INVESTIGATION OF GROUNDWATER QUALITY AND ITS SUITABILITY FOR DRINKING AND AGRICULTURAL USE IN DINAJPUR SADAR UPAZILLA OF BANGLADESH

A THESIS
BY

MD. BIPLOB MIA
EXAMINATION ROLL NO.: 16050221
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SESSION: 2016-2017
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MASTER OF SCIENCE
IN
FOOD SCIENCE AND NUTRITION

DEPARTMENT OF FOOD SCIENCE AND NUTRITION
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Submitted to the
Department of Food Science and Nutrition
In partial fulfillment of the requirements for the degree of

MMASTER OF SCIENCE
IN
FOOD SCIENCE AND NUTRITION

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BELOVED PARENTS

ACKNOWLEDGEMENTS

In full gratitude I would like to acknowledge the following individuals who encouraged, inspired, supported, assisted, and sacrificed themselves to help my pursuit of thesis work.

My utmost appreciation goes to my super supervisor, Habiba Khatun, Assistant Professor, Department of Food Science and Nutrition, in the first place for suggesting this topic and for supervising this work, her continuous encouragement and leading during the period of study. I deeply acknowledge her patience at unappoint sessions for reading this work and correcting this manuscript.

I would like to extend my special thanks to my co-supervisor, Dr. Anwara Akhter Khatun, Chairman and Assistant Professor, Department of Food Science and Nutrition for her valuable advice and encouragement during the course of my study and also for reading through the manuscript and correcting my mistakes.

My heartfelt gratitude also goes to Md. Atikul Islam, Assistant Professor, Department of Chemistry, for his valuable suggestion, instruction and assistance.

For all technical assistance and moral support I would like to express my sincere gratitude for Md. Abdul Wadut, Laboratory Attendant, Department of Agricultural Chemistry, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur.

Hajee Mohammad Danesh Science and Technology University (HSTU) and Department of Food Science and Nutrition (FSN) are also acknowledged for providing the facilities to use the laboratory for research work and to widen my academic horizon.

Last but not least, I am deeply indebted to my parents and my family members for their hard work, encouragement, love, affection and blessings to bring me to pursuit sound academic achievement, where I am now.

The Author

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ABSTRACT

For the assessment of the suitability of groundwater for drinking and irrigation uses, a study was conducted to examine the ionic concentrations of groundwater of the Sadar Upazilla in the District of Dinajpur, Bangladesh. Ten Water samples were collected from 10 hand tubewells from 10 different places and analyzed for p^H, EC, cations (Ca^{2+}, Mg^{2+}, Na^+, K^+, S^+ and Zn^{2+}), anions (HCO_3^-, $P^-$and Cl^-),TDS,SAR, SSP, Hardness, permeability index, Gibb's ratio and Kelly's ratio. The p^H value (6.30 to 6.90) indicated that the waters were slightly acidic in nature. All water samples were under 'very good', 'good' and 'permissible' categories according to Wilcox diagram. The content of Ca^{2+}(15.76 to 33.39 mg /L), K^+(0.22 to 3.10 mg/L), Na^+(0.35 to 2.52 mg/L), $Zn^{2+\ (17.87}$ to 86.30 mg/L), Cl^- (0.31 to 0.80 mg/L), revealed that all the samples considered in the present study were suitable for drinking and irrigation purpose. SAR and SSP are use to asses of irrigation suitability of water of all the samples were under 'excellent' class. Kelley's ratio for the tested samples were under 'good' classes that were suitable for irrigation purpose. PI of the tested samples were under classified as class II i.e, 'good' that were suitable for irrigation purpose. According to TDS values, all samples were classed as 'freshwater'. Maximum samples were within 'soft' class regarding hardness. According to EC values, the water samples were classified as Permissible. Gibbs diagram indicates that all the samples fall in the precipitation dominance field. Regarding cation and anion constituents, groundwater is suitable for irrigation and drinking purposes except of few wells.

CHAPTER I

INTRODUCTION

Quality of ground water is an important factor that deals an essential role for several purposes of healthy living (Mandal *et al.,* 2010). Water is essential for all living organisms on the earth for their survival, growth and development. Groundwater is an important source of freshwater for agricultural, drinking and domestic uses in many regions of the world including Bangladesh. Demand of groundwater has been increasing day by day for irrigation by bringing more area under cultivation. Approximately, one-third of the world's population use groundwater for drinking purpose with or without treatment (Nickson *et al.,* 2005). In Bangladesh, roughly 90% of drinking water (Shahid *et al.,* 2006) and 75% of irrigation water (Shahid *et al.,* 2006) are used directly from ground water sources without any treatment. The contribution of groundwater in irrigation has increased steadily over the years from about 40% during early 1980s to about 80% in recent years. Apart from irrigation, drinking water supply in Bangladesh has almost entirely been based on groundwater source through the use of an estimated 8.6 million hand tube wells (HTWs) (Rahman and Mondal 2015).

According to annual report of CIMMYT 1999, in the global water resources about 97.5% is saline water mainly in oceans and only 2.5% is available as freshwater and 70% of it is locked in icecaps and glaciers or lies in deep underground reservoirs. An infinitesimal proportion (0.007%) of all water on earth is readily available fresh water. Increased population, food insecurity, growing economy and poor water management are exerting unprecedented pressure on the world's freshwater resources (UNCSD, 2012). The use of groundwater to surface water is much higher in northwestern districts of Bangladesh as compared to other parts of the country. All rivers and cannels of the area dry up during dry season and force the people to completely depend on groundwater (Shahid, 2008; Shahid and Behrawan, 2008). As per Barind Multipurpose Development Authority (BMDA), the ground water level has declined substantially during the last decade threatening the sustainability of water use for irrigation and in other sectors in the region (Jahan *et al.,* 2010).

Ground water may become toxic due to presence of several elements in excess amount. Toxicity level depends on the type of metal, its biological role and the type of organisms that are exposed to it. The heavy metals in drinking water linked most often to human poisoning are lead, iron, cadmium copper, zinc, chromium etc .They are required by the body in small amounts, but can also be toxic in large doses (Singl *et al.*, 2011).Normally occurring toxic elements in groundwater 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 present in drinking water are As, Cd, Cr, Cl, Pb, Hg, Fe and Zn. (Freeze *et al.*,1979 and Tanninen *et al.*,2005). The presence of the excess amount of some chemical constituents, like, Ca, Mg, Na, Cl, K, B, SO_4, HCO_3, and arsenic in water may deteriorate the water quality that sometime causes the death of life (WHO-1997).

Series of water quality problems have been identified and addressed since the 1950s. These include point and non-point source pollutants such as nutrients, hydrocarbons, pesticides and heavy metals (Hakim *et al.*, 2003). In this water, the concentrations of toxic chemicals and biologically available nutrients in excess can lead to diverse problems such as toxic algal blooms, loss of oxygen, fish kills, loss of biodiversity and loss of aquatic plant beds and coal reefs (Voutsa *et al.*, 2001). Naturally occurring heavy metals especially arsenic contamination in ground and underground waters cause medical issues even death. In Bangladesh, 40 million people are at risk of arsenic poisoning-related disease. These ground waters get polluted from various ways; such as industries discharge their effluent without proper treatment, and chemical drifting from excessive use of fertilizer for crop production (Islam *et al.*, 2003). The hand tubewells water source is generally considered as the poor type of groundwater sources in terms of physicochemical properties contamination due to the lack of concrete plinth and surrounding drainage system (WHO-1997). So it is necessary to ensure quality water uses in daily life. The information on concentrations of some important chemical constituents of water are necessary to assess their suitability for irrigation, drinking and industrial uses. Groundwater quality for drinking is a burning issue regarding Arsenic (As) and iron (Fe) toxicity in Bangladesh (Chen *et al.*, 2002 and Mondal *et al.*,1998).

A few numbers of literatures are available regarding the analysis of groundwater quality in different upazillas in dinajpur district but to the best of our knowledge no data is available regarding the water quality of Dinajpur sadar upazilla. But there are a huge numbers of industries especially automatic rice mills which discharge an ample amounts of impurities regarding suitability for drinking water in this region (Dinajpur sadar upazilla) which is still unexplored.

Objectives

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

a. To analyze the physico-chemical composition of ground water.

b. To assess the suitability of ground water for drinking purpose.

CHAPTER II

REVIEW OF LITERATURE

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

2.1 P^H

The pH values of northern Bangladesh were 6.24 to 8.10 (Islam *et al.,* 2010a). The pH of groundwater of Dimla Upazilla in the District of Nilphamari fluctuated acidic to neutral or slightly alkaline (pH 6.5 to 7.4) (Islam *et al.*,2010b). The pH values of Nilphamary District were varied from 6.7 to 7.8 (Islam *et al.,* 2009). The range of pH values of groundwater at Chirirbandar in Dinajpur district was 7.1 to 7.7 (Hasanuzzaman *et al.* 2007). The pH range of some selected area of Dhaka city for groundwater was varied from 7.3 to 8.0 (Islam et al., 2005). The pH of surface water collected from Eastern Surma Kushiara floodplain and neighboring region of Sylhet division varied from 5.27 to 7.19 (Ahsan, 2004). The pH of surface water collected from Dinajpur district varied from 5.32 to 7.00 (Uddin, 2004). In Kushtia and Chuadanga district, the pH values of groundwater ranged between 6.87 to 7.43 (Azad, 2004).

Another report of Hakim *et al.* 2003, the pH of Khagrachari of surface water was 6.75 to 7.27. The pH value of groundwater collected from Pabna sadar upazila under Pabna district varied from 7.50 to 8.20 reflecting alkaline in nature (Arefin., 2002). The range of pH values of Buriganga river was varied from 6.95 to 8.30 (Zaman *et al.,* 2002). The pH of groundwater collected from Dinajpur district varied from 5.32 to 7.00 (Islam *et al.,* 2001). The pH of groundwater collected from Sherpur upazila under Bogra district varied from 4.20 to 8.80 reflecting acidic to alkaline properties (Rahaman, 2001). Sen *et al.* (2000) found that the pH of water sources at Tongi were within the range of 6.69 to 7.63. A research work was carried out by Sarker *et al.* (2000) revealed that the pH of groundwater and surface water of Narayangonj district averaged as 8.12 and 7.92, respectively. Haque (2000) delineated that Groundwater collected from Sherpur sadar under Old Brahmaputra Floodplain, had pH in the range of 7.64 to 8.90. Nizam (2000) found that the pH values of 103 water samples collected from 11 unions of Bhaluka upazila under Mymensingh district were within the range of 2.80 to 10.30. Jesmin (2000) observed that groundwater pH in Gaibandha aquifers varied from 6.73 to 8.66.

2.2 Electrical Conductivity

A significant variation in the EC values of groundwater was detected ranging from 198 to 552µScm^{-1} at northern of Bangladesh (Islam *et al.* 2010a). The EC of groundwater collected from northern parts of Bangladesh were C1(0-250 µS cm^{-1}) to C2(250 to 750 µS cm^{-1}) (Islam *et al.,* 2010b). Islam *et al.* (2009) worked with groundwater in Nilphamari district and found EC values of samples were 259 to 572µScm^{-1}. Joshi *et al.* (2009) concludes that the water available for plants in the soil solution decreases proportionately as the EC increases. Hasanuzzaman *et al.* (2007) worked on groundwater of Chirirbandar in Dinajpur district and observed the EC values were ranged from 452 to 749µScm^{-1}. The EC values of some selected area from Dhaka city were within the range of 428 to 580µScm^{-1} (Islam *et al.* 2005). The electrical conductivity (EC) of Eastern Surma Kushiara Floodplain and neighboring region of Sylhet division were found 19.57 to 1655.40 µS cm^{-1} from 136 groundwater samples (Ahsan, 2004). In Kushtia and Chuadanga districts, the EC were ranged from 412 to 1331 µS cm^{-1} (Azad, 2004). Uddin (2004) studied 93 groundwater samples of Dinajpur district and stated that the EC ranged from 75.47 to 565.35 µS cm^{-1}.

The EC values were ranged from 29 to 200µScm^{-1} at Khagrachari district (Hakim *et al.,* 2003). EC ranges 52 to 300 µS cm^{-1}Khagrachari in Bangladesh (Islam *et al.,* 2003). The EC of 46 groundwater samples collected from Pabna sadar upazila were found at 0.47 to 0.90 dScm^{-1} (Arefin, 2002). The mean EC value of Buriganga river was 222.80 µScm^{-1} for monsoon and 663.10 µScm^{-1} (Zaman *et al.,* 2002). The EC of 50 groundwater samples collected from Sherpur upazila under Bogra district were found to vary from 442.80 to 670.80 µS cm^{-1} (Rahman, 2001). The EC of groundwater samples collected from Sherpur sadar upazila under Sheipur district ranged from 174 to 522 µS cm^{-1} (Haque, 2000). The EC values were varied from 121 to 300 µScm^{-1} of groundwater at Dinajpur district (Islam *et al.,* 2000). Groundwater EC in Gaibandha aquifers ranged from 274 to 1465 µS cm^{-1} (Jesmin, 2000). Sarker *et al.* (2000) found that the EC of surface and groundwater samples of Narayangonj aquifers varied from 0.808 to 0.470 dS cm^{-1}.

2.3 Total Dissolve Solid

TDS was found at 260-817 mg L^{-1} levels in groundwater of Dimla Upazila under Nilphamari district (Islam *et al.* 2010a). The TDS ranged from 107 to 1044 mg L^{-1} of northern Bangladesh (Islam *et al.* 2010b). The TDS amount of groundwater of Nilphamari district was ranged from 355 to 797 mg L^{-1} (Islam *et al.* 2009). The estimated amounts of TDS ranged from 255 to 422 mg L^{-1} (Hasanuzzaman *et al.*, 2007). The amount of TDS in the Dhaka city was reported to vary from 180 to 462 mg L^{-1} (Islam *et al.* 2005). Ahsan (2004) reported that in Eastern Surma Kushiara floodplain and neighbouring regions of Sylhet the TDS ranged from 13.87 to 1036.88 mg L^{-1}. Azad (2004) reported that the TDS of Kushtia and Chuadanga districts ranged from 247.78 to 870.45 mg L^{-1}. The TDS of groundwater of Dinajpur district ranged from 52.02 to 422.51 mg L^{-1} (Uddin, 2004).

The value of TDS in the Khagrachari area was reported to vary from 20 to 120 mg L^{-1} (Hakim *et al.* 2003). The TDS values of water samples of Khagrahcari district were varied from 20 to 140 mg L^{-1} (Islam *et al.*, 2003). The total dissolved solids of groundwater of Pabna sadar upazila under Pabna district ranged from 336.26 to 671.89 mg L^{-1} (Arefin, 2002). The amount of TDS in monsoon and winter seasons ranged from 120 to 165 mg L^{-1} of Buriganga River (Zaman *et al.*, 2002). Rahman (2001) revealed that the TDS of groundwater of Sherpur under Bogra district ranged from 194.85 to 458.48 mg L^{-1}. Islam *et al.* (2000) worked on groundwater of Dinajpur district and found the TDS was ranged from 180 to 462 mg L^{-1}. Sarker *et al.* (2000) found that the TDS of groundwater and surface water in Narayangang district ranged from 112.6 to 1132.0 and 124.0 to 470.0 mg L^{-1}, respectively. Some surface and groundwater of Tongi under Gazipur district contained TDS from 123 to 675 mg L^{-1} (Sen *et al.*, 2000).

Table 2.1 Rating for Levels of TDS (mg/Liter)

Level of TDS (mg/Liter)	**Rating**
Less than 300	Excellent
300-600	Good
600-900	Fair
900-1200	Poor
Above 1200	Unacceptable

Sources: WHO (2004)

2.4 standard limits for various quality parameters for drinking water

Levels for various quality parameters for drinking water obtained from ground water according to different organization are shown in table 2.2 and table 2.3.

Table 2.2 Bangladesh Drinking Water Standards

Serial No.	**Parameters**	**Standards**
1	pH	6.5-8.5
2	Total Dissolved Solids (TDS) mg/L	500-1000
3	Electrical Conductivity (EC) (s/cm)	800-1000
4	Calcium (Ca) (mg/L)	75
5	Sodium (Na) (mg/L)	200
6	Potasium (K) (mg/L)	12
7	Sulphate (mg/L)	400
8	Phosphate (mg/L)	6
9	Magnesium (Mg) (mg/L)	30-35

Sources: Bangladesh Gazette (1997)

Table 2.3 World Health Organization Drinking Water Standards

Serial no.	**Parameters**	**Standards**
1	pH	6.5-8.5
2	Total Dissolved Solids (TDS) mg/L	<500
3	Electrical Conductivity (EC) (s/cm)	1500
4	Calcium (Ca) (mg/L)	<75
5	Sodium (Na) (mg/L)	200
6	Potasium (K) (mg/L)	20
7	Sulphate (mg/L)	400
8	Phosphate (mg/L)	0.8
9	Magnesium (Mg) (mg/L)	50-100

Sources: WHO (2004)

2.5 Cations

2.5.1 Calcium, magnesium, sodium and potassium

Ranges of calcium, magnesium, sodium and potassium values of some parts of Nilphamari district were respectively 0.86 to 2.55, 1.26 to 3.65, 0.45 to 2.15 and 0.25 to 1.45 (Islam *et al.* 2009). The concentrations of Ca, Mg, Na and K in groundwater samples collected from Eastern Surma Kushiara Floodplain 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 groundwater samples of Dinajpur district ranged from 4.21 to 72.54, 0.85 to 18.60, 2.29 to 54.02 and 0.39 to 57.08 mg L^{-1}, respectively (Uddin, 2004) and those in Kushtia and Chuadanga districts ranged from 23.20 to 162.00, 11.50 to 68.30, 2.76 to 56.33 and 0.43 to 17.60 mg L^{-1}, respectively (Azad, 2004). The ionic concentrations of Ca, Mg, K and Na were found to vary from 0.20-7.20, 0.70-6.60, 2.50-10.00 and 4.00-14.25 meq L^{-1} at Khagrachari district (Hakim *et al.,* 2003).

Mean values of Ca, Mg, K and Na ions of Buringanga river for winter season were 1.97, 2.84, 0.61 and 1.12 meq L^{-1} and for monsoon season were 0.75, 1.03, 0.17 and 0.23 meq L^{-1} (Zaman *et al.,* 2002). Ca, Mg, Na and K content in groundwater 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 meq L^{-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).

On an average, the Na, K, Ca, and Mg concentrations were 59.58, 16.16, 78.15, and 16.55 mg L^{-1}, respectively (Sarkar *et al.,* 2000). The contents of Ca, Mg, Na and K in groundwater collected from Gaibandha district ranged from 0.72 to 3.01, 1.80 to 6.80, 0.06 to 0.74 and 0.45 to 6.47 meq L^{-1}, respectively (Jesmin, 2000) while those of Sherpur sadar upazila ranged from 0.50 to 2.00, 0.40 to 2.00, 0.006 lo 0.42 and 0.09 to 2.26 mg L^{-1}, respectively (Haque, 2000). 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.

2.5.2 Zinc

Zinc is referred as trace elements present in groundwater. Islam *et al.* (2009) showed that the irrigation water of Jaldhaka in Nilphamari district contained Zn level at 0.012 to 0.074 mg L^{-1}.

The content of Zn in ground waters of Gazipur sadar thana varied from trace 0.08 mg L^{-1}, respectively (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}, respectively. 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}.

2.6 Anions

2.6.1 Bicarbonate

The HCO_3 is a major dissolving inorganic constituent (greater than 5 ppm) in groundwater whereas CO_3 is considered as minor (0.01-1.00 mg L^{-1}).

The concentration of HCO_3 in Eastern Surma Kushiara Floodplain and neighbouring region of Sylhet division ranged from 8.5 to 569.1 mg L^{-1} (Ahsan, 2004). In Kushtia and Chuadanga districts the amount of HCO_3 concentration was within the range of 115.33 to 475.96 mg L^{-1} (Azad, 2004). Islam *et al.* (2003) studied the quality of well and pond water of Khagrachari district and found that the HCO_3 range was 0.1-0.9 meq L^{-1}. In Pabna sadar upazilla, the concentration of HCO_3 ranged from 3.50 to 7.00 mg L^{-1} (Arefin, 2002). In ground water of Tongi under Gazipur district the concentration HCO_3 varied from 0.80 to 6.20 meq L^{-1}.

Haque (2000) reported that in ground water of Old Brahmaputra Floodplain the concentrations of HCO_3 in surface and groundwater varied from 0.60 to 3.50 meq L^{-1}, and in Gaibandha HCO_3 concentration was within the limit of 1.50 of 6.00 mg L^{-1} (Jesmin, 2000).

2.6.2 Chloride

Chloride is an important dissolved inorganic constituent in surface and groundwater. The concentration of Cl varied from 0.2 to 1.05 meq L^{-1} in Nilphamari district (Islam *et al.*, 2009). The concentration of chloride (Cl) in groundwater of Eastern Surma Kushiara Floodplain and neighbouring region of Sylhet division and ranged from 0.4 to 156.7 mg L^{-1} (Ahsan, 2004). In Dinajpur district it ranged from 5.67 to 63.46 mg L^{-1} (Uddin, 2004). 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 groundwater of Pabna sadar upazila ranged from 0.80 to 1.40 meq L^{-1} (Arefin, 2002). Islam and Gyananath (2002) observed that groundwater C1 concentration in Nanded district in India ranged from 92.3 to 226.7 mg L^{-1}.

Rahman (2001) mentioned that the ground waters of Sherpur upazila under Bogra district contained C1 within the range of 0.40 to 2.40 meq L^{-1}.Surface and groundwater samples in Tongi under Gazipur district contained Cl within the limit of 0.80 to 4.80 meq L^{-1} (Sen *et al.* 2000). The C1 concentration ranged from 42.60 to 383.4 mg L^{-1} in the groundwater samples and 49.7 to 255.6 mg L^{-1} in the surface water from Narayangonj district (Sarker *et al.*, 2000).

2.6.3 Sulphate

In Eastern Surma Kushiara Floodplain and neighbouring region of Sylhet division the concentration of sulphate (SO_4) ranged from 0.01 to 18.00 mg L^{-1} (Ahsan, 2004). Azad (2004) mentioned that groundwater 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 groundwater of Dinajpur district ranged from 0.20 to 21.60 mg L^{-1} (Uddin, 2004). The concentration of SO_4 in groundwater of Panba sadar upazila ranged from 0.14 to 5.58 mg L^{-1} (Arefin, 2002). Islam and Gyananath (2002) found that the SO_4 in groundwater in Nanded district in India ranged from 6.8 to 26.0 mg L^{-1}. Rahman (2001) mentioned that the collected groundwater samples of Sherpur upazila under Bogra district contained SO_4 within the range of trace to 10.30 mg L^{-1}.

Jesmin (2000) reported that the SO_4 content in groundwater collected from Gaibandha aquifers ranged from trace to 61.00 meq L^{-1}. Rahman (2000) stated that in Lower Atrai Basin and stated that SO_4 concentrations varied from trace to 0.40 mg L^{-1}.

2.6.4 Phosphate

For determining the quality of groundwater at Dimla upazila in Nilphamari district, Islam *et al.* (2010a) observed that the PO_4 concentration was 0.023 to 0.075 mg L^{-1}. Ahsan

(2004) conducted a field study in Eastern Surma Kushiara floodplain and neighboring regions of Sylhet division aquifers and showed that the phosphate (PO_4) content of groundwater samples varied from 0.041 to 12.00 mg L^{-1}.The contents of PO4 in ground waters of Kushtia and Chuadanga districts ranged from 0.31 to 7.66 mg L^{-1} (Azad, 2004). Uddin (2004) assessed the groundwater quality of Dinajpur district and found that the contents of PO_4 ranged from 0.01 to 2.50 mg L^{-1}. Arefin (2002) found that the concentration of PO_4 in groundwater of Pabna sadar upazila ranged from trace to 0.19 mg L^{-1}. Groundwater samples collected from Gaibandha aquifer contained small amount (trace to 1.10 mg L^{-1}) of PO_4 (Jesmin, 2000).

Nizam (2000) delineated that the content of PO_4 in surface and groundwater samples collected from Bhaluka upazila under Mymensingh district ranged from trace to 0.47 mg L^{-1}. Rahman (2000) investigated that the groundwater quality of Atrai upazila under Naogaon district and observed that the contents of PO_4 ranged from trace to 2.19 mg L^{-1}.The concentration of PO4 in surface and groundwater of Tongi varied from trace to 0.05 mg L^{-1} (Sen *et al.*, 2000).

2.7 Total hardness (H_T)

The groundwater samples collected from Dimla, Nilphamari district were ranged from 121 to 266 mg L^{-1} and “moderately hard” to “hard” in class (Islam *et al.* 2010a). The hardness (H_T) of groundwater samples in Eastern Surma Kushiara Floodplain and neighbouring regions of Sylhet division fluctuated between 3.71 to 322.35 mg L^{-1} (Ahsan, 2004),that of Kushtia and Chuadanga districts varied from 172.90 to 642.53 mg L^{-1} (Azad, 2004) and that of Dinajpur district ranged from 14.01 to 242.19 mg L^{-1} (Uddin, 2004).The hardness in groundwater of Pabna sadar upazila ranged from 183.08 to 376.72 mg L^{-1} (Arefin, 2002).The hardness (H_T) of groundwater in Nanded district in India ranged from 216 to 648 mg L^{-1} (Islam and Gyananath, 2002). Rahman (2001) mentioned that the H_T values ranged from 84.9 to 265.9 mg L^{-1} in groundwater 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) and that of Sherpur sadar under Sherpur district varied from 36.96 to 159.91 mg L^{-1} (Haque, 2000).

Sarker *et al.* (2000) revealed that 8 samples were "soft", 7 samples were "moderately hard", 7 samples were hard and the rest 3 samples were in very hard, classes and the water samples collected from the different locations of Narayangonj aquifers had the H_T value ranging from 6.06 to 569.25 mg L^{-1}, Out of 25 samples. Zaman (2000) showed that the H_T of ground waters collected from Bagmara, Mahadebpur and Nachoulupazila ranged from 79.94 to 279.68, 39.97 to 459.38 and 101.60 to 227.02 mg L^{-1}, respectively.

2.8 Sodium adsorption ratio (SAR)

An important chemical parameter for judging the degree of suitability of water for irrigation is sodium content or alkali hazard, which is expressed as the sodium adsorption ratio (SAR).Groundwater quality at Jaldhaka in Nilphamari district was observed and found the SAR value was ranged from 0.31 to 1.40 (Islam *et al.* 2009). In Eastern Surma Kushiara Floodplain and neighbouring region of Sylhet division the calculated sodium adsorption ratio (SAR) of groundwater ranged within 0.082 to 35.79 (Ahsan, 2004), that of Kushtia and Chuadanga district it ranged from 0.08 to 1.19% (Azad, 2004), and that of Dinajpur district ranged from 0.187 to 3.244 (Uddin, 2004). The SAR of groundwater is 'permissible' class of Kharachari in Bangladesh, (Islam *et al.* 2003). The SAR ranges from 0.36 to 3.34 of Khagrachari in Bangladesh (Islam *et al.* 2003). The SAR of groundwater of Pabna sadar upazila ranged from 0.38 to 1.05 with the mean value of 0.74 (Arefin, 2002). The groundwater of Sherpur upazila in Bogra district had SAR ranging from 0.22 to 0.90 (Rahman, 2001). The SAR value of groundwater of Sherpur sadar under Sherpur district ranged from 0.07 to 2.69 (Haque, 2000). In Dinajpur, under groundwater all samples were under 'good to excellent' classes (Islam *et al.*, 2000).

Jesmin (2000) observed that the SAR of groundwater collected from Gaibandha aquifers ranged from 0.29 to 3.28.The SAR of groundwater of Bhaluka upazila under Madhupur Tract ranged from 0.06 to 0.30 (Nizam, 2000).

2.9 Soluble sodium percentage (SSP)

The SSP value was 9 to 26 percent in the groundwater at Jaldhaka in Nilphamari district (Islam *et al.* 2009). The soluble sodium percentage (SSP) values in groundwater of Eastern Surma Kushiara Floodplain and neighbouring region of Sylhet division were within the range of 6.43 to 98.61% (Ahsan, 2004), that of Kushtia and Chuadanga districts ranges from 4.38 to 28.98% (Azad, 2004). In Dinajpur, the SSP ranged from 11.36 to 81.98% (Uddin. 2004). Most water samples were doubtful in Khagrachari in Bangladesh (Islam *et al.*, 2003). At Pabna sadar upazila the SSP ranges from 11.85 to

28.85% (Arefin, 2002). In Dinajpur, underground water all samples were under ‘good to exceilent’ classes (Islam *et al.* 2000). The SSP values of groundwater samples in Gaibandha aquifers ranged from 9.20 to 45.75 per cent (Jesmin, 2000). The SSP values of surface and groundwater samples collected from Bhaluka upazila under Madhupur Tract ranged from 2.38 to 17.41 percent as observed by Nizam (2000). Sarker*et al.* (2000) revealed that the SSP value in Narayangonj aquifers varied 6.31 to 64.46 percent.

The SSP values of groundwater collected from Bagmara, Mahadebpur and Nachoul upazila of Barind area varied from 25.53 to 75.61, 21.20 to 79.42 and 17.00 to 51.56%, respectively (Zaman, 2000).

2.10 Permeability Index (PI)

Doneen (1964) evolved a criterion for assessing the suitability of water for irrigation based on a permeability index (P.I.). Arveti Nagaraju *et al*. (2006) observed the P.I. values vary from 29.29 to 48.40 in the mining area samples and from 26 to 61.80 in the virgin area.

2.11 Kelly’s ratio

Sodium measured against calcium and magnesium was considered by Kelly (1940) and Paliwal (1967) to calculate this parameter. Kelly’s ratio arises from 0.06 to 0.49 in the virgin area and from 0.25 to 0.55 in mining area (Nagaraju *et al*., 2006).

2.12 Gibbs ratio

Viswanathaiah *et al.* (1978) emphasized the mechanism of controlling the chemistry of groundwater of Karnataka. Further, Ramesam and Barua (1973) carried out similar research work in the northwestern regions of India.

CHAPTER III

MATERIALS AND METHODS

Ground water samples were collected from 10 unions of Dinajpur sadar upazila under Dinajpur district and analyzed for pH, electrical conductivity (EC), total dissolved solids (TDS), Total Hardness (H_T), Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), Permeability Index (PI), Kelly's Ratio, Gibbs Ratio and major ionic constituents like Ca, Mg, K, Na, Zn, P, SO_4 and HCO_3.

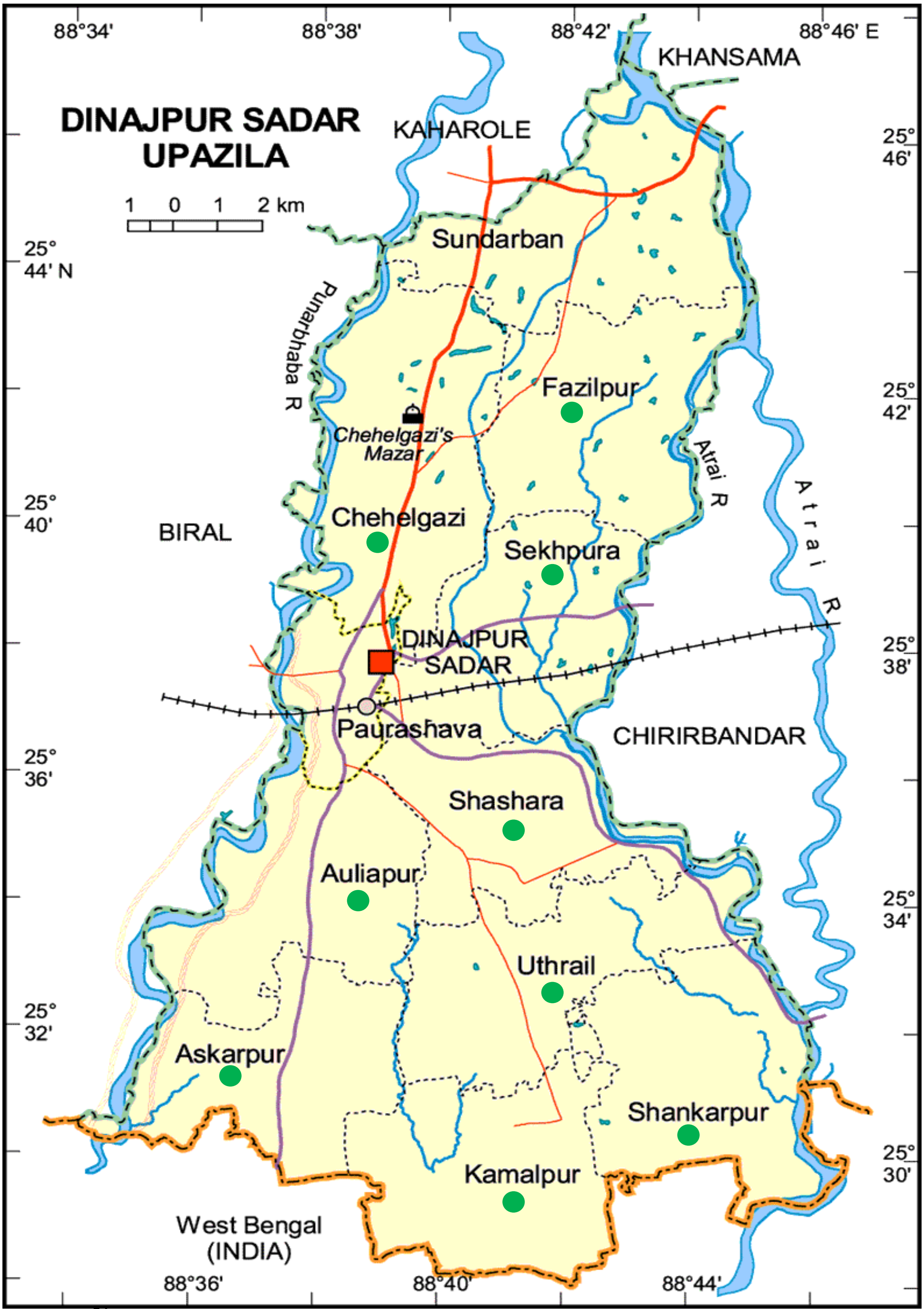
3.1 Collection and Analysis of Water Samples:

3.1.1 Site

Groundwater sampling sites were selected from different places of Dinajpur Sadar upazilla under 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. Ten samples were collected from the Selected Unions. The sites of water sampling for different sources of waters were shown in Figure 1. The information of different water samples collected for analysis was mentioned in Table 1. Water samples were collected in one 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 analyzed as quickly as possible on arrival at the laboratory.



Sampling Area

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

Table 1. Information regarding water sampling

Sl/No.	Source	Location (DinajpurSadar)		Depth (ft)
		Union	Village	
1	Deep Tubewell	Chehelgazi	Karnai	65
2	Deep Tubewell	Sundarban	Belbari	60
3	Deep Tubewell	Fazilpur	Raniganj	70
4	Deep Tubewell	Sankarpur	Shankarpur Hat	65
5	Deep Tubewell	Shashara	Fasiladanga	60
6	Deep Tubewell	Shekhpura	Kishan Bazar	70
7	Deep Tubewell	Uthrail	Godagari	65
8	Deep Tubewell	Auliapur	Ramnagar	60
9	Deep Tubewell	Kamalpur	Kamalpur	65
10	Deep Tubewell	Askarpur	Mahanpur	70

3.2 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) Zinc (Zn)

vi) Phosphorus (P)

vii) Bicarbonate (HCO_3)

viii) Sulphate (SO_4)

E. Total hardness and alkalinity.

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 Bicarbonate

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, bicarbonate forms rose red colour complex at the end of titration. The bicarbonates were estimated titrimetrically after Ghose et al. (1983). The reactions are mentioned below:

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

3.2.5 Phosphate

Phosphate was determined colorimtrically from the water samples using stannous chloride a reducing agent as described by Clesceri *et al.* (1989). This method involves 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:

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

3.2.6 Sulphate

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 were taken in spectrophotometer (Hitachi-U-2800) after 30 minutes of $BaCl_2$ addition al 425 nm wavelength following the methods of Wolf (1982).

3.2.7 Calcium

Complexometric titration was used for estimating the calcium from the water samples using disodium ethylene diaminetetraacetate ($Na_2H_2C_{10}H_{12}O_{28}N_2.2H_2O$) 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 ferrocyanid [$K_4Fe(CN)_6.3H_2O$], hydroxylamine-hydrochloride ($NH_2OH.HCl$) and triethanolamime ($C_6H_{15}NO_3$) were added to eliminate this interference of various non-target ions (Page *et al.,* 1982).

3.2.8 Magnesium

Magnesium was analysed by coplexometric method of titration using disodium ethylene diaminetetraacetate ($Na_2H_2C_{10}H_{12}O_{28}N_2.2H_2O$) 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 tri-ethanolamine ($C_6H_{15}NO_3$) 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).

3.2.9 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).

3.2.10 Zinc

Zinc was analysed by spectrophotometer(Hitechi-U-2800) at the wavelengths of 213.8 nm, by the laboratory of Chemistry Division, HSTU 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-

- **Hardness or Total Hardness (H_T)**

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

- **Sodium Adsorption Ratio (SAR) is expressed as:**

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

- **Todd (1980) defined Soluble Sodium Percentage (SSP) as**:

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

- **Kelly's Ratio** = **$Na^+ / (Ca^{2+} + Mg^{2+})$**
- **Permeability Index (P.I)** = $\frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+}$

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

3.4 Statistical Analysis

Water sample was collected from different union under DinajpurSadarupazilla to assess the quality of ground water sample for drinking purposes on the basis of different region. Therefore, to know the effect of different region on drinking water quality parameters single factor experiment in completely randomized design (CRD) was employed. The statistical software package SPSS 22 version was used for the analysis of variance (ANOVA) and Duncan's Multiple Range Test for water quality parameters.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Physical Analysis of Drinking Water

4.1.1 pH

Analysis of the data showed that pH values of the different water samples were significantly ($p<0.05$) different. It was observed that the mean pH values of the water sample were ranged from 6.30 to 6.90. Figure 4.1 shows that the highest pH value was founds in Askarpur union and lowest pH was found for water sample that was collected from Uthrail union. The pH value of all samples indicated that these samples of water were acidic in nature and might be due to the presence of lower concentration of Ca, Mg, Na and HCO_3^-. The results of this experiment are in good agreement with the reported values of Uddin (2004) that the pH of the ground water ranged from 5.32 to 7.0. However, the pH values of the analyzed sample are slightly dissimilar from the reported values of WHO (2006) that the standard pH values of drinking water range from 6.5 to 8.5.

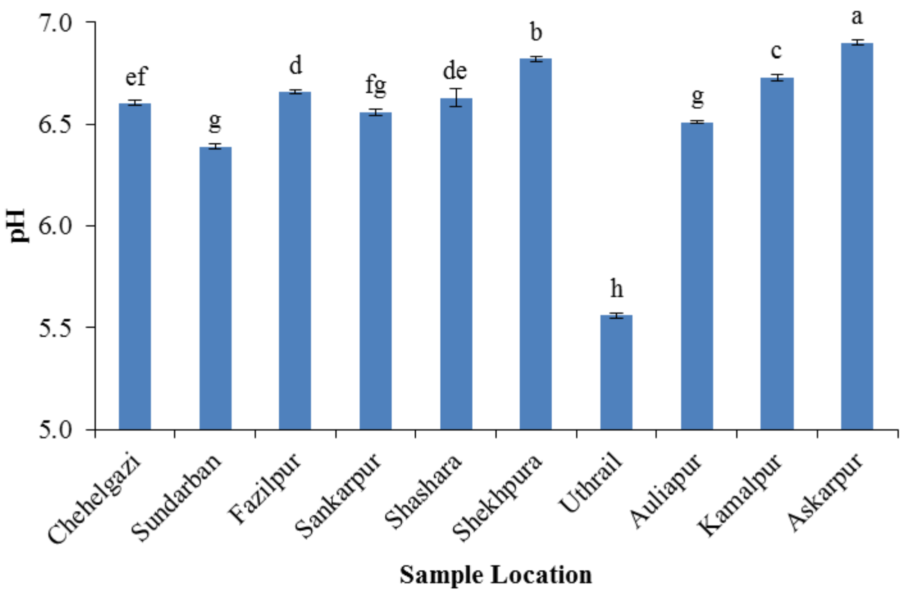


Fig. 4.1 Mean pH value with standard error of water samples

*a-h (lowercase) different subscript alphabet in each column indicate significant difference among the samples ($p<0.05$)

4.1.2 Electrical Conductivity (EC) (µs/cm)

Regarding electrical conductivity (EC), water samples of different locations were significantly ($p<0.05$) different. It was observed that the mean EC values of the water samples ranged from 1280.33 to 2398.30 µs/cm. It is obvious from Fig. 4.2 that the highest EC value for the analysed water sample was found in Shashara union and lowest was found for Askarpur union. Our result is in conformation with the specification reported by AHS (Alberta Health Services),(2011) which implies electrical conductivity of the most drinking water will be lower than 2500 µs/cm. It noted that the result of this experiment is higher than that of the reported in Bangladesh Gazette (1997) that the electrical conductivity of the drinking water should lies between 800-1000 µs/cm.

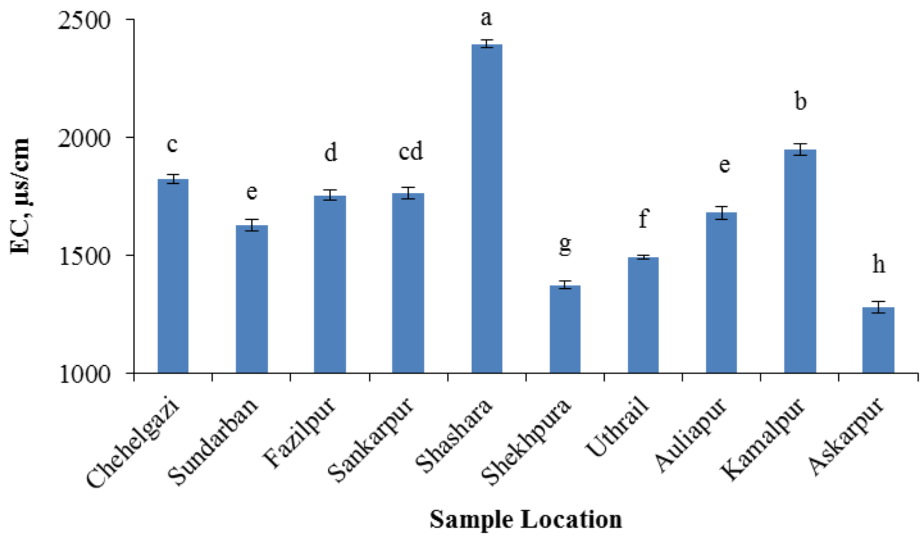


Fig. 4.2 Mean EC value with standard error of water samples

*a-h (lowercase) different subscript alphabet in each column indicate significant difference among the samples ($p<0.05$)

4.1.3 Total Dissolve Solids (TDS) (mg/L)

Significant difference ($p<0.05$) in water samples of the unions under Dinajpur Sadar Upazilla was observed in respect to total dissolve solids. The concentration of TDS was found within the range from 162.33 to 553.67 mg/L. Maximum and minimum TDS value was found at Kamalpur and Auliapur union, respectively. Results of this experiment is integrated with Uddin (2004) which reported the TDS value of the drinking water sample ranged from 52.02 to 550.51 mg L^{-1}. According to WHO (2000) TDS value should be less than 500 mg L^{-1} for drinking water. Hench the TDS in ground water from Kamalpur was found to exceeds the acceptable limit leading its unsuitability as drinking water. The value of TDS is directly proportional to that of total soluble mineral ions and other dissolved substances in water bodies. Similar observations were expressed by Sarker *et al.*, (2000).

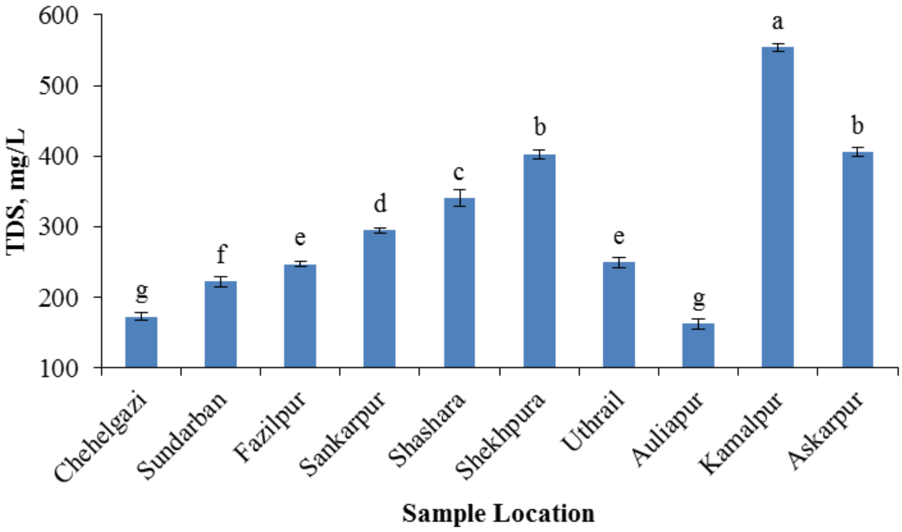


Fig. 4.3 Mean TDS value with standard error of water samples

*a-g (lowercase) different subscript alphabet in each column indicate significant difference among the samples ($p<0.05$)

4.1.4 Temperature (°C)

Analysis of the data showed that temperatures of the different water sample were significantly ($p<0.05$) at various location of the water Upazilla. The temperatures of the different water sample were different within the range from 21.27 to 22.07. It is apparent from Fig. 4.4 that the highest temperature of the analysed water sample was found in Kamalpur union and lowest was found at Sundarban union.

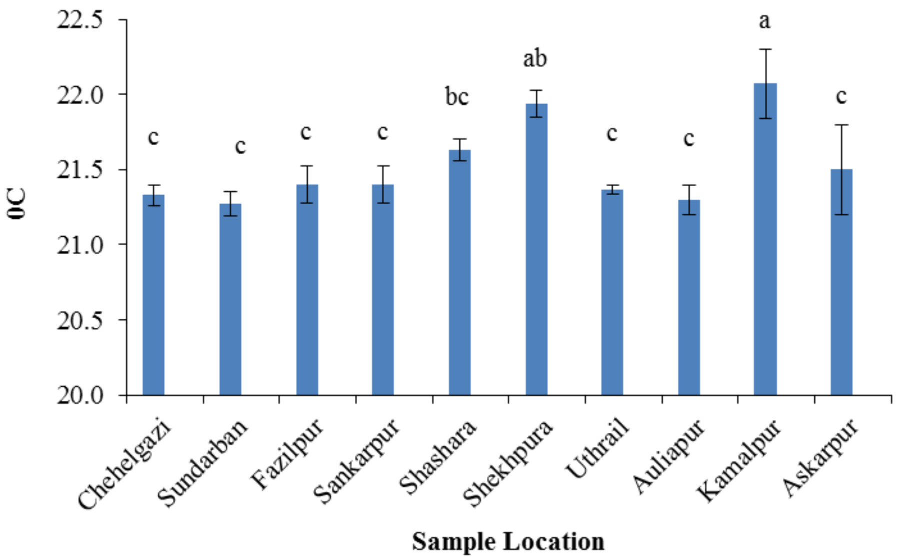


Fig. 4.4 Mean Temperature value with standard error of water samples

*a-c (lowercase) different subscript alphabet in each column indicate significant difference among the samples ($p<0.05$)

4.2 Inorganic Chemical Analysis of Drinking Water

4.2.1 Calcium Content (mg/L)

Analysis of the data showed that mean calcium content of the water sample were significantly ($p<0.05$) different. It was observed that the mean calcium content of the water sample ranged from 15.76 to 33.39 mg L^{-1}. Figure 4.5 shows that the highest calcium content was found in Askarpur union and lowest calcium content was found for water sample collected from Shashara union. The results of this study concord with the reported values of Uddin (2004) that the calcium content in ground water of Dinajpur district ranged from 4.21 to 72.54 mg L^{-1}. WHO (2004) documented that the tolerance range for Ca for drinking water is less than 75 mg L^{-1}.Similar findings were also reported by Bangladesh Gazette (1997).

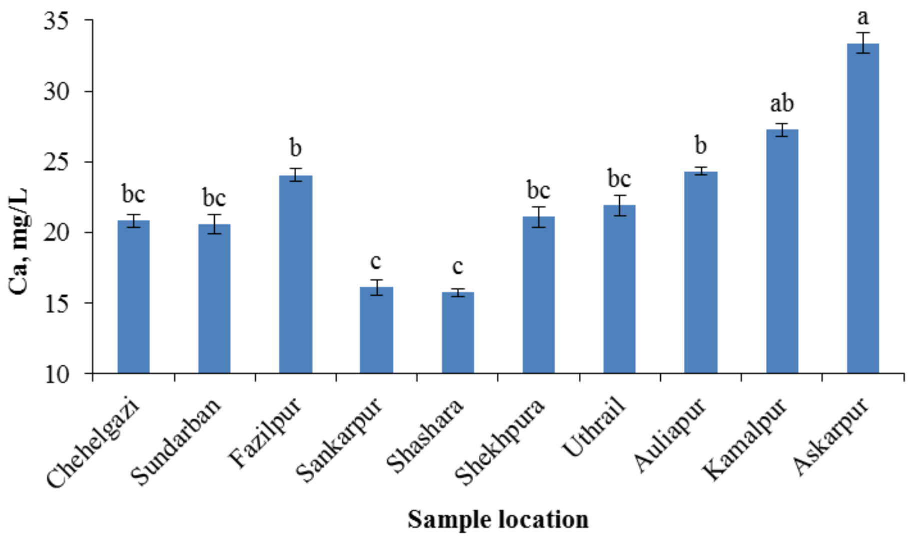


Fig. 4.5 Mean Calcium content with standard error of water samples

*a-c (lowercase) different subscript alphabet in each column indicate significant difference among the samples ($p<0.05$)

4.2.2 Magnesium (Mg) Content (mg/L)

As can be seen from figure 4.6 that magnesium content was significantly ($P < 0.05$) affected by the location of the water sample. The mean magnesium content of the water sample ranged from 6.64 to 32.08 mg L^{-1}. The highest concentration of Magnesium was found at Askarpur union and lowest was found at Sundarban union. Finding of the present study was higher than the result (0.57 to 3.04 mg L^{-1}) reported by Islam *et al.*, (2016) in ground water sample of Dinajpur sadar upazilla. WHO (2004) noted that the tolerance level for Mg is ranged from 50-100 mg L^{-1}.

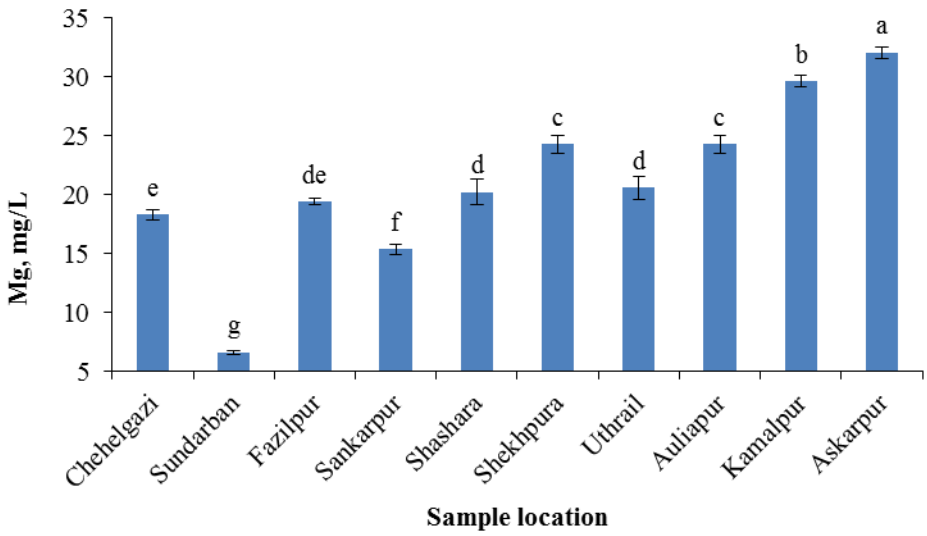


Fig. 4.6 Mean Magnesium content with standard error of water samples

*a-g (lowercase) different subscript alphabet in each column indicate significant difference among the samples (p<0.05)

4.2.3 Sodium (Na) Content (mg/L)

Regarding sodium content, water samples were significantly ($p<0.05$) different at the locations. The concentration of Na was observed within the range of 0.35 to 2.52. The highest concentration was found from Shekhpura union and lowest amount found from Chehelgazi union (Fig. 4.7). Similar findings were also reported by Islam (2016) that ground water collected from Dinajpur sadar upazilla contain 0.13 to 1.35 meq/L . Over 200 mg L-1 is considered high and may cause corrosion of water supply system if the water is warm and alkaline. According to AHS for people on salt restricted diets or those suffering from hypertension, congestive heart failure, the recommended limit is 20 mg L^{-1}. Most water supplies in our study areas contained less than 20 mg of sodium per liter.

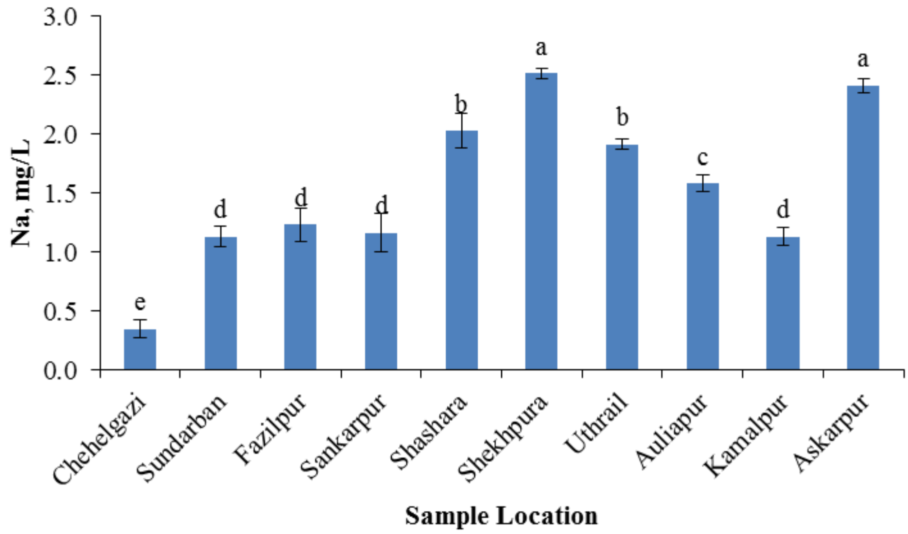


Fig. 4.7 Mean Sodium content with standard error of water samples

*a-d (lowercase) different subscript alphabet in each column indicate significant difference among the samples ($p<0.05$)

4.2.4 Potassium (K) Content (mg/L)

As can be seen from figure 4.8 Potassium contents of the water samples were significantly ($p<0.05$) affected by the location. The concentration of potassium was found within the range of 0.22 to 3.10 mg L^{-1}. It is clear from fig. 4.8 that the highest concentration (3.10 mg L^{-1}) of potassium for ground water sample was found at Kamalpur union and lowest concentration (0.22 mg L^{-1}) was found at Fazilpur union. Uddin (2004) reported that the K content in ground water samples of dinajpur district ranged from 0.39 to 57.08 mg L^{-1} which is higher than that of our findings. This might be due to the presence of K bearing mineral in the parent paterials in soils like sylvite (KCl), nitre (KNO_3) in the aquafiers (Karanth, 1994). According to Drinking Water Standard in Bangladesh, the Potassium content for drinking water is 12 mg L^{-1} (Bangladesh Gazette, 1997). WHO (2004) also reported that Potassium concentration above 100 mg L^{-1} may cause a laxative effect and levels above 340 mg L^{-1} may affect taste.

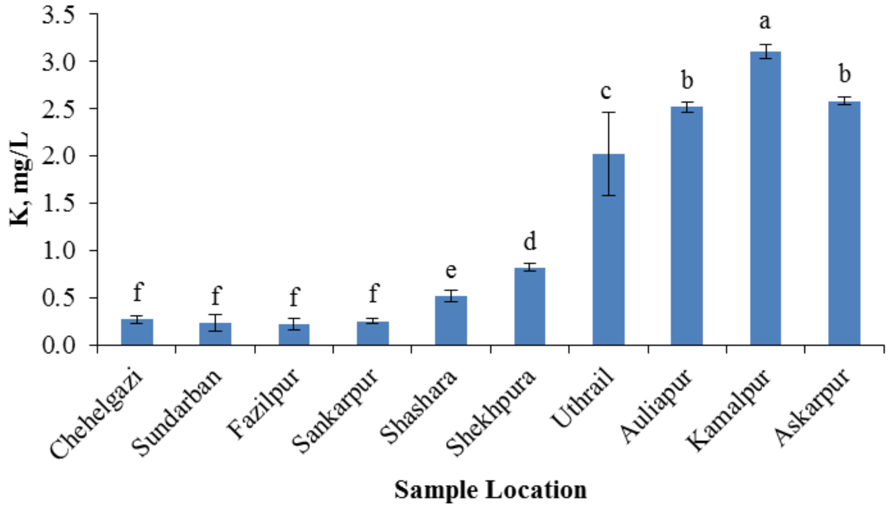


Fig. 4.8 Mean Potassium content with standard error of water samples

*a-f (lowercase) different subscript alphabet in each column indicate significant difference among the samples ($p<0.05$)

4.2.5 Sulphate (SO_4) Content (mg/L)

Analysis of the data showed that mean Sulphate content of the water sample were significantly ($p<0.05$) different at the locations from where the water sample were collected. The concentration of Sulphate content ranged from 0.103 to 0.93 mg L^{-1}. It is noticed from fig. 4.9 that the highest concentration (0.93 mg L^{-1}) of sulphate for ground water sample was found in Sankarpur union and lowest concentration (0.103 mg L^{-1}) was found in Fazilpur union. Results of this study is in agree with the reported values of (Uddin, 2004) that the concentration of sulphate for ground water of Dinajpur district ranged from 0.20 to 21.60 mg/L^{-1}. The recommended maximum level is 500 mg L^{-1}. Excess sulphate levels may have a laxative effect on new users and produce objectionable taste. Regular users tend to become accustomed to high sulphate levels according to AHS. According to Drinking Water Standards in Bangladesh, the sulphate content for drinking water is 400 mg L^{-1} (Bangladesh Gaztte, 1997).

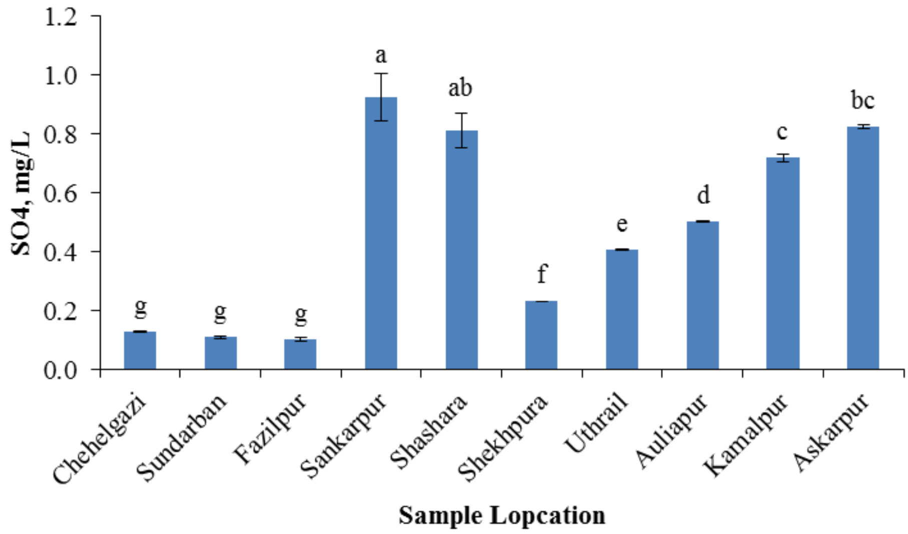


Fig. 4.9 Mean Sulphate content with standard error of water samples

*a-g (lowercase) different subscript alphabet in each column indicate significant difference among the samples ($p<0.05$)

4.2.6 Phosphate (PO_4) Content (mg/L)

Analysis of the data showed that mean Phosphate contents of the water samples were significantly ($p<0.05$) affected by the location of the water sample. The concentration of Phosphate content was found within the range of 0.023 to 0.32 mg L^{-1}. It is noticed from fig. 4.10 that the highest concentration (0.32 mg L^{-1}) of Phosphate for ground water sample was found in Auliapur union and lowest concentration (0.103 mg L^{-1}) was found in Sundarban union. Uddin (2004) assessed the ground water quality of Dinajpur districts and found that the contents of Phosphate ranged from 0.01 to 2.50 mg L^{-1}. The recommended limit of Phosphate is 0.8 mg L^{-1} (WHO, 2004). According to Drinking water Standard in Bangladesh, the Phosphate content for drinking water is less than 6 mg L^{-1} (Bangladesh Gazette, 1997).

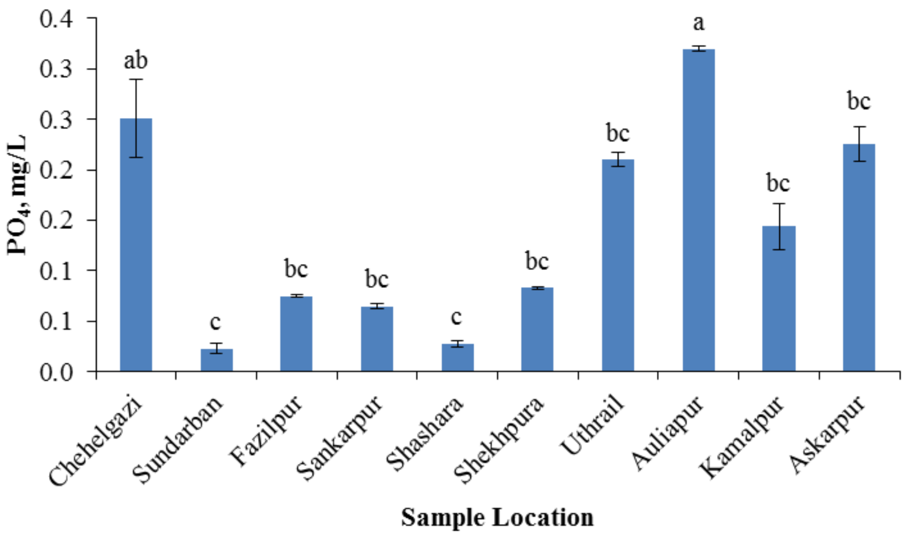


Fig. 4.10 Mean Phosphate content with standard error of water samples

*a-c (lowercase) different subscript alphabet in each column indicate significant difference among the samples ($p<0.05$)

4.2.7 Bi-carbonate Content

Analysis of the data showed that mean bi-carbonate contents of the water samples were significantly ($p<0.05$) affected by the location of the water samples. The concentration of bi-carbonate content was found within the range of 1.13 to 5.93 mg L^{-1}. It is observed from fig. 4.11 that the highest concentration (5.93 mg L^{-1}) of bi-carbonate for ground water sample was found in Askarpur union and lowest concentration (1.13 mg L^{-1}) was found in Sundarban union. Results of this study for bi-carbonate content in water sample is lower than the reported values of Uddin (2004) who noted that in Dinajpur district the concentration bi-carbonate varies from 21.97 to 266.05 mg/L. The maximum recommended limit for bi-carbonate content is 1000 mg L-1. In high levels, it ia often observed as white bubbles (sodium bi-carbonate). Excessive bicarbonate contributes to the production of scale in water heaters and kettles according to AHS (2011).

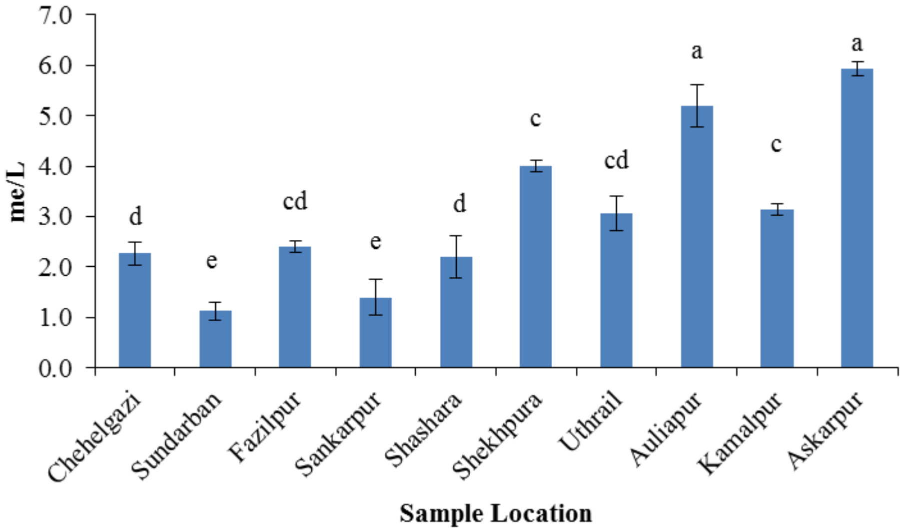


Fig. 4.11 Mean Bi-carbonate content with standard error of water samples

*a-e (lowercase) different subscript alphabet in each column indicate significant difference among the samples ($p<0.05$)

4.2.8 Chlorine (Cl) Content

Regarding chlorine contents, water samples were significantly ($p<0.05$) different at the locations. The concentration of chlorine contents were found within the range of 0.31 to 0.80 mg L^{-1}. It is observed from fig. 4.12 that the highest concentration (0.80 mg L^{-1}) of chlorine for ground water sample was found in Kamalpur union and lowest concentration (0.31 mg L^{-1}) was found in Shashara union. The recommended level of Choride content for drinking water is 250 mg/L WHO (2004) (Appendix V).

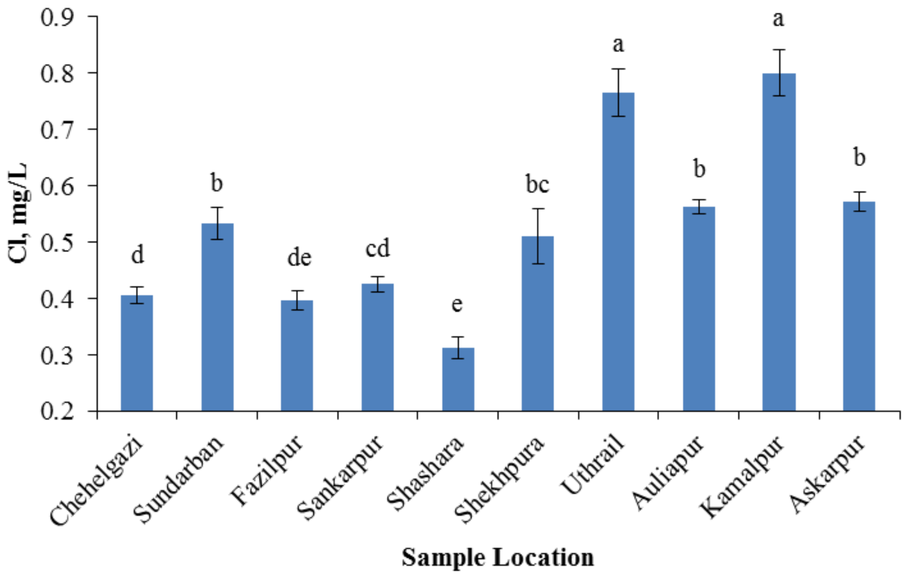


Fig. 4.12 Mean Chlorine content with standard error of water samples

*a-e (lowercase) different subscript alphabet in each column indicate significant difference among the samples ($p<0.05$)

4.3 Heavy Metal Content

4.3.1 Zinc Content (mg/L)

Analysis of the data showed that mean zinc contents of the water samples were significantly ($p<0.05$) different at the locations of the water samples. The concentration of zinc content was found within the range of 17.87 to 86.30 mg L^{-1}. It is observed from fig. 4.13 that the highest concentration (86.30 mg L^{-1}) of zinc for ground water sample was found in Askarpur union and lowest concentration (17.87 mg L^{-1}) was found in Sundarban union. The recommended level of Zinc is 5 mg/L WHO (2004) (Appendix V).

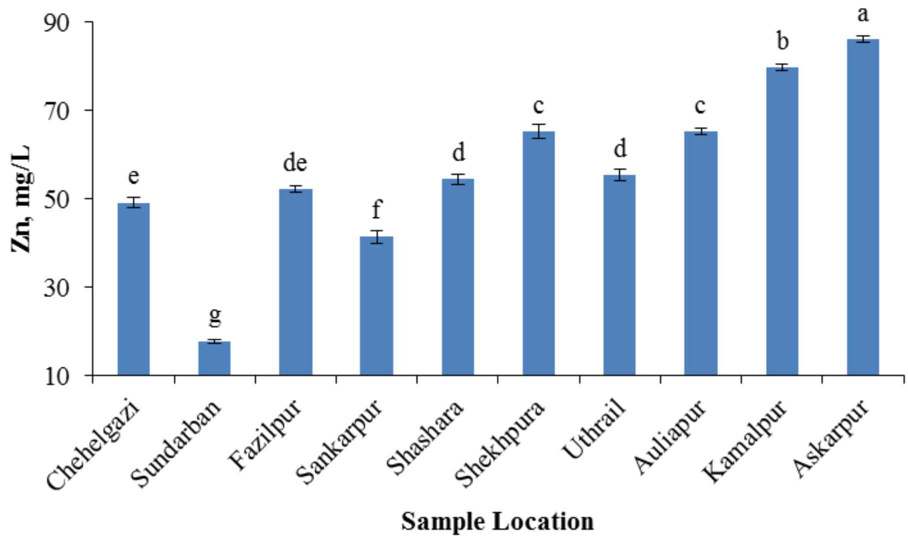


Fig. 4.13 Mean Zinc (Zn) contents with standard error of water samples

*a-g (lowercase) different subscript alphabet in each column indicate significant difference among the samples ($p<0.05$)

4.3. Total hardness:

The total hardness (H_T) of water samples were within the range of 27.22 to 65.48 mg L^{-1}. Regarding hardness, water samples were significantly ($p<0.05$) affected by the location. It is observed from fig. 4.14 that the highest value (65.48 mg L^{-1}) of hardness for ground water sample was found in Askarpur union and lowest concentration (27.22 mg L^{-1}) was found in Sundorbon union. . Based on Hardness, Sawyer and McCarty (1967) classified irrigation water into four classes as mentioned in Appendix IV. According to this classification all samples were classified as soft water. Hardness resulted due to the presence of appreciable amount of divalent cations like Ca and Mg (Todd, 1980).

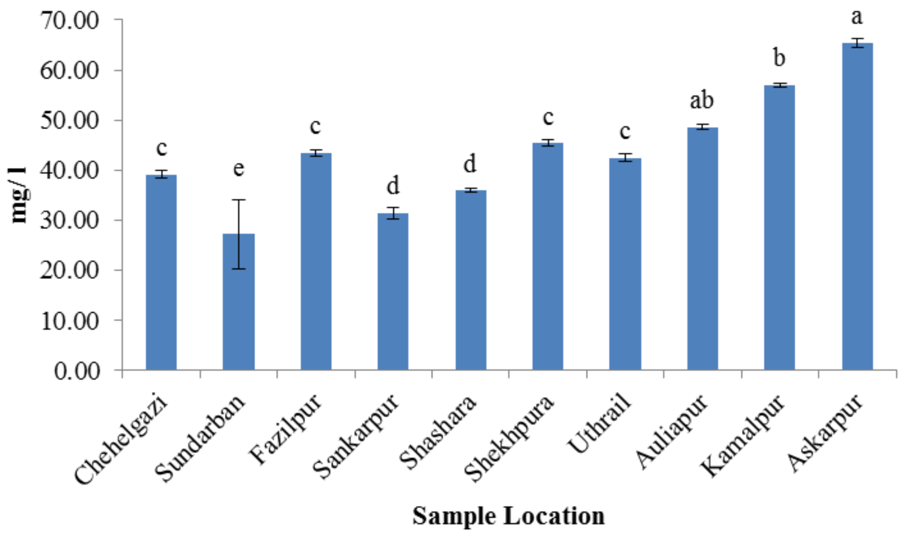


Fig 4.14: Mean hardness content with standard error of water samples

*a-e (lowercase) different subscript alphabet in each column indicate significant difference among the samples ($p<0.05$)

Table 4.1: Evaluation of water quality for irrigation

Parameter's / Sample Name	Soluble Sodium Percentage	Kelly's Ratio	Sodium Absorption Ratio	Permeability Index	Gibb's ratio Anion	Gibb's ratio Cat ion
Chehelgazi	0.390±.07[e]	.008±.001[e]	.07±.01[e]	4.67±.17[e]	.15±.01[bcd]	.02±.00[e]
Sundarban	2.13±.13[ab]	.03±.002b[c]	.27±.01[cd]	6.25±.38[d]	.32±.02[a]	.04±.00[d]
Fzilpur	1.26±.12[c]	.02±.002[c]	.26±.02[cd]	6.21±.28[d]	.14±.00[cde]	.05±.00[d]
Shankarpur	1.55±.16[c]	.03±.003[b]	.29±.03[c]	7.09±.63[cd]	.25±.04[a]	.08±.00[c]
Shashara	2.18±.11[ab]	.05±.003[a]	.47±.03[ab]	9.18±.62[a]	.13±.01[de]	.13±.00[ab]
Sekhpura	2.20±.07[a]	.05±.001[a]	.52±.01[a]	9.42±.23[a]	.11±.00[de]	.15±.00[ab]
Uthrail	1.88±.03[b]	.04±.001[bc]	.41±.01[b]	8.26±.27[ab]	.20±.00[abc]	.14±.00[a]
Auiapur	1.34±.07[c]	.03±.001[bc]	.32±.01[c]	7.69±.19[bc]	.09±.00[de]	.13±.00[ab]
Kamalpur	0.80±.05[d]	.01±.001[d]	.21±.01[d]	4.99±.15[e]	.20±.01[ab]	.13±.00[b]
Askarpur	1.54±.02[c]	.03±.00[b]	.42±.00[b]	7.14±.06[cd]	.08±.00[e]	.10±.00[b]

*a-e (lowercase) different subscript alphabet in each column indicate significant difference among the samples ($p<0.05$)

4.4 Suitability for irrigation based on Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, PI and Kelly's ratio

The concentration of major cations such as Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}, in groundwater were recommended concentration of these parameters (15.76, 6.64, 0.35, 3 mg/L, respectively).

The permeability index (PI) value is used to evaluate the sodium hazards of irrigation water and consequently is used as indicator whether or not the groundwater is suitable for irrigation. Doneen (1964) evolved a criterion for assessing the suitability of water for irrigation based on permeability index (PI).According to Doneen's classification, water can be classified as Class I, Class II and Class III orders. Class I and Class II waters are categorized as good for irrigation with 75% or more of maximum permeability. Class III waters are unsuitable with 25% of maximum permeability. This study calculated the PI and it ranged from 4.67-9.42% respectively. It was confirmed that the maximum PI values ranged between Class II and Class I, so in terms of PI groundwater were more suitable for irrigation and Class II water are categorized as good for irrigation however, all sample showed the unsuitable range with PI value <25% (Table 4.1).

The permeability index (PI) value is used to evaluate the sodium hazards of irrigation water and consequently is used as indicator whether or not the groundwater is suitable for irrigation. The of Na^{+} measured against Ca^{2+} and Mg^{2+} is known as Kelly's ratio, based on which irrigation water can be rated. Groundwater having Kelly's ratio more than one is generally considered as unfit for irrigation. Kelley's ratio for the tested samples ranged from 0.008 and 0.56 indicating the suitability of all the samples for irrigation purpose.

4.5 Suitability for irrigation based on pH, EC, SAR and SSP

All the groundwater samples suitable for irrigation according to the results for pH since the acceptable pH for agricultural use ranges from 6.0 to 8.5 (Ayers and Westcot, 1985). We found significant variability in EC values, with the values ranging from1280.33 to 2398.30 µS/cm. Higher EC values reflected higher concentrations of dissolved constituents that may affect the irrigation waterquality in relation to salinity hazard. Nine out of Ten samples,were rated as permissible while one sample was rated as doubtful for irrigation purposes based on Wilcox requirement(Appendix I). The salts, besides affecting the growth of the plants directly, also affect soil structure, permeability and aeration, which indirectly affect plant growth (Singh *et al.,* 2008).

The sodium adsorption ratio (SAR), which indicates the effect of relative cation concentration on Na+ accumulation in the soil, is used for evaluating the sodicity of irrigation water. The degree to which irrigation water tends to enter into cation-exchange reactions in soil can be indicated by the sodium adsorption ratio. SAR is an important parameter for the determination of the suitability of irrigation water because it is responsible for the sodium hazard (Todd and Mays, 2005). With respect to the SAR values, all the groundwater samples were classified as excellent for crop irrigation and would not be expected to negatively affect soil quality (Appendix II). Both a low salt content (low EC) and high SAR can mean there is a high potential for permeability or water infiltration problems.

Soluble sodium percentage (SSP) is an important criterion for soil physical properties and can affect plant growth. Among the groundwater samples we collected, 4 were rated as 'excellent', 5 were rated as 'good' and 1 was rated as 'poor' according to Wilcox (Appendix I). Water belonging to the 'excellent' and 'good' categories may be used for irrigation purposes.

4.6 Suitability for irrigation based on TDS, HT, Cl, $HCO3^-$

The TDS values ranged from 162.33 to 553.67 mg/L with an average value of 250 mg/L. A water containing TDS less than 1000 mg/L can be considered to be 'fresh water' for irrigation use and will not affect the osmotic pressure of soil solution (Hakim *et al.*, 2009). All the waters except one were rated as ‘fresh’ according to the guidelines given in Freeze and Cherry (1979). In our study, almost all the water samples were suitable for growing crops (Appendix II).

Hardness in water is also derived from the solution of carbon dioxide released from the bacterial action in soil in percolating water. Among the samples, 6 samples were classified as ‘soft’, 3 samples were grouped as ‘moderately hard’, 1 samples were as ‘hard’ waters (data not shown); these can be considered to be suitable for irrigation(Appendix IV)

According to Ayers and Westcot (1985), the recommended concentration of chloride is 4.0 mg/L. Our results showed that chloride concentration ranged from 0.31 to 0.80 mg/L and all waters were suitable for irrigation.

Gibbs Ratio

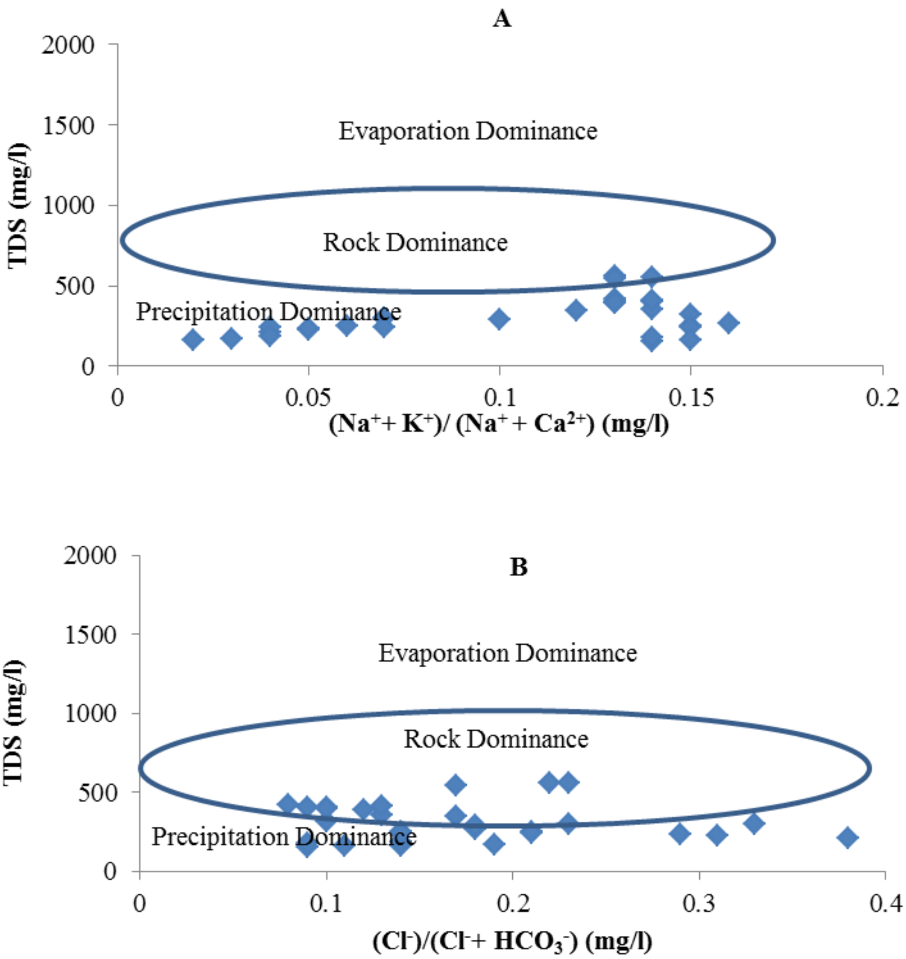


Figure : The Gibb's Ratios (weight ratio) of A TDS versus $(Na^+ + K^+)/(N^+ + K^+ + Ca^{2+})$ and B TDS and $Cl^-/(Cl^- + HCO_3^-)$

Gibbs (1970) proposed a diagram to understand the relationship of the chemical components of waters from their respective aquifer lithologies. Three distinct fields, namely precipitation dominance, evaporation dominance, and rock dominance areas, are shown in the Gibbs diagram (Fig. 4.15). Gibbs ratios for the study area samples are plotted against their respective total dissolved solids as shown in Figure 4.15 to know whether the ground water chemistry is due to rock dominance, evaporation dominance or precipitation dominance. In the present study, Gibbs ratio observed from the diagrams fall into the precipitation dominance area. It indicates that the interaction between precipitation dominance and groundwater in the subsurface. Because our study area has a higher rate of evapotranspiration characterized by tropical climate and restricted fresh water exchange, salt layers may form near the evaporating surface (Karnath, 1994).

CHAPTER V

SUMMARY AND CONCLUSION

Water samples were collected to study the dissolved chemical constituents and to their suitability for drinking and irrigation purpose. In order to assess the suitability classes for drinking and irrigation uses, we measured measured pH, EC, TDS, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Zn^{2+}, $HC0_3^{2-}$, S and Cl^{-}.

pH value of the water samples were slightly acidic in nature. In the present study the content of Ca^{2+}, Na^{+}, K^{+}, Zn^{2+}, $HC0_3^{2-}$, Cl^{-} revealed that all the samples were suitable for drinking and irrigation purpose. All sample belonged to 'excellent' class for irrigation regarding SAR and SSP. According to Kelly's ratio all the sample lied in 'good' category. According to TDS values, all samples were classified as 'freshwater'. Maximum samples were within 'soft' class regarding hardness. EC values indicated that, all the water samples were classified as 'permissible'. Gibbs diagram revealed that all the samples fall in the precipitation dominance field.

From the present investigation, it can be concluded that all the collected groundwater samples under test would not create severe problem for drinking and irrigation crops grown in the study area but the Hardness and PI were in unsatisfactory level for irrigation.

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APPENDICES

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

Water class	Soluble Sodium Percentage	Electrical Conductivity (EC) μScm^{-1}
Excellent	<20	<250
Good	20-40	250-750
Permissible	40-60	750-2000
Doubtful	60-80	2000-3000

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

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

Appendix III: 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 IV: 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 V: Recommended Concentration (mg L^{-1}) of different ions for drinking water (WHO, 2004)

Element	Recommended limit
Bicarbonate	11
Calcium (Ca)	75.00
Chloride (Cl)	250
Copper (Cu)	1.00
Hardness (H_T)	200-500
Iron (Fe)	0.10-0.30
Magnesium (Mg)	30-35
Manganese (Mn)	0.01-0.04
Nitrate (NO_3)	10.00
Phosphate (PO_4)	6.00
Potassium (K)	12
Sulfate (SO_4)	150.00
Sodium (Na)	200
Zinc (Zn)	5.00