3.75	0.071	0.077	0.62	0.033
8	16.57	14.26	2.50	3.68	0.062	0.071	0.60	0.033
9	16.45	14.33	2.46	3.62	0.059	0.067	0.57	0.026
10	18.47	16.53	2.51	3.75	0.062	0.081	0.44	0.017
11	18.35	16.35	2.61	3.58	0.053	0.073	0.35	0.022
12	18.90	16.44	2.44	3.68	0.054	0.065	0.36	0.010
13	17.79	13.51	2.56	3.65	0.068	0.063	0.42	0.029
14	17.63	13.33	2.42	3.60	0.060	0.055	0.34	0.021
15	17.85	13.47	2.54	3.57	0.057	0.067	0.26	0.022
16	15.35	14.89	2.53	3.75	0.057	0.066	0.52	0.019
17	15.77	14.35	2.50	3.55	0.046	0.052	0.40	0.014
18	15.56	14.86	2.43	3.62	0.055	0.047	0.37	0.006
Mean	17.393	14.631	2.694	3.652	0.058	0.067	0.391	0.019
Min.	15.35	13.33	2.42	2.08	0.038	0.047	0.26	0.006
Max.	18.90	16.53	3.75	5.02	0.077	0.081	0.62	0.033

Appendix XIII: Anionic constituents of the collected ground water samples of Birol

Serial no.	SO_4^- mg L^{-1}	PO_4^- mg L^{-1}	HCO_3^- mg L^{-1}	Cl^- mg L^{-1}
1	0.511	1.283	2.00	19.496
2	0.681	1.222	2.00	19.522
3	0.641	1.277	2.00	19.428
4	0.361	0.918	2.80	12.038
5	0.359	0.920	2.70	12.112
6	0.387	0.897	3.00	16.112
7	4.220	0.511	3.00	12.012
8	4.125	0.626	3.10	13.256
9	3.921	0.672	3.20	12.525
10	0.752	0.604	2.20	21.128
11	0.786	0.715	2.50	18.956
12	0.804	0.620	2.20	19.857
13	2.166	0.616	1.20	12.048
14	2.212	0.594	1.00	13.124
15	2.021	0.602	1.40	12.053
16	0.692	0.791	1.20	12.762
17	0.655	0.800	1.00	12.564
18	0.685	0.792	1.10	12.613
19	2.527	0.686	2.00	20.416
20	2.625	0.668	2.20	20.241
21	2.420	0.694	2.40	20.222
22	2.944	0.568	1.40	12.048
23	2.666	0.524	1.50	11.988
24	2.752	0.613	1.30	12.055
25	0.883	0.674	1.40	20.416
26	0.789	0.664	1.20	20.255
27	0.823	0.651	1.30	20.094
28	1.772	0.439	0.60	20.416
29	1.658	0.435	0.90	19.759
30	0.702	0.421	0.60	19.989
31	1.472	0.476	3.00	13.685
32	1.465	0.462	3.30	12.568
33	1.252	0.464	2.90	12.232
34	1.775	0.546	1.60	17.864
35	1.852	0.499	1.50	14.268
36	1.622	0.523	1.10	13.863
Mean	1.570	0.680	1.88	15.944
Minimum	0.359	0.421	0.60	11.988
Maximum	4.220	1.283	3.30	21.128

Appendix XIV: Anionic constituents of the collected ground water samples of Bochagonj

Serial no.	SO_4^- mg L^{-1}	PO_4^- mg L^{-1}	HCO_3^- mg L^{-1}	Cl^- mg L^{-1}
1	1.544	0.953	1.80	20.208
2	1.486	0.856	1.50	18.854
3	1.522	0.899	1.70	20.213
4	0.557	0.627	1.60	20.208
5	0.656	0.611	1.00	20.115
6	0.552	0.588	1.30	19.762
7	0.444	0.651	1.80	22.762
8	0.483	0.634	1.10	23.584
9	0.465	0.624	1.30	21.584
10	1.940	1.012	1.80	20.208
11	1.858	1.005	1.40	18.595
12	1.887	0.998	1.30	17.598
13	0.388	1.162	1.50	14.864
14	0.374	1.086	0.90	13.561
15	0.366	1.001	1.10	13.464
16	0.277	0.825	1.60	21.864
17	0.265	0.767	1.40	20.563
18	0.256	0.796	1.20	18.255
Mean	0.851	0.839	1.41	19.237
Minimum	0.265	0.588	0.90	13.464
Maximum	1.940	1.162	1.80	23.584

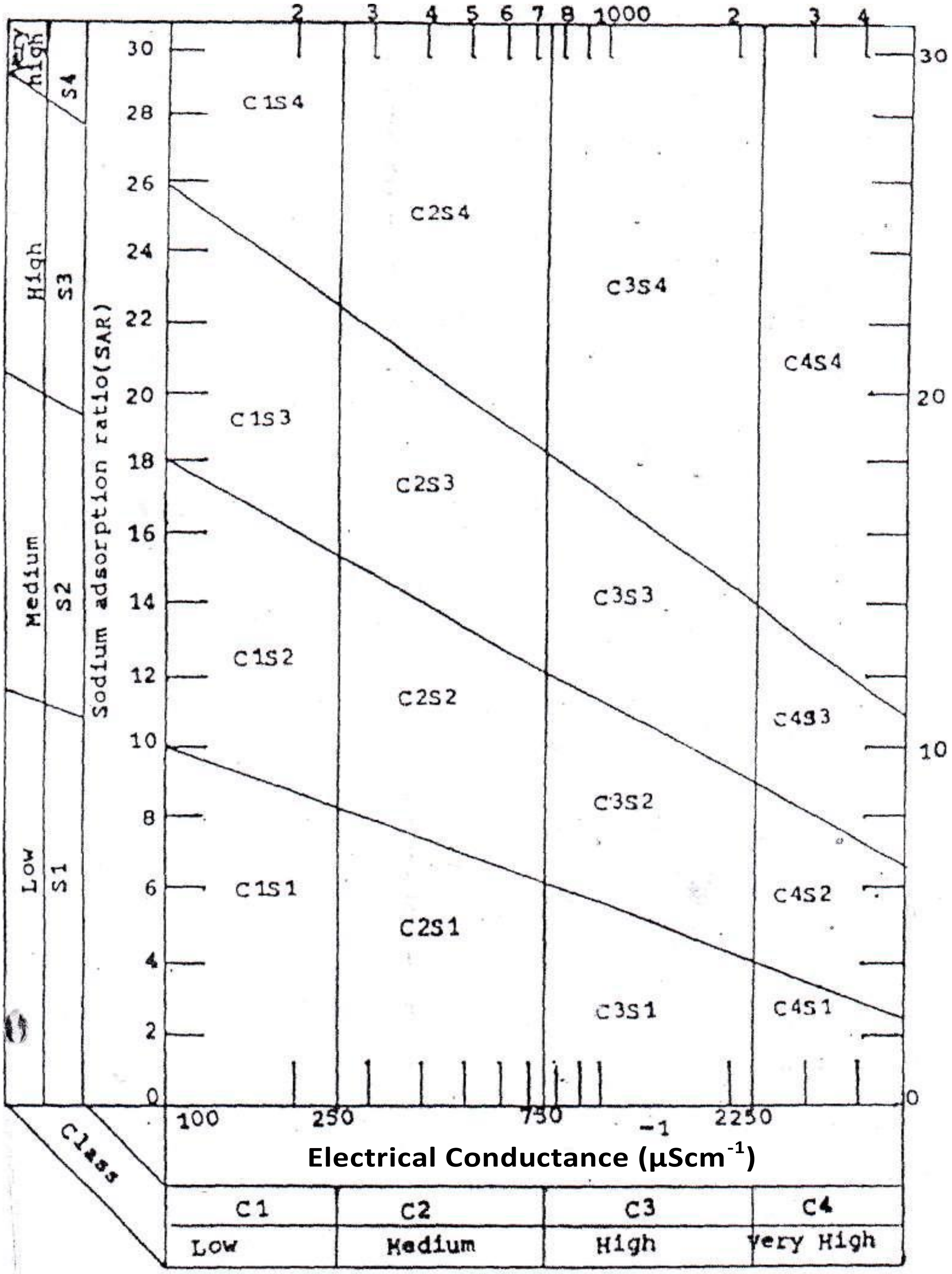
Appendix XV: SAR, H_T, SSP, PI and Kelly's ratio of ground water samples of Birol

Serial no.	SAR	SSP %	H_T mg L^{-1}	PI	PS mg L^{-1}	Kelly's ratio
1	0.912	8.238	107.878	0.137	76.305	0.111
2	0.934	8.400	106.413	0.140	57.333	0.114
3	0.984	8.876	105.898	0.146	60.618	0.121
4	0.824	8.436	99.651	0.143	66.693	0.104
5	0.954	9.670	98.368	0.156	67.476	0.121
6	0.976	9.964	99.946	0.160	83.266	0.124
7	0.952	8.770	99.376	0.158	5.693	0.121
8	0.896	8.446	97.882	0.155	6.427	0.115
9	0.936	8.691	98.363	0.159	6.389	0.119
10	0.653	6.590	99.025	0.122	56.191	0.084
11	0.628	6.374	99.160	0.122	48.234	0.080
12	0.651	6.550	99.502	0.121	49.396	0.083
13	0.810	9.563	63.925	0.162	11.125	0.128
14	0.784	9.341	64.567	0.155	11.866	0.124
15	0.768	9.148	64.932	0.160	11.928	0.121
16	0.805	9.995	61.761	0.164	36.884	0.129
17	0.766	9.633	61.201	0.156	38.363	0.123
18	0.794	9.966	60.880	0.162	36.826	0.128
19	0.827	7.651	133.829	0.115	16.158	0.091
20	0.811	7.532	132.575	0.116	15.422	0.090
21	0.790	7.379	133.028	0.115	16.712	0.087
22	0.566	5.434	127.170	0.088	8.185	0.063
23	0.576	5.534	127.748	0.089	8.993	0.064
24	0.552	5.333	126.734	0.085	8.761	0.062
25	0.706	7.472	83.881	0.130	46.242	0.098
26	0.724	7.735	81.585	0.132	51.343	0.102
27	0.687	7.372	81.829	0.129	48.831	0.096
28	0.807	9.996	62.343	0.148	23.043	0.128
29	0.810	9.996	63.717	0.154	23.835	0.127
30	0.780	9.912	58.783	0.149	56.949	0.127
31	0.734	8.748	71.950	0.165	18.594	0.108
32	0.670	8.129	71.174	0.163	17.158	0.099
33	0.646	7.764	72.181	0.154	19.540	0.095
34	0.660	6.805	91.899	0.121	20.128	0.087
35	0.653	6.790	90.076	0.120	15.408	0.087
36	0.630	6.529	90.487	0.111	17.094	0.084
Mean	0.768	8.132	91.381	0.138	29.733	0.104
Minimum	0.552	5.333	60.880	0.085	5.693	0.062
Maximum	0.984	9.996	133.028	0.165	83.266	0.129

Appendix XVI: SAR, H_T, SSP, PI and Kelly's ratio of ground water samples of Bochagonj

Serial no.	SAR	SSP %	H_T mg L^{-1}	PI	PS mg L^{-1}	Kelly's ratio
1	0.906	9.236	110.466	0.134	20.980	0.109
2	0.862	8.801	108.506	0.128	19.597	0.105
3	0.874	8.844	109.371	0.131	20.974	0.106
4	0.637	6.393	99.921	0.112	20.487	0.081
5	0.632	6.419	98.609	0.105	20.443	0.081
6	0.650	6.610	98.457	0.111	20.038	0.083
7	0.653	6.770	99.885	0.117	22.984	0.083
8	0.637	6.618	99.890	0.106	23.826	0.081
9	0.627	6.545	99.889	0.108	21.817	0.080
10	0.600	5.997	113.931	0.103	21.178	0.072
11	0.627	6.306	112.919	0.102	19.524	0.075
12	0.580	5.816	114.665	0.095	18.542	0.069
13	0.647	6.721	99.877	0.112	15.058	0.082
14	0.615	6.462	98.699	0.101	13.748	0.078
15	0.642	6.715	99.822	0.106	13.647	0.081
16	0.651	6.804	99.435	0.116	22.003	0.084
17	0.644	6.815	98.263	0.113	20.696	0.083
18	0.623	6.577	99.820	0.107	18.383	0.080
Mean	0.673	6.914	103.468	0.111	19.662	0.084
Minimum	0.580	5.816	98.263	0.095	13.647	0.069
Maximum	0.906	9.236	114.665	0.134	23.826	0.109

Appendix XVII: Diagram for classification of irrigation waters (Richards, 1968).



Appendix XVIII: Quality classification and suitability assessment of water samples for irrigation in Birol Upazila

Serial no.	EC	TDS	SAR	SSP	HT	Water class based on					Alkinity and Salinity Hazard
						EC	TDS	SAR	SSP	HT	
1	248	124	0.912	8.238	107.878	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
2	250	120	0.934	8.4	106.413	Good	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
3	245	122	0.984	8.876	105.898	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
4	250	125	0.824	8.436	99.651	Good	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
5	243	122	0.954	9.67	98.368	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
6	245	130	0.976	9.964	99.946	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
7	248	132	0.952	8.77	99.376	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
8	241	130	0.896	8.446	97.882	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
9	238	121	0.936	8.691	98.363	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
10	245	130	0.653	6.59	99.025	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
11	242	121	0.628	6.374	99.16	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
12	243	120	0.651	6.55	99.502	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
13	212	115	0.81	9.563	63.925	Excellent	Fresh Water	Excellent	Excellent	Soft	C_1S_1
14	234	117	0.784	9.341	64.567	Excellent	Fresh Water	Excellent	Excellent	Soft	C_1S_1

Appendix XVIII: Quality classification and suitability assessment of water samples for irrigation in Birol Upazila (contd.)

15	230	116	0.768	9.148	64.932	Excellent	Fresh Water	Excellent	Excellent	Soft	C_1S_1
16	200	105	0.805	9.995	61.761	Excellent	Fresh Water	Excellent	Excellent	Soft	C_1S_1
17	214	106	0.766	9.633	61.201	Excellent	Fresh Water	Excellent	Excellent	Soft	C_1S_1
18	208	114	0.794	9.966	60.88	Excellent	Fresh Water	Excellent	Excellent	Soft	C_1S_1
19	242	170	0.827	7.651	133.829	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
20	264	180	0.811	7.532	132.575	Good	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
21	240	170	0.79	7.379	133.028	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
22	248	125	0.566	5.434	127.17	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
23	245	129	0.576	5.534	127.748	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
24	244	126	0.552	5.333	126.734	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
25	222	115	0.706	7.472	83.881	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
26	226	112	0.724	7.735	81.585	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
27	218	113	0.687	7.372	81.829	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
28	219	114	0.807	9.996	62.343	Excellent	Fresh Water	Excellent	Excellent	Soft	C_1S_1
29	230	118	0.81	9.996	63.717	Excellent	Fresh Water	Excellent	Excellent	Soft	C_1S_1
30	228	115	0.78	9.912	58.783	Excellent	Fresh Water	Excellent	Excellent	Soft	C_1S_1

Appendix XVIII: Quality classification and suitability assessment of water samples for irrigation in Birol Upazila (contd.)

31	214	117	0.734	8.748	71.95	Excellent	Fresh Water	Excellent	Excellent	Soft	C_1S_1
32	212	112	0.67	8.129	71.174	Excellent	Fresh Water	Excellent	Excellent	Soft	C_1S_1
33	215	101	0.646	7.764	72.181	Excellent	Fresh Water	Excellent	Excellent	Soft	C_1S_1
34	221	121	0.66	6.805	91.899	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
35	223	112	0.653	6.79	90.076	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1
36	235	117	0.63	6.529	90.487	Excellent	Fresh Water	Excellent	Excellent	Moderately Hard	C_1S_1

Legend: C_1= Low salinity and S_1= Low alkalinity

Appendix XIX: Quality classification and suitability assessment of water samples for irrigation in Bochagonj Upazila

Serial no.	EC	TDS	SAR	SSP	HT	Water class based on					Alkinity and Salinity Hazard
						EC	TDS	SAR	SSP	HT	
1	240	120	0.906	9.24	110.412	Excellent	Fresh Water	Excellent	Excellent	moderately hard	C_1S_1
2	236	117	0.862	8.801	108.497	Excellent	Fresh Water	Excellent	Excellent	moderately hard	C_1S_1
3	230	115	0.874	8.844	109.371	Excellent	Fresh Water	Excellent	Excellent	moderately hard	C_1S_1
4	240	120	0.637	6.393	99.921	Excellent	Fresh Water	Excellent	Excellent	moderately hard	C_1S_1
5	248	122	0.632	6.419	98.609	Excellent	Fresh Water	Excellent	Excellent	moderately hard	C_1S_1
6	241	118	0.65	6.61	98.457	Excellent	Fresh Water	Excellent	Excellent	moderately hard	C_1S_1
7	199	102	0.653	6.77	99.885	Excellent	Fresh Water	Excellent	Excellent	moderately hard	C_1S_1
8	200	103	0.637	6.618	99.89	Excellent	Fresh Water	Excellent	Excellent	moderately hard	C_1S_1
9	195	100	0.627	6.545	99.889	Excellent	Fresh Water	Excellent	Excellent	moderately hard	C_1S_1
10	222	111	0.6	5.997	113.931	Excellent	Fresh Water	Excellent	Excellent	moderately hard	C_1S_1
11	205	110	0.627	6.306	112.919	Excellent	Fresh Water	Excellent	Excellent	moderately hard	C_1S_1
12	225	115	0.58	5.816	114.665	Excellent	Fresh Water	Excellent	Excellent	moderately hard	C_1S_1

Appendix XIX: Quality classification and suitability assessment of water samples for irrigation in Bochagonj Upazila (contd.)

13	220	112	0.647	6.721	99.877	Excellent	Fresh Water	Excellent	Excellent	moderately hard	C_1S_1
14	210	109	0.615	6.462	98.699	Excellent	Fresh Water	Excellent	Excellent	moderately hard	C_1S_1
15	190	110	0.642	6.715	99.822	Excellent	Fresh Water	Excellent	Excellent	moderately hard	C_1S_1
16	198	105	0.651	6.804	99.435	Excellent	Fresh Water	Excellent	Excellent	moderately hard	C_1S_1
17	203	106	0.644	6.815	98.263	Excellent	Fresh Water	Excellent	Excellent	moderately hard	C_1S_1
18	201	105	0.623	6.577	99.82	Excellent	Fresh Water	Excellent	Excellent	moderately hard	C_1S_1

Legend: C_1= Low salinity and S_1= Low alkalinity

Appendix XX: Quality classification and suitability assessment of water samples for drinking in Birol Upazila

Serial no.	Ca	Mg	Zn	Cu	Fe	Mn	SO_4	pH	TDS	HT	Water class based on									
											Ca	Mg	Zn	Cu	Fe	Mn	SO_4	pH	TDS	HT
1	19.24	14.58	0.038	0.076	0.27	0.066	0.511	6.98	124	107.878	HD	HD	HD	D	D	HD	HD	HD	HD	D
2	19.31	14.18	0.036	0.074	0.24	0.064	0.681	7.14	120	106.413	HD	HD	HD	D	D	HD	HD	HD	HD	D
3	18.94	14.28	0.037	0.075	0.23	0.065	0.641	6.96	122	105.898	HD	HD	HD	D	D	HD	HD	HD	HD	D
4	17.54	13.61	0.045	0.066	0.22	0.046	0.361	7.17	125	99.651	HD	HD	HD	D	D	HD	HD	HD	HD	HD
5	17.65	13.23	0.044	0.065	0.23	0.042	0.359	6.91	122	98.368	HD	HD	HD	D	D	HD	HD	HD	HD	HD
6	17.33	13.81	0.043	0.064	0.25	0.044	0.387	7.15	130	99.946	HD	HD	HD	D	D	HD	HD	HD	HD	HD
7	17.43	13.61	0.056	0.088	0.26	0.063	4.22	7.08	132	99.376	HD	HD	HD	D	D	HD	HD	HD	HD	HD
8	16.98	13.52	0.052	0.085	0.26	0.062	4.125	7.26	130	97.882	HD	HD	HD	D	D	HD	HD	HD	HD	HD
9	17.32	13.43	0.054	0.085	0.24	0.061	3.921	7.21	121	98.363	HD	HD	HD	D	D	HD	HD	HD	HD	HD
10	16.24	14.25	0.063	0.081	0.39	0.041	0.752	7.25	130	99.025	HD	HD	HD	D	D	HD	HD	HD	HD	HD
11	16.13	14.35	0.064	0.081	0.37	0.042	0.786	7.29	121	99.16	HD	HD	HD	D	D	HD	HD	HD	HD	HD
12	16.48	14.22	0.065	0.08	0.35	0.039	0.804	7.37	120	99.502	HD	HD	HD	D	D	HD	HD	HD	HD	HD
13	11.22	8.75	0.043	0.074	0.33	0.043	2.166	6.92	115	63.925	HD	HD	HD	D	D	HD	HD	HD	HD	HD
14	10.87	9.12	0.045	0.072	0.34	0.044	2.212	7.06	117	64.567	HD	HD	HD	D	D	HD	HD	HD	HD	HD
15	11.18	9.02	0.047	0.073	0.32	0.042	2.021	7.14	116	64.932	HD	HD	HD	D	D	HD	HD	HD	HD	HD
16	11.24	8.21	0.044	0.089	0.46	0.029	0.692	6.99	105	61.761	HD	HD	HD	D	D	HD	HD	HD	HD	HD
17	11.18	8.11	0.047	0.087	0.43	0.024	0.655	7.18	106	61.201	HD	HD	HD	D	D	HD	HD	HD	HD	HD
18	11.15	8.05	0.044	0.085	0.43	0.026	0.685	7.15	114	60.88	HD	HD	HD	D	D	HD	HD	HD	HD	HD
19	21.65	19.44	0.032	0.085	0.28	0.027	2.527	7.49	170	133.829	HD	HD	HD	D	D	HD	HD	HD	HD	D

Appendix XX: Quality classification and suitability assessment of water samples for drinking in Birol Upazila (contd.)

20	21.46	19.25	0.034	0.083	0.26	0.024	2.625	7.58	180	132.575	HD	HD	HD	D	D	HD	HD	HD	HD	D
21	21.51	19.33	0.033	0.081	0.25	0.025	2.42	7.62	170	133.028	HD	HD	HD	D	D	HD	HD	HD	HD	D
22	22.25	17.45	0.068	0.065	0.23	0.038	2.944	7.78	125	127.17	HD	HD	HD	D	D	HD	HD	HD	HD	D
23	22.35	17.53	0.066	0.067	0.24	0.035	2.666	7.42	129	127.748	HD	HD	HD	D	D	HD	HD	HD	HD	D
24	22.42	17.24	0.064	0.066	0.22	0.036	2.752	7.55	126	126.734	HD	HD	HD	D	D	HD	HD	HD	HD	D
25	14.43	11.66	0.064	0.069	0.24	0.046	0.883	7.18	115	83.881	HD	HD	HD	D	D	HD	HD	HD	HD	HD
26	14.02	11.35	0.064	0.067	0.23	0.042	0.789	7.32	112	81.585	HD	HD	HD	D	D	HD	HD	HD	HD	HD
27	13.97	11.44	0.067	0.065	0.25	0.044	0.823	7.12	113	81.829	HD	HD	HD	D	D	HD	HD	HD	HD	HD
28	11.85	7.98	0.059	0.076	0.29	0.044	1.772	7.15	114	62.343	HD	HD	HD	D	D	HD	HD	HD	HD	HD
29	12.17	8.12	0.054	0.075	0.27	0.042	1.658	6.95	118	63.717	HD	HD	HD	D	D	HD	HD	HD	HD	HD
30	11.41	7.38	0.055	0.074	0.28	0.043	0.702	7.04	115	58.783	HD	HD	HD	D	D	HD	HD	HD	HD	HD
31	14.43	8.75	0.047	0.082	0.17	0.018	1.472	6.98	117	71.95	HD	HD	HD	D	D	HD	HD	HD	HD	HD
32	13.89	8.89	0.045	0.079	0.18	0.017	1.465	6.99	112	71.174	HD	HD	HD	D	D	HD	HD	HD	HD	HD
33	14.26	8.91	0.046	0.081	0.16	0.019	1.252	7.04	101	72.181	HD	HD	HD	D	D	HD	HD	HD	HD	HD
34	16.03	12.64	0.038	0.083	0.4	0.048	1.775	7.04	121	91.899	HD	HD	HD	D	D	HD	HD	HD	HD	HD
35	15.76	12.36	0.037	0.08	0.38	0.045	1.852	7.05	112	90.076	HD	HD	HD	D	D	HD	HD	HD	HD	HD
36	15.99	12.32	0.039	0.083	0.37	0.048	1.622	7.11	117	90.487	HD	HD	HD	D	D	HD	HD	HD	HD	HD

Legend: HD= Highest Desirable and D= Desirable

Appendix XXI: Quality classification and suitability assessment of water samples for drinking in Bochagonj Upazila

Serial no.	Ca	Mg	Zn	Cu	Fe	Mn	SO_4	pH	TDS	HT	Water class based on									
											Ca	Mg	Zn	Cu	Fe	Mn	SO_4	pH	TDS	HT
1	18.75	15.51	0.077	0.072	0.35	0.011	1.544	7.72	120	110.466	HD	HD	HD	D	D	HD	HD	HD	HD	D
2	18.59	15.13	0.068	0.061	0.28	0.006	1.486	7.62	117	108.506	HD	HD	HD	D	D	HD	HD	HD	HD	D
3	18.56	15.36	0.076	0.059	0.32	0.012	1.522	7.64	115	109.371	HD	HD	HD	D	D	HD	HD	HD	HD	D
4	17.64	13.62	0.042	0.088	0.47	0.024	0.557	6.96	120	99.921	HD	HD	HD	D	D	HD	HD	HD	HD	HD
5	17.26	13.53	0.038	0.068	0.42	0.021	0.656	6.98	122	98.609	HD	HD	HD	D	D	HD	HD	HD	HD	HD
6	17.35	13.43	0.045	0.072	0.36	0.014	0.552	7.05	118	98.457	HD	HD	HD	D	D	HD	HD	HD	HD	HD
7	16.25	14.46	0.071	0.077	0.62	0.033	0.444	7.24	102	99.885	HD	HD	HD	D	D	HD	HD	HD	HD	HD
8	16.57	14.26	0.062	0.071	0.60	0.033	0.483	7.22	103	99.890	HD	HD	HD	D	D	HD	HD	HD	HD	HD
9	16.45	14.33	0.059	0.067	0.57	0.026	0.465	7.19	100	99.889	HD	HD	HD	D	D	HD	HD	HD	HD	HD
10	18.47	16.53	0.062	0.081	0.44	0.017	1.940	7.24	111	113.931	HD	HD	HD	D	D	HD	HD	HD	HD	D
11	18.35	16.35	0.053	0.073	0.35	0.022	1.858	7.21	110	112.919	HD	HD	HD	D	D	HD	HD	HD	HD	D
12	18.90	16.44	0.054	0.065	0.36	0.010	1.887	7.27	115	114.665	HD	HD	HD	D	D	HD	HD	HD	HD	D
13	17.79	13.51	0.068	0.063	0.42	0.029	0.388	7.32	112	99.877	HD	HD	HD	D	D	HD	HD	HD	HD	HD
14	17.63	13.33	0.06	0.055	0.34	0.021	0.374	7.38	109	98.699	HD	HD	HD	D	D	HD	HD	HD	HD	HD
15	17.85	13.47	0.057	0.067	0.26	0.022	0.366	7.35	110	99.822	HD	HD	HD	D	D	HD	HD	HD	HD	HD
16	15.35	14.89	0.057	0.066	0.52	0.019	0.277	7.44	105	99.435	HD	HD	HD	D	D	HD	HD	HD	HD	HD
17	15.77	14.35	0.046	0.052	0.40	0.014	0.265	7.38	106	98.263	HD	HD	HD	D	D	HD	HD	HD	HD	HD
18	15.56	14.86	0.055	0.047	0.37	0.006	0.256	7.42	105	99.82	HD	HD	HD	HD	D	HD	HD	HD	HD	HD

Legend: HD= Highest Desirable and D= Desirable