# ASSESSMENT OF GROUNDWATER QUALITY AND SUITABILITY FOR IRRIGATION PURPOSES AT NAGESHWARI UPAZILA

**A THESIS**

**BY**

**MD. SHIHAB AHAMED**

**Student No. 1701351**

**Session: 2024-2025**

**Thesis Semester: January – June, 2025**

**MASTER OF SCIENCE (M.S.)**

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**AGRICULTURAL CHEMISTRY**

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**JUNE 2025**

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**JUNE 2025**

*Dedicated*

*to my*

*Beloved Parents*

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*The Author* *June 2025*

# ABSTRACT

A study was conducted to evaluate the quality of groundwater in different unions of Nageshwari upazila under Kurigram District of Bangladesh for irrigation purposes. Forty water samples were collected and analyzed in the Agricultural chemistry laboratory of Hajee Mohammad Danesh Science and Technology University for the assessment of their quality based on a number of pH, total dissolved solids (TDS), electrical conductivity (EC), sodium adsorption ratio (SAR), Kelly‟s ratio (KR), residual sodium carbonate (RSC), soluble sodium percentage (SSP), total cations ($Ca^{2+}$, $Mg^{2+}$, $Na^{+}$ and $K^{+}$) and anions ($HCO_3^{-}$, $SO_4^{2}$, $PO_4^{3-}$ and $Cl^{-}$). Several computed variables such as SAR (Sodium Adsorption Ratio), $H_T$ (Total Hardness), PI (Permeability Index), PS (Potential Salinity) and Kelly‟s Ratio were used to evaluate the suitability of groundwater for specific uses. Most of the water samples were slightly acidic in nature (pH value varied from 5.88 to 7.15 for ground water) and had a great impact on crop production. As regards to EC values, 21 samples were classed as „good‟ and 12 samples were classed as „excellent‟ and 7 samples were „permissible‟ categories for irrigation. All samples were fresh for irrigation in respect to TDS. Based on SAR values, all water samples were under „excellent‟ categories for irrigation. On the basis of $Ca^{2+}$, $Mg^{2+}$,$Na^{+}$ and $K^{+}$ content, the entire water samples can safely be used for irrigation and would not affect the soil $^{+}$**.** On the basis of $PO_4^{3}$, $SO_4^{2-}$, $HCO_3^{-}$ and $Cl^{-}$, all water samples under investigation were suitable for irrigation. For hardness, 7 samples were soft, 28 samples were moderately hard and 5 sample were hard for irrigation. Some compositional relations were also evaluated. The results also provided data for water quality of groundwater resources of study region to match national and international standards for agricultural requirements. The study revealed that the quality of groundwater for most of the locations in the area was permissible, good and suitable for irrigation purposes.

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# CHAPTER I

# INTRODUCTION

Water is the most vital element among the natural resources, and is crucial for the survival of all living organisms. However, the role of GIS in analyzing the spatial distribution of groundwater has been investigated by many authors (Verma *et al*., 2016; Gorai and Kumar, 2013; Srivastava *et al*., 2012). It is an important natural sourse of water irrigation domestic purpose sand the competition of water use is increasing among these sectors. In Bangladesh, groundwater is the main source of drinking and irrigation water, and approximately 90% of drinking water and 75% of irrigation water come from groundwater sources without any treatment (Shahid *et al*., 2006; Shariot-Ullah, 2018). Groundwater has been used for many purposes like domestic, agriculture, and industrialization in many regions of the world (Li *et al*., 2018). The sustainable development of groundwater resources facilitates sustainable economic and societal development (Li *et al*., 2017; Gaglioti *et al*., 2019; Rao *et al*., 2019). However, nowadays the increase of population, expansion of urban areas, industrial activities affect both the quality and quantity of groundwater resources (Li, 2016). Irrigation with poor quality water reduces soil productivity and changes soil physical and chemical properties (Talukder *et al*., 1989). Hasan *et al*. (2016) carried out a study to evaluate the groundwater quality for irrigation purpose; finally, they found that the enhanced dissolution of calcium ions may be expected to block the filter of the pumping well and deteriorate the quality of groundwater for irrigation purposes. Groundwater is a critical source of water for irrigation, domestic and industrial uses in Bangladesh. Presently the cultivated land under irrigation with groundwater accounts for more than 70% of the total irrigated area and contributes significantly to Bangladesh‟s grain production (Islam *et al*., 2014). Roy *et al*. (2016) conducted a study on groundwater quality assessment for both irrigation and drinking purposes in Comilla district of Bangladesh. Irrigation is the most important water use sector accounting for about 70 percent of the global fresh water withdrawals and 90 percent of consumptive water uses (Siebert *et al*., 2010). About 90 percent of irrigation water in Bangladesh is provided from groundwater (Zahid and Ahmed, 2006). As a result of dense population and higher level of rural poverty, Bangladesh is very much in need of higher crop production. Currently, about 4.2 million ha of land is irrigated by groundwater (Tube well, both shallow and deep Tube-wellss) whereas only 1.03 million ha is irrigated by surface water using low lift pumps (BADC, 2013). By 2006, nearly 78 % of the irrigated rice-fields were supplied by groundwater of which about 80 % of the irrigation water derived from tube well, shallow Tube-wells and the rest was irrigated by deep Tube-wells (UNDP, 1982; BBS, 2009). Thus, groundwater irrigation is of vital importance as an input to the agricultural economy and for food security (Haque *et al*., 2013). Bangladesh is considered as one of the most climate vulnerable countries in the world. In the southern part, it has approximately 710 km coastal line with highly susceptible areas to sea level rise. Water and soil salinity are regular hazards for many parts specially south east, central (Shammi *et al*., 2012, 2015), and southwest (Shammi *et al*., 2016; Bahar and Reza, 2010; Halim *et al*., 2010).

High yields can get from the corps by practicing suitable water management practices based on the quality of groundwater. Thus, knowledge of irrigation water quality is critical to the understanding of necessary management changes for long-term productivity (Bauder *et al*., 2004).

Such irrigation water needs to be of appropriate quality. The quality of irrigation water depends on the concentration of dissolved salt within the recommended permissible limits. 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. The chemical constituents of irrigation water can affect plant growth directly through toxicity or deficiency, or indirectly by altering plant availability of nutrients (Ayers and Westcot, 1985; Rowe and Magid, 1995). Bad irrigation water not only can affect crop production, but also soil fertility that influences soil physical condition (Alomran *et al*., 2010). The problems associated with the use of poor-quality water include reduction in infiltration rate and toxicity due to certain ions and excessive nutrients (Ayers and Westcot, 1994). In certain conditions, especially where there is accumulation of sodium ions in the soil structure due to extended use of irrigation water, could cause deterioration in the soil physical properties, and thereby results in the decrease of the crop yield (Oladeji *et al*., 2012). 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).

Since physio-chemical composition of groundwater is a measure of its suitability as a source of water for agriculture (irrigation), industrial and domestic purposes, it is necessary to evaluate the hydrochemical characteristics of groundwater and this present study seeks to assess the quality of groundwater for irrigation purposes.

Demand of groundwater has been increasing day by day for irrigation by bringing more area under cultivation. Water generally contains different species of cations and anions in varying amounts. The principle soluble ions are $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$ and $K^{+}$ as cations and Cl, $SO_4^{2-}$, $CO_3^{2-}$and $HCO_3^{-}$as anions. Besides these, $Cu^{2+}$, $PO_4^{3-}$, $Fe^{3-}$, $Mn^{2+}$, $Zn^{2+}$, $B^{+}$, $Si^{2+}$ and $F^{-}$ are present in small amounts. Out of soluble constituents $Ca^{2+}$, $Mg^{2+}$, $Fe^{3+}$, $Na^{+}$, Cl, $HCO_3^{-}$, $SO_4^{2-}$ and $B^{+}$ are of prime importance in determining the quality and suitability of irrigation, 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. The classification of irrigation water is generally based on some quality factors like SAR, SSP, RSC, TDS and EC. 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 concentration or any elements in water attain level that causes significant degradation of water and this element is considered as pollutant. When polluted water is applied to soil for long-term irrigation, soluble salts containing toxic elements may accumulate in the soil thus destroying soil properties. So, the concentration of some important chemical constituents of water is necessary to assess their suitability for irrigation.

Some studies on the quality of water in some selected areas of Bangladesh namely, Dinajpur sadar, Kalihati, Laksmipur, Noakhali, Madhupur, Pangsha, Shahzadpur, Jamalpur, Gazipur, Meherpur, Phulpur, Trishal, Muktagacha, Matiranga, Sherpur and Pabna sadar upazilla has been conducted. Most of the chemical analyses of these investigation included pH, EC, $Ca^{2+}$, $Mg^{2+}$, $CO_3^{2-}$, $HCO_3^{-}$, $Cl^{-}$, $Na^{+}$, $Cu^{2+}$, $Mn^{2+}$, $Zn^{2+}$ and $Fe^{3+}$. But little attention has been given to the concentration of micronutrients and toxic elements (e.g. $Cu^{2+}$, $Mn^{2+}$, $Zn^{2+}$, $Fe^{3+}$, $As^{5+}$, $Cr^{4+}$, $Pb^{2+}$, $Hg^{2+}$ etc.). Now-a-days, analyses of water from groundwater sources to determine the toxic elements are very important for irrigating crops, domestic uses, drinking, livestock, poultry, aquaculture and industrial usage. Unfortunately, there is no laboratory for systematic investigation of the water quality in Bangladesh.

Groundwater seems to be pure and free from suspended material in comparison to surface water, yet many compound and/or ions in varying amounts may be present in dissolved and/or ionic forms. When these waters are used in various irrigation, drinking and industrial purposes, they deteriorate the quality of the products. In some cases, ionic toxicity may occur and respective products become unsuitable for beneficial uses. For each use there is a water quality recipe that specifies limiting concentrations of such variables as pH, Total Dissolved Solid (TDS), Total Hardness ($H_T$), temperature and some ionic constituents (Mckee and Wolf, 1963). In spite of these chlorine and sulphate are the significant variables to assess the toxicity and suitability of the water for industrial usage (Raghunath, 1987).

However, if it is possible to identify which water type(s) is suitable for irrigation in a specific area then it will be more convenient and less time consuming to identify suitability of irrigation water. In view of this, an attempt has been made to analyze the groundwater quality in several unions of Nageshwari upazila under Kurigram District of Bangladesh to determine the exact level of physico-chemical parameters with special emphasis on its irrigation suitability and find out the best type of water to be used as irrigation water at Nageshwari upazila.

In view of importance for the formulation of a base line data, an investigation has been conducted to assess the toxicity of groundwater for irrigation usage in several unions of Nageshwari upazila. Nageshwari is a upazila of kurigram district in the Rangpur Division of northern Bangladesh. It is located near the border with India, with the Brahmaputra River flowing through the region. Nageshwari is known for its rural landscapes, rivers, and agricultural activities. It is approximately 352 kilometers from Dhaka, the capital of Bangladesh. It is located in between 25°59´ and 26°13´ north latitudes and in between 89°35´ and 89°52´ east longitudes. It covers an area of 417.56 sq. km. and the population of this area is 444699(2022). It has 14 unions. The annual average maximum temperature is 32-33°C and the minimum of 5-10°C. The annual average rainfall is about 3000 mm. Main source of income in Agriculture is 70.41%. Main crops of this area are paddy, wheat, jute, potato, mustard, vegetables. Keeping these in mind, the present research reports the bench mark survey of irrigation water quality of several unions of Nageshwari upazila.

In the study area, there have different water sources in which of shallow Tube-wells, deep Tube-wells are mainly applied for irrigation. In cropping sequences; rice, vegetable and robi crops were also found to be cultivated. Farmers apply irrigation water from groundwater sources without testing of water quality. But there is no organization to assess the extent of water toxicity systematically at field level to assess groundwater quality of Nageshwari upazila. Keeping all these facts in mind, this area was selected to evaluate the toxicity levels of groundwater with the objectives as below:

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

- To categorize groundwater on the basis of standard criteria
- To evaluate the suitability of these water for irrigation uses.
- To achieve the baseline information on groundwater quality at Nageshwari upazila.

# CHAPTER 2

# REVIEW OF LITERATURE

Water contains variable quantities of organic inorganic substance. It is very important for determine the quality of water. These qualities have effects on soil properties due to longterm irrigation and its drinking and industrial usage.

Human and ecological use of groundwater depends on ambient water quality. The concentration and composition of dissolved constituents in water actually determines its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Generally, the suitability of groundwater for agriculture and domestic purposes largely depends on the site specific with possible temporal variations caused by climatic conditions, as well as the residence time of water within the aquifer materials and anthropogenic activities (Oladeji, 2012; Ewusi *et al*., 2013).

Irrigation water quality is related to its effect on soils and crops and its management. High quality crops can be produced only by using high quality irrigation water keeping other inputs minimal (Islam and Shamsad, 2009).

According to Chowdhury (2007) mentioned in the daily itteefaq that "The amount of arsenic iron increased abnormally at eight districts of north side of country the people suffering from stomach and skin diseases. So, this is the main situation about the water of Boda Upazila in Panchagarh.

Much work has been done on quality of irrigation water at home and aboard to assess its suitability for irrigation purposes. But systematic research work on the Bogura is limited. An attempt has been made in this chapter to review the pertinent research information related to water pollution or quality assessment. Some related research reports are mention here under the following order:

## 2.1 Water quality related to pH

The pH is a measure of acidity or alkalinity of water-soluble substances (pH stands for „potential of hydrogen"). The pH of pure water is 7 is considered neutral. In general, water with a pH lower than 7 is considered acidic, and with a pH greater than 7 is considered basic. The pH of water is a very important measurement concerning water quality. The normal range for pH in surface water system is 6.5 to 8.5 and the pH range for groundwater system is 6 to 8.5.

Basically, the pH value is a good indicator of whether water is hard or soft. The measurement of alkalinity and pH is needed to determine the corrosiveness of the water. In general, water with a pH <6.5 could be acidic, soft, and corrosive. Acidic water could contain metal ions such as iron, manganese, copper, lead, and zinc. In other words, acidic water contains elevated levels of toxic metals. Metals tend to be more toxic at lower pH because they are more soluble. Acidic water can cause premature damage to metal piping and have associated aesthetic problems such as metallic or sour taste. Water with a pH >8.5 could indicate that the water is hard. Hard water can also cause aesthetic problems.

The pH values of northern Bangladesh were 6.3 to 8.1 (Islam *et al*., 2010). The pH values of nilphamari district were varied from 6.7 to 7.8 (Islam *et al.*, 2009). The pH of groundwater of Nilphamari district was 6.81 to 7.81 indicated slightly acidic to slightly alkaline as per Luna (2010). The pH of some groundwater in Chirirbandar Upazila of Dinajpur district ranged from 6.77 to 7.77 (Sarker *et al*., 2009). The pH values of 45 groundwater samples collected from 4 unions of Atpara upazilla under the district of Netrakona area ranged from 7.04 to 8.48 (Khanam, 2009). The pH of groundwater of coalmine area of Phulbari upazila in Dinajpur was 7.24 (Nasirullah *et al*., 2007). The range of pH values of groundwater at Chirirbandar in dinajpur district was 7.1 to 7.7 (Hasanuzzaman *et al*., 2007). An experiment was conducted to determine water pollution of Mauna and Mouchak industrial areas of Gazipur district during 1998-2002. It was found that pH values of industrial effluents, surface and groundwater samples were within the range of 6.00 to 8.78 in 1998 and 6.01 to 8.83 in 1999 (Begum, 2006).

The pH values of groundwater collected from Lakshmipur and Noakhali district ranged from 6.24 to 7.6 reflecting slightly acidic to alkaline (Uddin, 2005). Roy *et al*.(2005) reported that the pH values of Rangpur district was acidic to alkaline in nature (pH=5.98.0). The pH of groundwater collected from Dinajpur district varied from 5.32 to 7.00 (Uddin, 2004). The pH values of groundwater collected from Kashia and Chuadanga district ranged from 6.87 to 7.43 (Azad, 2004). The pH of groundwater collected from Eastern Surma Kushiara floodplain and neighboring region of Sylhet division varied from 5.27 to 7.99 (Ahsan, 2004).

The pH of groundwater collected from Pabna sadar upazila under Pabna district varied from 7.50 to 8.20 reflecting slightly acidic to alkaline in nature (Arefin, 2002). Groundwater pH in Gaibandha aquifers varied from 6.73 to 8.66 (Jesmin, 2000). The pH of groundwater collected from Sherpur upazila under Bogura district varied from 4.20 to 8.80 reflecting acidic to alkaline properties (Rahman, 2000). 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 (Nizam, 2000). The pH of groundwater of Bagmara, Mahadebpur and Nachoul Upazila ranged from 7.48 to 9.44, 6.74 to 9.33 and 6.40 to 8.20, respectively (Zaman, 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 respective pH of groundwater of Muktagacha (Hossain and Ahmed, 1999) and Narayangonj (Sarker, 2001) ranged from 7.50 to 8.50 and 6.86 to 8.60, respectively. The pH of ground water of Bathinda district of Punjab in India varied from 7.60 to 8.80 (Anil Sood *et al*., 1998). The pH of groundwater of Nachoul Upazilla at High Barind Tract fluctuated form 6.80 to 8.20 (Ali, 1997). 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). Researchwork with 15 water samples collected from river, deep and shallow tubewells of Shahjadpur.

Thana under the district of Sirajgonj showed that the pH values varied from 8.20 to 8.50 (Zaman and Rahman, 1996). 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). The water quality at different, locations in Northeast, North and Northwest of China was evaluated by Zheng *et al*. (1996).

## 2.2 Electrical Conductivity and Salinity

Electrical Conductivity (EC) is a calculation of waters capability to pass electrical flow. A significant variation in the EC values of groundwater was detected ranging from 198 to 552 µS/cm at northern of Bangladesh (Islam *et al*., 2010a). The electrical conductivity of groundwater collected from northern parts of Bangladesh were $C_1$ (0-250 µS/cm) to $C_2$ (250 to 750 µS/cm) (Islam *et al*., 2009b). These conductive ions come from dissolved salts and inorganic materials such as alkalis, chlorides, sulfides, and carbonate compounds. The more ions that are present, the higher the conductivity of water. Salinity is the total concentration of all dissolved salts in water. Dissolve ions increase salinity as well as conductivity. Likewise, the fewer ions that are in the water, the less conductivity it is.

Electrical conductivity is widely used as an indicator of the dissolved solids or salts in groundwater.

The EC of groundwater and surface water of Nilphamari district was 284 to 745 µS $cm^{-1}$ depicted by Luna (2010). Some groundwater in Chirirbandar upazilla of Dinajpur district had 523 µS $cm^{-1}$ (Sarker *et al*., 2009). The EC of groundwater of Phulbari upazilla in Dinajpur was 585.4 µS $cm^{-1}$ (Nasirullah *et al*., 2007). The Electrical Conductivity (EC) of groundwater of Lakshmipur and Noakhali district water sample was within the limit of 159.86 to 1087.97 µS $cm^{-1}$ (Uddin, 2005). The EC of 93 groundwater samples from Dinajpur district to ranged from 75.47 to 565.35 µS $cm^{-1}$ (Uddin, 2004). The EC of 85 groundwater samples collected from Kushtia and Chuadanga districts were found to range from 412 to 1331 µS$cm^{-1}$ (Azad, 2004). The electrical conductivity of eastern surma kushiara floodplain and neighbouring region of sylhet division were found 19.57 to 1655.40pS/cm from 136 groundwater samples (Ahsan, 2004). Latha *et al*.(2002) analyzed 133 water samples from Avinashi, Pollachi and Palladam areas of Tamil Nadu, the EC values was varied from 0.45 to 4.50, 2.27 to 9.95 and 0.2 to 2.7 $dSm^{-1}$, respectively and also observed that EC > 3 $dSm^{-1}$ were unsuitable for irrigation as they liable to cause salinity in soils. The EC of 46 groundwater samples collected from Pabna sadar upazila were found varied from 0.47 to 0.90 dS $cm^{-1}$ (Arefin, 2002). The EC of 50 groundwater samples collected from Sherpur upazila under Bogura district were found to range from 442.80 to670.80 $Scm^{-1}$ (Rahman, 2001). Groundwater EC in Gaibandha aquifers ranged from 274 to 1465µS$cm^{-1}$ (Jesmin, 2000).

The EC of groundwater samples of Bagmara, Mahadebpur and Nachoul fluctuated from 235 to 1682, 256 to 1334 and 285 to780 µS$cm^{-1}$, respectively bµut they did not explain causes of variations of electrical conductance (Zaman, 2000). Nizam (2000) observed that EC of surface and groundwater collected from Bhaluka upazila under Madhupur Tract varied from 244.64 to 822.0 µS$cm^{-1}$. 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 groundwater ranged from 185 to 992µS$cm^{-1}$.

Gumtang *et al*. (1999) conducted an investigation from October 1994 to March 1996 to assess groundwater dynamics and quality in relation to land use and farm input nitrogen fertilizer in a highly diversified and intensive agricultural area at Magnuang, Batac. They reported that the EC in all wells were from 700 to 3000 mmhos $cm^{-1}$, which exceeded the FAO threshold quality for irrigation but were not related to the farm management practices.

The EC values of the waters of Nokia, Kolayat, Loonkaransor under Bikaner district of Rajasthan Pradesh in India ranged from 1.00 to 6.10, 0.80 to 10.30, 2.30 to 7.90 dS $m^{-1}$, respectively (Lai *et al*.,1998).

The EC of surface and groundwater samples of Narayangonj aquifers varied from 164 to 1894 $\mu Scm^{-1}$ (Sarker, 1997). The EC values of 15 groundwater samples collected from Pangsha Thana of Rajbari district varied from 240 to 670µ $Scm^{-1}$ (Zaman and Mohiuddin, 1995). 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 from 500 to 834 $\mu Scm^{-1}$. The EC of groundwater at Madhupur Thanaunder Tangail district varied from 220 to 570 $\mu Scm^{-1}$ (Zaman and Majid, 1995).

The EC of groundwater sources of Muktagacha Thanaunder the district of Mymensingh varied from 150 to 408 $\mu Scm^{-1}$ (Ahmed *et al*., 1993). Tatwat (1993) investigated the ground water pollution in India and observed that the EC of groundwater at distance of <225 m from the river was varied from 3.15 to 5.60 $dSm^{-1}$ while effluent unaffected ground water had EC variation of 2.32 to 2.43 $dSm^{-1}$. The groundwater of Kailsagar project of Andhra Pradesh in India was of high salinity (C3) (Raju and Goud, 1990).

### 2.3 Total Dissolved Solids (TDS)

The Total Dissolved Solids (TDS) is and calculate of the assembled total of organic and inorganic substances contained in a liquid. Total Dissolved Solids (TDS) assemble the sum of all ions particles that are smaller than 2 microns (0.0002 cm). This includes all of the disassociated electrolytes that make up salinity concentrations, as well as other compounds such as dissolved organic matter. These solids are primarily minerals, salts and organic matter that can be a general indicator of water quality. In clean water, TDS is approximately equal to salinity. In waste water or polluted areas, TDS can include organic solutes (such as hydrocarbons and urea) in addition to the salt ions. TDS can affect water taste and often indicates a high alkalinity or hardness.

The measured TDS in Chirirbandar Upazilla in Dinajpur varied from 224 to 662 mg $L^{-1}$ (Sultana *et al*., 2011). Some groundwater in Sugar industry area in Setabganj and Thakurgaon varied from 264.9 to 839.5 mg $L^{-1}$ TDS (Sarker *et al*., 2010). The TDS of groundwater and surface water of Nilphamari district was 104.5 to 458 mg $L^{-1}$revealed by

Luna (2010). TDS was found at 260-817 mg/L levels in groundwater in Dimla upazila under Nilphamari district (Islam *et al*., 2010a). The TDS ranged from 107–1044 mg/L of northern Bangladesh (Islam *et al*., 2010b). The TDS amount of groundwater of Nilphamari district was ranged from 355 -422mg/L (Islam *et al*., 2009). The TDS of groundwater of coalmine area of Phulbari upazila in Dinajpur ranged from52.02 to 345 mg $L^{-1}$ (Nasirullah *et al*., 2009). The collected water sample from Lakshmipur and Noakhali district, the values of TDS was within the range from 106.27 to 768.43 mg $L^{-1}$ (Uddin, 2005).

Thirumathal and Sivakumar (2004) studied groundwater quality at Swaminathapuram, Dindigul district and Tamil Nadu showed that groundwater samples contained total dissolved solids to range from 86 to 1165 mg $L^{-1}$. The TDS of groundwater of Dinajpur district ranged from 52.02 to 422.51 mg $L^{-1}$ (Uddin, 2004). The TDS of Kushtia and Chuadanga districts ranged from 247.78 to 870.45 mg $L^{-1}$ (Azad, 2004). The Total Dissolved Solids (TDS) of groundwater of Eastern Surma Kushiara floodplain and neighbouring regions of Sylhet division varied from 13.87 to 1036.88 mg $L^{-1}$ (Ahsan, 2004). 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 Total Dissolved Solids of groundwater of Sherpur under Bogura district ranged from 194.85 to 458.48 mg $L^{-1}$ (Rahman, 2001).

The Total Dissolved Solids of groundwater in Gaibandha aquifers ranged from 192 to 1000 mg $L^{-1}$ (Jesmin, 2000). Groundwater at Atrai Basin under Naogaon district varied from 242.19 to 479.17 mg $L^{-1}$ (Rahman, 2000). The values of TDS of groundwater collected from Bagmara, Mahadebpur and Nochoul upazila ranged from 152 to 1077, 164 to 1854 and 265 to 546 mg$L^{-1}$, respectively (Zaman, 2000). The TDS of some surface and groundwater of Tongi under Gazipur district ranged from 123 to 675 mg $L^{-1}$ (Sen *et al*., 2000). Ali (1997) stated that the TDS of groundwater of Nochoul at high Barind Tract ranged from 185 to 546 mg $L^{-1}$. 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 groundwater of Shahzadpur Thana under Sirajgonj district contained TDS within the limit of342 to 550 mg$L^{-1}$ reflecting freshwater in quality (Zaman and Rahman, 1996). The TDS of both ground and surface waters at Kalihati and Ghatail Thanas of Tangail district varied from 90 to212 mg$L^{-1}$ (Razzaque, 1995). Zaman and Majid (1995) stated that the groundwater samples of Madhupur Thanaunder Tangail district contained TDS ranging from

100 to 600 $mgL^{-1}$ showing freshwater in quality. The TDS of irrigation water collected from sadar Thana under Gazipur district ranged from 70 to 260 $mgL^{-1}$ (Quayum, 1995).

### 2.4 Calcium (Ca), Magnesium (Mg), Sodium (Na) and Potassium (K)

Roy *et al*. (2012) reported that $Ca^{2+}$ content in Cumilla was 0.70 to 7.41 meq $L^{-1}$. The $Ca^{2+}$ content in groundwater collected from Phulbari upazila in Dinajpur varied from 4.21 to 72.54 mg $L^{-1}$ (Sultana *et al*., 2011). $Ca^{2+}$ concentration of groundwater of Chirirbandar upazila of Dinajpur was 2.5 meq $L^{-1}$ as reported by Sarker *et al*. (2010). Themean value of calcium of groundwater and surface water of Nilphamari district was 3.529 meq $L^{1}$revealed by Luna (2010). 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 major cations basically $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$ and $K^{+}$ collected in groundwater 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 $mgL^{-1}$, respectively (Uddin, 2005).

The concentration of Calcium ($Ca^{2+}$), Magnesium ($Mg^{2+}$), Sodium ($Na^{+}$) and Potassium ($K^{+}$) in groundwater samples collected from Eastern Surma Kushiara floodplain and neighboring 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 $mgL^{-1}$, respectively (Ahsan, 2004).$Ca^{2+}$, $Mg^{2+}$, $Na^{+}$ and $K^{+}$ content 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 $mgL^{-1}$, respectively (Azad, 2004). Thirumathal and Sivakumar (2004) studies groundwater quality at Swaminathapuram, Dindigul districts, Tamil Nadu. 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 at khagrachari district (Hakim *et al*., 2003). They found that $Ca^{2+}$ content varied from 6.2 to 22 mg $L^{-1}$. $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$ 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 $meqL^{-1}$, respectively (Arefin, 2002) and those of Sherpur upazila under Bogura 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). The contents of $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$ 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 to 0.42 and 0.09 to 2.26 mg $L^{-1}$, respectively (Hoque, 2000). The $Ca^{2+}$ content in groundwater of Bagmara, Mahadebpur and Nachoul Upazilas varied from 0.80 to 4.00, 0.20 to 3.60 and 1.50 to 3.50 meq $L^{-1}$, respectively (Zaman, 2000). The content of those elements in groundwater samples collected from Bhaluka upazila under Mymensingh district ranged from 0.10 to 2.80, 0.40 to 4.40, trace to 0.08 and 0.33 to 0.08 meq$L^{-1}$, respectively (Nizam, 2000). Sen *et al.* (2000) observed that the concentration of $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$ 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.

The $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$ and $K^{+}$ content in of groundwater of Mukatagacha ranged from 0.20 to 1.50, 0.63 to 1.73, 0.35 to 4.09 and 0.021 to 0.056 meq$L^{-1}$ with the mean values of 1.10, 1.09, 1.86 and 0.039 meq $L^{-1}$ respectively (Hossain and Ahmed, 1999). Anil Sood *et al.* (1998) reported that the concentration of $Ca^{2+}$, $Mg^{2+}$ and $Na^{+}$ of underground water of Bathinda district of the Punjab in India ranged from 1.30 to 47.30 and 3.00 to 90.10 meq $L^{-1}$, respectively. The contents of these four elements in irrigation water collected from Shahzadpur upazilla under Sirajgonj district varied from 2.00 to 4.40, 1.09 to 2.19, 0.10 to 0.42 and 0.91 to 1.39 meq $L^{-1}$, respectively (Rahman and Zaman, 1995) and in groundwater samples of Pangsha Thana under Rajbari district varied from 1.20 to 2.90, 1.00 to 1.30, 0.43 to 3.05 and 0.05 to 0.18 meq $L^{-1}$, respectively (Zaman and Mohiuddin, 1995).

Shahidullah (1995) reported that the concentration of $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$ 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 groundwater 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 groundwater collected from Gazipur sadar Thana contained $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$ and $K^{+}$ within the range of 0.55 to 1.65, 0.04 to 0.08, 0.43 to 1.00 and 0.02 to 0.05 meq$L^{-1}$, respectively. Puce *et al.* (1992) carried out an experiment on confining unit effects on water quality in the New Jersey Coastal Plain and stated that the concentrations of $Ca^{2+}$ and $Mg^{2+}$ ranged from 1.70 to 666.00 mg $L^{-1}$ and 0.30 to 140.00 mg $L^{-1}$, respectively.

**2.5 Iron (Fe)**

Iron content in groundwater collected from Phulbari upazila in Dinajpur varied from 0.01 to 0.27 mg $L^{-1}$ (Sultana *et al.*, 2011). Sarker (2011) revealed that $Fe^{3+}$ content of Narayanganj aquifers was in trace or minor concentration. The mean value of $Fe^{3+}$ in groundwater and surface water of Nilphamari district was 0.001 to 0.004 mg $L^{-1}$ revealed by Luna (2010). Roy *et al*. (2010) reported that $Fe^{3+}$ content in Cumilla was trace to 0.005 mg $L^{-1}$. Islam *et al*. (2010a) found that Fe varied from 0.014-0.73 mg/L at Dimla, Nilphamari district. The concentration of Iron ($Fe^{3+}$) in groundwater samples from Lakshmipur and Noakhali district ranged from 0.02 to 0.81 mg $L^{-1}$ (Uddin, 2005). The concentration of Iron ($Fe^{3+}$) in groundwater samples collected from Eastern Burma Kushiro floodplain and neighboring region of Sylhet division varied from 0.05 to 61.0 mg $L^{-1}$ (Ahsan, 2004), in groundwater samples of Dinajpur district ranged from 0.01 to 1.27 mg $L^{-1}$ (Uddin, 2004) and in groundwater samples of Kustia and Chuadanga districts ranged from 0.07 to 8.32 mg $L^{-1}$ (Azad, 2004). Tamil Nadu found that $Fe^{3+}$ ranged from 0.60 to 4.10 mg $L^{-1}$. Iron concentration in groundwater of Pabna sadar upazila varied from 0.028 to 0.488 mg $L^{-1}$ (Arefin, 2002), in Sherpur aquifers under Bogura district it varied from 0.07 to 1.25 mg $L^{-1}$ (Rahman, 2000). Sen *et al.* (2000) reported that concentration of $Fe^{3+}$ in surface and groundwater collected from Torigi aquifers ranged from trace to 0.09 mg $L^{1}$. The concentration of $Fe^{3+}$ in groundwater collected form Gaibandha aquifer ranged from 0.15 to 1.00 mg $L^{-1}$ (Jesmin, 2000). Nizam (2000) analyzed 20 water samples collected from different sources of two unions of Bhaluka upazila under Mymensingh district and found that most of the water samples were unsuitable for drinking and livestock consumption due to the presence of higher amounts of iron ($Fe^{3+}$ = 0.35-3.11 mg $L^{-1}$).

$Fe^{3+}$ content in groundwater of Bagmara, Mahadebpur and Nachoul ranged from 0.005 to 0.39, 0.01 to 3.72 and trace to 0.44 mg $L^{-1}$, respectively (Zaman *et al*., 2000). Husain and Ashamed (1999) reported that Fe concentration of Muztagata aquifers ranged from 0.01 to 0.06 mg $L^{-1}$, with the mean value of 0.03 $mgL^{-1}$. Mitra and Gupta (1999) reported that $Fe^{3+}$ content of Tube-wells water of vegetable growing area around Kolkata during monsoon and winter were 17.60 and 80.60 $\mu gL^{-1}$, respectively. Sarker (1997) found that $Fe^{3+}$ content of Narayangonj aquifers varied from 0.025 to 0.16 mg $L^{-1}$.

The concentration of $Fe^{3+}$ in groundwater of Phulpur Thana under Mymensingh district was within the range of 0.10 to 1.30 mg $L^{-1}$ (Shahidullah, 1995). 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 groundwater of Shahzadpur Thana in Sirajgonj district contained $Fe^{3+}$ within the range of 0.10 to 0.42 $mgL^{-1}$ and iron was dominant in groundwater compared to surface water. Quddus (1993) cited that the concentration of $Fe^{3+}$ in surface and groundwater of Meherpur sadar Thana ranged from traces to 0.05 $mgL^{-1}$.

**2.6 Manganese (Mn)**

The $Mn^{2+}$ content in groundwater collected from Phulbari upazila in Dinajpur varied from 0.014 to 1.58 mg $L^{-1}$ (Sultana *et al*., 2011). The concentration of $Mn^{2+}$ was found within the range of 0.0005 to 0.57 mg $L^{-1}$ with the mean value of 0.0247 mg $L^{-1}$ (Luna, 2010). Manganese occurs in natural waters as minor elements. Manganese concentrations in groundwater of jaldhaka in Nilphamari district ranged from 0.012 to 0.321 mg/L (Islam *et al*., 2009). The concentration of $Mn^{2+}$ in water samples collected from four unions Sherpur upazila under Bogura district ranged from 0.30 to 0.18 mg $L^{-1}$ (Rahman *et al*., 2007). The content of $Mn^{2+}$ in water samples collected from five unions under Atrai upazila of Naogaon district varied from 0.05 to 0.20 mg $L^{-1}$ (Rahman *et al*., 2006). The concentration of $Mn^{2+}$ in water samples collected from three districts namely Sherpur, Gaibanda and Naogaon ranged from 0.04 to 0.50 mg $L^{-1}$ (Rahman *et al*., 2005). The concentration of manganese ($Mn^{2+}$) in collected groundwater samples from Lakshmipur and Noakhali district ranged from 0.01 to 0.88 $mgL^{-1}$ (Uddin, 2005).

The concentration of manganese ($Mn^{2+}$) in collected groundwater samples of Eastern Surma and Kushiara floodplain and neighbouring regions of Sylhet division ranged from 0.015 to 3.97 mg $L^{-1}$ (Ahsan, 2004). $Mn^{2+}$ concentration in groundwater samples of Dinajpur district ranged from 0.014 to 1.58 mg $L^{-1}$ (Uddin, 2004) and in Kushtia and Chuadanga districts it varied from trace to 0.18 mg $L^{-1}$ (Azad, 2004). Manganese concentration in groundwater of Pabna sadar upazila varied from 0.008 to 0.403 mg $L^{-1}$ (Arefin, 2002). Zaman *et al*. (2001) carried out a study by collecting waters from different village of Mymensingh district and reported that the concentration of $Mn^{2+}$ ranged from 0.014 to 0.205 mg $L^{-1}$. In Tongi aquifers, the concentration of $Mn^{2+}$ in groundwater samples varied from trace to 0.30 mg $L^{-1}$ (Sen *et al*., 2000). An experiment was conducted by Hoque (2000) to evaluate the water quality in Sherpur upazila under the district of Sherpur. He found that the concentrations of $Mn^{2+}$ in those areas ranged from 0.05 to 0.58 mg $L^{-1}$. Jesmin (2000) found that the respective concentration of $Mn^{2+}$ in water samples collected from Gaibandha qualifier varied from 0.03 to 0.10 mg $L^{-1}$. Nizam (2000) analyzed 20 water samples collected from different sources of two unions of Bhaluka upazila under Mymensingh district and reported that most of the water samples were unsuitable for drinking and livestock consumption due to the presence of manganese ($Mn^{2+}$=0.091-0.347 mg $L^{-1}$). Zaman *et al*. (2000) conducted a study at three upazilas (Bagmara, Mahadebpur and Nachoul) in Barind area and observed that the mean values of Mn in groundwater were 0.11, 0.134 and 0.0478 mg $L^{-1}$, respectively.

The concentration of $Mn^{2+}$ in water of Madhupur Tract was within the range of 0.70 to 0.22 mg $L^{-1}$ (Alamgir *et al*., 1999). The concentration of $Mn^{2+}$ in groundwater of Muktagacha Thana ranged from 0.02 to 0.86µg $L^{-1}$ with the average value of 0.29µg $L^{-1}$ (Hossain and Ahmed, 1999). The concentration of $Mn^{2+}$ in groundwater samples collected from Northern and Eastern Piedmont Plains varied from 0.30 to 0.92 mg $L^{-1}$ and these ionic concentrations were not problematic for irrigating agricultural crops but were also considered as toxicant for drinking and livestock use (Ali, 1999).

Helaluddin (1996) stated that $Mn^{2+}$ content in surface and groundwater varied from trace to 0.70 mg$L^{-1}$. Hahidullah (1995) found that the concentration of $Mn^{2+}$ in groundwater 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 $Mn^{2+}$ within the rangeof 0.01 to 0.07 mg $L^{-1}$ (Mohiuddin, 1995). Quayum (1995) reported that the $Mn^{2+}$ content in groundwater of Gazipur sadar Thana varied from trace to 0.20 mg $L^{-1}$.

From the results of chemical analyses, Razzaque (1995) reported that $Mn^{2+}$content of some surface and groundwater samples of Kalihati and Ghatail Thanaunder Tangail district ranged from 0.01 to 0.07 mg$L^{-1}$. Rahman and Zaman (1995) investigated that the concentration of $Mn^{2+}$ in water samples collected from some villages of Shazadpur under Sirajgonj district ranged from 0.034 to 0.062 mg $L^{-1}$ and their concentrations were far below the toxic level for irrigation.

## 2.7 Copper (Cu)

The concentration of $Cu^{2+}$ collected groundwater samples of Lakshmipur and Noakhali district ranged from 0.02 to 0.20 mg $L^{-1}$ (Uddin, 2005). A study was conducted at 93 different unions of Dinajpur district and found that the concentration of $Cu^{2+}$ within the range of 0.01 to 0.14 mg $L^{-1}$ (Uddin, 2004). The concentration of copper ($Cu^{2+}$) collected groundwater samples of Eastern Surma and Kushiara floodplain and neighbouring regions of

Sylhet division ranged from 0.002 to 0.02 mg $L^{-1}$ (Ashan, 2004) and in Kushtia and Chuadanga districts it varied from trace to 0.05 mg $L^{-1}$ (Azad, 2004).

Jonnalagadda and Nenzou (1996) studied the effect of arsenic rich abandoned mine dumps in Zimbabwe on the adjacent Mature River and subsequently on the Odzi and Saui Rivers, they found that the river water sample next to the mine dumps during the rainy season contained $Cu^{2+}$ 0.057 $mgL^{-1}$. Quddus and Zaman (1996) reported that the concentration of $Cu^{2+}$ in surface and groundwater of some villages in Meherpur sadar varied from trace to 0.1 mg $L^{-1}$. Helaluddin (1996) analyzed 88 ground and surface water samples of Khagrachari district and found the concentration of $Cu^{2+}$ ranged from trace to 0.05 mg $L^{1}$. The content of $Cu^{2+}$ in ground waters of Gazipur sadar Thana varied from trace to 0.05 mg $L^{-1}$ (Quayum, 1995).

Mohiuddin (1995) showed that the collected irrigation water samples of Pangsha Thana of Rajbari district contained $Cu^{2+}$ within the range of 0.01 to 0.06 mg $L^{-1}$. The concentration of $Cu^{2+}$ in ground waters of Phulpur Thana under Mymensingh district was in the range of 0.01 to 0.03 mg $L^{-1}$ (Shahidullah, 1995). The collected surface and ground water contained $Cu^{2+}$within the range of 0.029 to 0.063 mg $L^{-1}$(Rahman, 1993). The river water in Thika area of Kenya was analyzed by Davics *et al*. (1993). They found that $Cu^{2+}$ was within the safety limits for drinking water. Quddus (1993) indicated that the concentration of $Cu^{2+}$ in surface and ground waters of Meherpur sadar Thana varied from trace to0.1 $mgL^{-1}$.

## 2.8 Phosphate ($PO_4^{3-}$)

For determining the quality of groundwater at Dimla upazila in Nilphamari district, Islam *et al*. (2010a). The concentration of $PO_4^{3-}$ in water samples collected from four unions of Sherpur upazila under Bogura district ranged from trace to 2.19 mg $L^{-1}$ (Rahman *et al*., 2007). Phosphate ($PO_4^{3-}$) content of groundwater samples of Lakshmipur and Noakhali district ranged from 0.07 to 0.80 mg $L^{-1}$ (Uddin, 2005). Phosphate content of groundwater samples of Eastern Surma Kushiara floodplain and neighbouring regions of Sylhet division aquifers varied from 0.041 to 12.00 mg $L^{-1}$ (Ahsan, 2004). Uddin (2004) assessed the groundwater quality of Dinajpur district and found that the concentration of $PO_4^{3-}$ ranged from 0.01 to 2.50 $mgL^{-1}$. The concentration of $PO_4^{3-}$ collected groundwater samples of Kushtia and Chuadanga districts ranged from 0.31 to 7.66 mg $L^{-1}$ (Azad, 2004). The concentration of $PO_4^{3-}$ in groundwater of Pabna sadar upazila ranged from trace to 0.19 mg $L^{-1}$ (Arefin, 2002). Islam and Gyananath (2002) observed that groundwater $PO_4^{3-}$ content in

Nanded district in India ranged from 0 to 0.216 mg $L^{-1}$. The concentration of $PO_4^{3-}$ in surface and groundwater collected from Tongi varied from trace to 0.05 mg $L^{-1}$ (Sen *et al*., 2000). Groundwater samples collected from Gaibandha aquifer contained small amount of trace to 1.10 mg $L^{-1}$ of $PO_4^{3-}$ (Jesmin, 2000).

The content of $PO_4^{3-}$ in surface and groundwater samples collected from Bhaluka upazila under Mymensingh district ranged from trace to 0.47 mg $L^{-1}$ (Nizam, 2000). Siddique (2000) assessed the groundwater quality of Atrai upazila under Naogaon district and observed that the content of $PO_4^{3-}$ varied from trace to 2.19 mg $L^{-1}$. Phosphate content of groundwater 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) 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). In Northern and Eastern Piedmont Plains, surface and groundwater samples contained small amount (0.001 to 0.012 mg $L^{-1}$) of $PO_4^{3-}$ (Ali, 1999).

The $PO_4^{3-}$ during both monsoon and winter seasons was 0.02 mg $L^{-1}$in Tube-wells water of vegetable growing area around Kolkata (Mitra and Gupta, 1999). The $PO_4^{3-}$content in waters collected from Narayangonj aquifers varied from 0.005 to 2.12 mg $L^{-1}$ (Sarker, 1997). An experiment was earned out by Zaman and Majid (1995) to evaluate the groundwater pollution at Rajbari district and showed that the $PO_4^{3-}$ concentration in all collected water samples ranged from 0.02to 0.09 mg $L^{-1}$. The $PO_4^{3-}$ content of surface, shallow and deep Tube-wells waters of Meherpur sadar under Meherpur district ranged from 0.12 to 0.32 mg $L^{-1}$ (Quddus and Zaman, 1996).

**2.9 Boron (B)**

The concentration of Boron in water samples collected from four unions of Sherpur upazila under Bogura district ranged from 0.02 to 2.20 mg $L^{-1}$ (Rahman *et al*., 2007). The content of Boron in water samples collected from five unions under Atrai upazila of Naogaon district varied from 0.20 to 0.54 mg $L^{-1}$ (Rahman *et al*., 2006). The concentration of Boron in water samples collected from three districts namely Sherpur, Gaibandha and Naogaon ranged from 0.04 to 0.62 mg $L^{-1}$ (Rahman *et al.*, 2005). Boron content of groundwater of of Lakshmipur and Noakhali district ranged from 0.45 to 1.2 mg $L^{-1}$ (Uddin, 2005). Boron content of groundwater of Eastern Surma Kushiara floodplain and neighbouring regions of Sylhet division ranged from 0.01 to 0.3 mg $L^{-1}$(Ashan, 2004), that of Dinajpur district ranged from

0.10 to 0.58 mg $L^{-1}$ (Uddin, 2004) and of Kushtia and Chuadanga districts varied from trace to 0.1 mg $L^{-1}$ (Azad, 2004).

The content of Boron in water samples collected from different villages of Mymensingh district varied from 0.08 to 0.54 mg $L^{-1}$ (Zaman *et al*., 2001). The concentration of Boron in ground water samples collected from Tongi Thana under the district of Gazipur ranged from 0.006 to 0.067 mg $L^{-1}$ (Sen at al., 2000). Nizam (2000) stated that Boron content in groundwater samples collected from 11 unions of Bhaluka upazila under Madhupur Tract ranged from 0.06 to 1.10 mg $L^{-1}$. Alamgir *et al*. (1999) analyzed groundwater samples of Madhupur Tract and recorded that the concentration of Boron ranged from 0.10 to 0.20 mg$L^{-1}$ and these waters were not problematic for irrigating agricultural crops. Sarker (1997) showed that Boron content of Narayangonj aquifers ranged from 0.06 to 0.62 mg $L^{-1}$. Quddus and Zaman (1996) reported that Boron content in surface and ground waters in some villages of Meherpur sadar under Meherpur district ranged from 0.10 to 0.63 mg $L^{-1}$ that of Shahzadpur Thana under the district of Sirajganj ranged from 0.10 to 0.40 mg $L^{-1}$ and all the waters under test were safe for irrigation (Rahman and Zaman, 1995). Zaman and Mohiuddin (1995) found that Boron content in ground waters of Pangsha Thana under Rajbari district varied from 0.08 to 0.45 mg $L^{-1}$.

Out of the 160 water samples Boron concentration was recorded over 1.50 mg$L^{-1}$ for only 8% samples from the Catoledo Rochamicro region (Costa *et al*., 1995). An investigation was conducted by Quayum (1995) and to evaluate the quality of groundwater collected from Gazipur sadar under Gazipur district and showed that Boron concentration varied from 0.15 to 0.54 mg$L^{-1}$. The content of Boron in water samples collected from Ghalial Thana under Tangail district was within the range of 0.01 to 0.45 mg $L^{-1}$ and all the waters were excellent to good in quality for irrigation usage (Razzaque, 1995). Boron content of different waters used for irrigation in Rajasthan of India varied from 0.238 to 7.66 mg $L^{-1}$ and some water samples were not suitable for irrigation (Mondol, 1964).

**2.10 Arsenic (As)**

The concentration of Arsenic in groundwater of Lakshmipur and Noakhali district ranged from 0.004 to 0.369 mg $L^{-1}$ (Uddin, 2005). The concentration of Arsenicin groundwater of Dinajpur district ranged from 0.006 to 0.509 mg $L^{-1}$ (Uddin, 2004). Azad (2004) reported that Arsenic content in groundwater samples collected from Kushtia and Chuadanga district ranged from 0.02 to 1.1 mg $L^{-1}$. The concentration of Arsenic (As) in groundwater of Eastern Surma Kushiara floodplain and neighbouring regions of Sylhet division varied trace to 0.25 mg $L^{-1}$ (Ahsan, 2004). The concentration of Arsenic (As) in groundwater of Pabna sadar upazila was not detectable (Arefin, 2002).

Zaman *et al*. (2001) analyzed 18 groundwater samples collected from shallow and deep Tube-wells of different villages of Balkan upazila under Mymensingh district and found that only two samples were showed to as test, where the concentration of as in each sample was 0.05 mg $L^{-1}$and were safe for irrigating agricultural crops. Out of the 103 surfaces and groundwater samples collected from Madhupur tract, the content of as fluctuated within the limit of trace to 0.05 mg $L^{-1}$ and among the samples only 3 samples contained 0.05 mg $L^{-1}$ of as (Nizam, 2000). A study was conducted by Zaman (2000) to evaluate the groundwater quality in Barind are and he observed that in 30 water samples collected from Bagmara upazila, as content of only three water samples were 0.05, 0.19 and 0.35 mg $L^{-1}$, respectively. Ali (1999) observed that in Northern and Eastern Piedmont plains arsenic, content of surface and groundwater was deflected in trace amount (0.05 mg$L^{-1}$) and these waters were not toxic to soils and crops.

Arsenic (As) pollution was not deflected in all the waters samples collected from Tongi aquifers because the content of Arsenic (As) was below 0.05 mg $L^{-1}$ as cited by Sen *et al*. (1997). A DPHE/DF1D regional survey showed that in 59 districts of Bangladesh, groundwater was contaminated with as (Shahidullah, 1995).

## 2.11 Sulphate ($SO_4^{2-}$)

The concentration of $SO_4^{2-}$in water samples collected from four unions of Sherpur upazila under Bogura district ranged from 0.14 to 10.30 mg $L^{-1}$ (Rahman *et al*., 2007). The content of $SO_4^{2-}$ in water samples collected from five unions under Atrai upazila of Naogaon district varied from trace to 12.00 mg $L^{-1}$ (Rahman *et al*., 2006). The concentration of sulphate ($SO_4^{2-}$) in groundwater of of Lakshmipur and Noakhali district ranged from 11.17 to 22.91 mg $L^{-1}$ (Uddin, 2005). The concentration of $SO_4^{2-}$in water samples collected from three districts namely Sherpur. Gaibanda and Naogaon ranged from 1.90 to 59.40 mg$L^{-1}$ (Rahman *et al*., 2005). The concentration of $SO_4^{2-}$ in groundwater of Dinajpur district ranged from 0.20 to 21.60 mg $L^{-1}$ (Uddin, 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 sulphate ($SO_4^{2-}$) in Eastern Surma Kushiara floodplain and neighboring region of Sylhet division ranged from 0.01 to 18.00 mg $L^{-1}$ (Ahsan, 2004). Islam and Gyananath (2002) found that the groundwater samples contain $SO_4^{2-}$ in Nanded district in India ranges from 6.8-26.0 mg $L^{-1}$. The concentration of $SO_4^{2-}$ in groundwater of Panba sadar upazila ranged from 0.14 to 5.58 mg $L^{-1}$ (Arefin, 2002).

Sen *et al*. (2000) found that ground water samples in Tonga under the district of Gaspar containedSO$_4^{2-}$within the limit of trace to 11.00 mgL$^{-1}$. In all water samples, $SO_4^{2-}$ content varied from trace to 61.00 meqL$^{-1}$ at Gaibandha aquifers (Jesmin, 2000). Rahman (2000) carried out an experiment for the assessment of water quality in Lower Atrai Basin and stated that $SO_4^{2-}$ concentrations varied from trace to 0.40 meq $L^{-1}$. The contents of $SO_4^{2-}$ in surface and groundwater in some village of Meherpur sadar under Meherpur district varied from trace to 7.20 meq $L^{-1}$ (Quddus and Zaman, 1996).

**2.12 Chloride ($Cl^-$)**

Chloride is an important dissolved inorganic constituent in surface and groundwater. The concentration of Cl varied from 0.2 to 1.05 meq/L in Nilphamari district (Islam *et al*., 2009). The concentration of $Cl^-$in water samples collected from four unions of Sherpur upazila under Bogura district ranged from 0.40 to 1.80 mg $L^{-1}$ (Rahman *et al*., 2007). The contents of $Cl^-$ in water samples collected from five unions under Atrai upazila of Naogaon district varied from trace to 0.40 to 2.20 meq $L^{-1}$ (Rahman *et al*., 2006). The concentration of $Cl^-$in water samples collected from three districts namely Sherpur. Gaibanda and Naogaon ranged from 0.20 to 4.90 meqL$^{-1}$ (Rahman *et al*., 2005). The concentration of Clin groundwater of Lakshmipur and Noakhali district ranged from 2.1 to 48.0 mg $L^{-1}$ (Uddin, 2005). The concentration of $Cl^-$ in groundwater of Eastern Surma Kushiara floodplain and neighbouring region of Sylhet division ranged from 0.40 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 mgL$^{-1}$. Zaman *et al*. (2001) carried out a study by collecting waters from different village of Mymensingh district and reported that the concentration of $Cl^-$ ranged from 0.20 to 0.80 meqL$^{-1}$. The concentration of $Cl^-$ in groundwater of Pabna sadar upszila ranged from 0.80 to 1.40 meq $L^{-1}$ (Arefin, 2002).

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). Nizam (2000) sated that $Cl^-$ content in all groundwater of Madhupur Tract ranged from 0.2 to 2.6 meq $L^{-1}$. Jesmin (2000) found that $Cl^-$ content of all groundwater varied from 0.50 to 7.60 meq $L^{-1}$at Gaibandha aquifers. The content of $Cl^-$ in groundwater of Bagmara, Mohadebpur and Nachoul upazilas in Barind area varied from 0.11 to 4.79, 0.846 to 4.65 and 0.78 to 1.78 meq $L^{-1}$, respectively (Zaman, 2000) and in Muktagacha aquifers it varied from 0.20 to 0.70 meq $L^{-1}$, having the mean value of 0.44 meq $L^{-1}$ (Hossain and Ahmed, 1999).

The quantity of $Cl^-$ in Tube-wells waters at Bikaner district of Rajasthan in India ranged from 3.70 to 44.20 mmol $L^{-1}$ (Lai *et al*., 1998). Anil Sood *et al*.(1998) earned out an experiment on the assessment and management of underground water quality in Talwandi Sabo Tensil of Bathinda distinct of Punjab in India and stated that $Cl^-$ content in irrigation water in that area ranged from 1.00 to 171.70 meq $L^{-1}$. A field study was conducted by Kumar *et al*. (1998) for assessing groundwater quality and salinity build up in irrigated soils of Sikandarabad area of Bulandshahar district of Uttar Pradesh in India as influenced by irrigation with mixed industrial effluent of various industries during June, 1995 and found that $Cl^-$ concentration of hand pump and Tube-wells waters varied from 8.70 to 50.10 and 10.70 to 47.20 meq $L^{-1}$, respectively.

The groundwater of Nachoul Thana under Nowabgonj district contained $Cl^-$within the limit of 0.78 to 1.60 meq $L^{-1}$ (Ali, 1997), in Narayangonj aquifers it fluctuated from 1.00 to 12.80 meq $L^{-1}$(Sarker, 1997), 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). Alvarez *et al*. (1995) stated that irrigation water containing 14 meq $L^{-1}$ adversely affected the fruit yield and quality of Red Spanish pineapple cultivar.

## 2.13 Carbonate ($CO_3^{2-}$) and bicarbonate ($HCO_3^-$)

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). The concentration of carbonate ($CO_3^{2-}$) in groundwater of Lakshmipur and Noakhali district ranged from trace to 45 mg $L^{-1}$ and the concentration of bicarbonate ($HCO_3^-$) ranged from 12 to 356 mg $L^{-1}$ (Uddin, 2005). The concentration of carbonate ($CO_3^{2-}$) in Eastern Surma Kushiara floodplain and neighboring region of Sylhet division was not detectable and the concentration of bicarbonate ($HCO_3^-$) ranged from 8.5 to 569.1 mg $L^{-1}$ (Ahsan, 2004), in Dinajpur district $CO_3^2$varied from 21.97 to 266.05 mg $L^{-1}$ (Uddin, 2004). In Kushtia and Chuadanga districts the amount of $CO_3^{2-}$ in all the groundwater 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 $CO_3^{2-}$ 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 $CO_3^{2-}$ 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 $L^{-1}$. Hoque (2000) reported that in ground water of Old Brahmaputra Flood plain the concentrations of $CO_3^2$and $HCO_3^-$ in surface and groundwater varied from 0.05 to 1.50 meq $L^{-1}$and 0.60 to 3.50 meq $L^{-1}$, respectively and in Gaibandha aquifers $CO_3^{2-}$ content was not within detectable range and $HCO_3^-$ concentration was within the limit of 1.50 of 6.00 mg $L^{-1}$ (Jesmin, 2000).

The concentration of $CO_3^{2-}$ and $HCO_3^-$ of groundwater collected from Bagmara, Mahadebpur and Nachoul aquifers varied from trace to 1.20, 1.0 to 4.40; trace to 1.20, 1.20 to 3.60 and trace to trace, 4.22 to 5.40 meq $L^{-1}$, respectively (Zaman, 2000). Hossain and Ahmed (1999) collecting 25 groundwater samples from Muktagacha aquifer stated that $CO_3^{2-}$ and $HCO_3^-$ contents of those waters varied from 0.10 to 0.30 and 1.00 to 3.58 mg $L^{-1}$, respectively. Lai *et al*. (1998) determined the quality of underground waters of non-command area of Bikaner district Rajasthan, India slated that $CO_3^{2-}$ and $HCO_3$contents were within the range of 1.60 to 7.80 mmol $L^{-1}$. The concentration of $CO_3^2$ and $HCO_3^-$ of groundwater collected from Narayangonj aquifers varied from 0.08 to 1.16 and 0.32 to 6.10 meq$L^{-1}$, respectively (Sarker, 1997).

Ali (1997) assessed the groundwater quality of high Barind Tract and showed that $HCO_3^-$ content of those waters varied from 2.00 to 5.40 meq $L^{-1}$. 66 water samples were collected from 5 different groundwater sources of Tangail district and were analyzed. All the samples contained $HCO_3^-$ and $CO_3^{2-}$ within the range of 0.60 to 0.85 meq $L^{-1}$ (Razzaque, 1995). Zaman and Majid (1995) found that groundwater of Meherpur Sadar under Meherpur district contained $CO_3^{2-}$ and $HCO_3^-$ within the range of 0.04 to 0.04 and 0.80 to 2.52 meq $L^{-1}$, respectively in Pangsha Thana 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).

## 2.14 Sodium Adsorption Ratio (SAR)

An important chemical parameter for judging the degree of suitability of water for irrigation is sodium content or alkali hazard, whice is expressed as the sodium adsorption ratio (SAR). Ground water 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). The computed Sodium Adsorption Ratio (SAR) of groundwater samples collected from four unions of Sherpur upazila under Bogura district ranged from 0.07 to 0.90 (Rahman *et al*., 2007). SAR values of water samples collected from five unions under Atrai upazila of Naogaon district varied from trace to 0.41 to 0.90 (Rahman *et al*., 2006). The computed Sodium Adsorption Ratio (SAR) of groundwater from Eastern Surma Kushiara floodplain and neighboring region of Sylhet division ranged within 0.082 to 35.79 (Ahsan, 2004), that of Dinajpur district ranged from 0.187 to 3.244 (Uddin, 2004), and in Kushtia and Chuadanga district it ranged from 0.08 to 1.19 (Azad, 2004). The computed Sodium Adsorption Ratio (SAR) of groundwater of Lakshmipur and Noakhali district ranged from 0.40 to 4.20 (Uddin, 2005). The SAR of groundwater of Pabna sadar upazila ranged from 0.38 to 1.05 with the mean value of 0.74 (Arefin, 2002). Jesmin (2000) observed that the SAR of groundwater collected from Gaibandha aquifers ranged from 0.29 to 3.28. The SAR of groundwater of Bagmara, Mahadebpur and Nachoul upazilas ranged from 0.73 to 5.05, 0.51 to 3.29 and 0.36 to 1.83, respectively (Zaman, 2000). Nizam (2000) found that SAR values of Bhaluka upazila under the district of Mymensingh ranged from 0.60 to 0.30. Hossain and Ahmed (1999) observed that the SAR of groundwater of Muktagacha Thana under Mymensingh district varied from 0.35 to 4.31.

Anil Sood *et al*. (1998) sated that the SAR of irrigation water of Bathinda district of Punjab in India ranged from 2.30 to 31.30 and showed excellent to poor in quality with respect to SAR. Ali (1997) observed that the SAR of groundwater of Nachoul Thana at high Barind Tract ranged from 0.36 to 2.70 and the waters were categorized as „excellent‟ for irrigation. Sarker (1997) found that the SAR of most of the groundwater of Narayangonj aquifers was of excellent class for irrigation. 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 values of surface and groundwater collected from Shahzadpur Thana under Sirajgonj district varied from 0.56 to 0.85 and waters were classified into low sodium waters, S1 (Rahman and Zaman, 1995). Razzaque (1995) cited that the SAR values of water collected from Kalihati and Ghatail Thanas under the district of Tangail varied from 16.95 to 43.61. SAR values of the irrigation waters of Madhupur under Tangail district were categorized as low alkalinity hazard (S1) (Zaman and Majid, 1995). The SAR of water samples of Gazipur sadar varied from 0.50 to 0.94 as reported by Quayum (1995). Singh and Naran (1984) showed that the seasonal fluctuation of water quality was small at 26 sites in a Tract of the Agra district in North India and maximum SAR was in June, minimum in December and intermediate in February. Reo *et al.*(1982) analyzed 605 water samples used for irrigation collected from five taluka of Bijapur district, Karnataka, India and found high SAR value (>10) in large number of water samples of Bagalkot region.

**2.15 Soluble Sodium Percentage (SSP)**

The SSP value was 9 to 26 percent in the groundwater at Nilphamari district (Islam *et al*., 2009). The computed Soluble Sodium Percentage (SSP) of groundwater samples collected from four unions of Sherpur upazila under Bogura district ranged from 5.30 to 30.50 % (Rahman *et al*., 2007). SSP values of water samples collected from five unions under Atrai upazila of Naogaon district varied from 9.50 to 34.9% (Rahman *et al*., 2006). SSP values of groundwater samples collected from three districts namely Sherpur. Gaibanda and Naogaon ranged from 8.70 to 51.0% (Rahman *et al*., 2005). Soluble sodium percentage (SSP) values in groundwater of Lakshmipur and Noakhali district ranged from 17.03 to 90.92 % (Uddin, 2005). The Soluble Sodium Percentage (SSP) values in groundwater of Eastern Surma Kushiara floodplain and neighboring region of Sylhet division were within the range of 6.43 to 98.61% (Ahsan, 2004) that of Dinajpur district ranged from 11.36 to 81.98% (Uddin, 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). Most water samples were doubtful in khagrachari in Bangladesh (Islam *et al*., 2003). The SSP values of groundwater samples collected from different villages of Mymensingh district varied from 4.54 to 13.17% (Zaman *et al*., 2001). Noam (2000) found that SAP values of 103 surface and groundwater samples collected from 11 unions of Bhaluka upazila under Mymensingh district ranged from 2.38 to 17.41 %. The SSP values of groundwater samples in Gaibandha aquifers ranged from 9.20 to 45.75 % and all water samples under test were excellent, good and permissible classes (Jesmin, 2000).

SSP values of groundwater collected from Bagmara, Mahadebpur and Nachoul upazilas of Barind area varied from 25.53 to 75.61, 21.20 to 79.42 and 17.00 to 51.56%, respectively

(Zaman, 2000). Exactly 25 groundwater samples were collected from the Muktagacha aquifers to evaluate the water quality for irrigation and the computed SSP value ranged from 15.99 to 69.67% showing excellent in quality (Hossain and Ahmed, 1999). Ali (1997) analyzed groundwater of Nachoul upazila at High Barind Tract and found that the SSP of those waters varied from 17.00 to 51.56%. The SSP of groundwater collected from Narayangonj ranged from 6.31 to 91.2% and on the basis of SSP, the water samples of that area were classified as excellent, good and permissible and doubtful. SSP values of hand Tube-wells and surface waters of Matiranga Thana under Khagrachari district ranged from 20.39 to 69.37% (Helaluddin, 1996). Quddus and Zaman (1996) earned out an experiment to assess the quality of groundwater collected from Meheipur sadar under Meherpur district and showed that the SSP of those waters was within the limit of 8.14 to 14.70% and all water were excellent in class. Quayum (1995) found that the values of SSP ranged from 18.31 to 40.95% in groundwater of Gazipur sadar under the district of Gazipur. The SSP of 19 surfaces and groundwater of Shahzadpur Thana under Sirajgonj district were within the limit of 13.18 to 21.93%. Fourteen samples lied under the category of excellent and the rest 5 under good (Rahman and Zaman, 1995).

SSP values of 41 groundwater samples of Phulpur Thana under Mymensingh district ranged from 6.81 to 28.99%, 3 samples were found as excellent and the rest were under good class (Shahidullah, 1995). The SSP of groundwater of Madhupur Thana under Tangail district varied from 2.14 to 31.50% and found that 20 samples were „excellent" and 3 were in „good" classes (Zaman and Majid, 1995). Another study was conducted by Zaman and Mohiuddin (1995) 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.

## 2.16 Residual Sodium Carbonate (RSC)

The values of RSC of groundwater of Dimla upazila was -5.25 to -1.59 meq/L (Islam *et al*., 2010a). Residual Sodium Carbonate (RSC) values of groundwater samples collected from four unions of Sherpur upazila under Bogura district ranged from -1.00 to -0.10 meq $L^{-1}$ (Rahman *et al*., 2007). RSC values of water samples collected from five unions under Atrai upazila of Naogaon district varied from -1.80 to 0.30 meq $L^{-1}$ (Rahman *et al*., 2006).

RSC values of groundwater samples collected from three districts namely Sherpur, Gaibanda and Naogaon ranged from -4.20 to 0.90 (Rahman *et al*., 2005). The Residual Sodium

Carbonate (RSC) values of groundwater 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 groundwater collected from Eastern Surma Kushiara floodplain and neighboring regions of Sylhet division fluctuated between -1.002 to 7.5 meq $L^{-1}$ (Ahsan, 2004). The RSC values of groundwater samples of Dinajpur ranged from -0.01 to 1.48 meq $L^{-1}$(Uddin, 2004) 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 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).

The RSC values of groundwater samplescollected from different villages of Mymensingh district varied from 0.40 to 3.90 meq $L^{-1}$ (Zaman *et al*., 2001). Siddique (2000) reported that in all water samples collected from Lower Atrai Basin, RSC values varied from -1.80 to 0.15 meq $L^{-1}$ and these water samples were rated as suitable and marginal classes. Jesmin (2000) observed that RSC of groundwater collected from Gaibandha aquifers ranged from 0.10 to 0.61 meq $L^{1}$. Nizam (2000) stated that the RSC values of groundwater collected from Madhupur Tract fluctuated between -0.30 to 5.8 meq $L^{-1}$ and these water samples were suitable and unsuitable classes. Sen *et al*. (2000) observed that ground water samples in Tongi aquifers contained RSC within the limit of trace to 11.00 meq $L^{-1}$.

An experiment was conducted by Lai el al.(1998) collecting 173 water samples from Bikaner district of Rajasthan Pradesh in India studied the quality of ground waters for their suitability for irrigation they reported that 75.70, 21.20 and 3.00 per cent samples had RSC of < 2.50, 2.50 to 5.00 and > 5.00 meq$L^{-1}$ respectively. Anil Sood el al.(1998) with underground water collected from the 88 villages of Bathinda district of Punjab Pradesh in India and found that the RSC of those waters ranged from nil to 14.60 meq $L^{-1}$ and 55 percent samples had RSC less than 2.50 meq $L^{-1}$ whereas 33 per cent samples showed RSC more than 5.00 meq $L^{-1}$.They apprehended that the continuous and indiscriminate use of these underground waters were might build up excessive Na in soil solution and exchange complex would lead to drainage problem.

The value of RSC of groundwater 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) and out of 112 water samples, 109 were in suitable and the rest 3 were in marginal class. Ali (1997) found that the RSC of groundwater collected from Nachoul Thana under Nawabgonj district varied from -0.03 to

0.75 meqL$^{-1}$. 25 surface and groundwater samples were collected from some villages of Meherpur sadar under Meherpur district were analysed and RSC value was found to be (0.23-0.93) and were found suitable for irrigation (Quddus and Zaman, 1996). The RSC value of 19 surface and groundwater 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). Zaman and Mohiuddin (1995) carried out an experiment on 15 groundwater of Pangsha Thana under Rajbari district and observed that 14 samples were suitable for irrigation, as RSC values were below 1.25 meq L$^{-1}$ and one sample was found marginal for irrigation with RSC value of 1.34 meq L$^{-1}$. 23 groundwater samples from some villages of Madhupur Thana, Tangail were analyzed by Zaman and Majid (1995). They reported that 22 samples were free from Residual Sodium Carbonate and the rest one sample showed RSC value of 0.38 meq L$^{-1}$.

**2.17 Total Hardness ($H_T$)**

The groundwater samples collected from Dimla, Nilphamari district were ranged from 121 to 266 mg/L and “moderately hard” to “hard “in class (Islam *et al*., 2010a). Total Hardness ($H_T$) values of ground water samples collected from four unions of Sherpur upazila under Bogura district ranged from 129.90 to 259.60 mg L$^{-1}$ (Rahman *et al*., 2007). The Hardness ($H_T$) values of ground water samples collected from five unions under Atrai upazila of Naogaon district varied from 139.6 to 299.5 mg L$^{-1}$ (Rahman *et al*., 2006). The Hardness ($H_T$) values of ground water samples collected from three districts namely Sherpur, Gaibanda and Naogaon ranged from 70.00 to 454.20mgL$^{-1}$ (Rahman *et al*., 2005). The Hardness ($H_T$) of groundwater samples in Lakshmipur and Noakhali district ranged from 29.83 to 217.13 mg L$^{-1}$ (Uddin, 2005). The Hardness ($H_T$) of groundwater samples in Eastern Surma Kushiara floodplain and neighboring regions of Sylhet division fluctuated between 3.71 to 322.35 mg L$^{-1}$ (Ahsan, 2004), that of Dinajpur district ranged from 14.01 to 242.19 mg L$^{-1}$ (Uddin, 2004) and in Kushtia and Chuadanga districts varied from 172.90 to 642.53 mg L$^{-1}$ (Azad, 2004). The Hardness in groundwater of Pabna sadar upazila ranged from 183.08 to 376.72 mg L$^{-1}$ (Arefin, 2002).

The Hardness values of groundwater samples collected from different villages of Mymensingh district varied from 34.97 to 259.52 mg L$^{-1}$ (Zaman *et al*., 2001). Noam (2000) found that the Hardness values of groundwater samples collected from 11unions of Balkan upazila under Madhupur tract ranged from 29.94 to 304.39 mg $L^{-1}$ indicating soft to very hard water in category. Jasmine (2000) found that in 55 groundwater samples collected from Gaibandha aquifers, the hardness of all water samples was within the limit of 109.64 to 459.24 mg $L^{-1}$ showing moderately hard to very hard in quality. Siddique (2000) stated that hardness values of water ranged from 64.90 to 299.49 mg $L^{-1}$ in lower Atrai Basin.

The $H_T$ of groundwater in Nanded district in India ranged from 216 to 648 mg $L^{-1}$ (Islam and Gyananath, 2002). $H_T$ of natural water resulted due to the presence of divalent cations like Ca and Mg (Todd, 1980). Zaman (2000) showed that the $H_T$ of groundwater collected from Bagmara, Mahadebpur and Nachoul upazilas ranged from 79.94 to 279.68, 39.97 to 459.38 and 101.60 to 227.02 mg $L^{-1}$, respectively.

The groundwater samples collected from the different locations of Narayangonj aquifers had the $H_T$ value ranging from 49.00 to 569.60 mg $L^{-1}$ (Sarker, 1997). Out of 112 samples of this study 16 were „soft", 39 were „moderately hard", 45 were „hard" and the rest 12 were in „very hard", classes. The $H_T$ values of groundwater of Nachoul upazila at High Barind Tract ranged from 49.98 to 227.02 mg $L^{-1}$with the average value of 149.69 mg $L^{-1}$ and out of 50 samples, 25 samples were in „hard class" (Ali, 1997). 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.

Zaman and Mohiuddin (1995) performed a research work with 15ground water samples of Pangsha Thana under Rajbari district and found that hardness values ranged from 114.84 to 199.72 mg $L^{-1}$. They also found that 9 samples were moderately hard and 6 samples were hard classes. Quddus and Zaman, (1996) analyzed groundwater samples collected from some villages of Meherpur sadar under Meherpur district and observed that the hardness values were within the limit of 166.47 to 201.38 mg$L^{-1}$. Quayum (1995) revealed that all groundwater samples collected from Gazipur sadar Thana were in soft class. The Hardness ($H_T$) values of groundwater samples ranged from 94.88 to 184.27 mg $L^{-1}$at Phulpur Thana under Mymensingh district and out of the 41 samples, 25 samples were graded as moderately hard and the rest 16 samples were hard in class (Shahidullah, 1995).

### 2.18 Permeability index (PI)

Doneen (1964) envoled a criterion for assessing the suitability of water for irrigation based on a permeability index 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.

### 2.19 Potential salinity (PS)

Doneen (1995) pointed out that the suitability of water for irrigation is not dependent on the concentration of soluble salts. The potential salinity of the water samples range from 4.06 to 9.60 in the adjacent area it varies from 1.47 to 7.82 (Arveti Nagaraju *et al*., 2006).

### 2.20 Kelly's ratio

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

### 2.21 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 3

# MATERIALS AND METHODS

Water quality is an important factor for successfully crop production from agricultural points of view. Water analysis is performed to evaluate the quality of groundwater to assess its suitability for irrigation, drinking, industrial and domestic usages. Water analysis is the most significant aspect of water management irrespective of its utilities. Hence correct analysis is the basic requirement for the assurance of water quality. To be sure about the correctness of the obtained results, the analysis must know about the usual presence of the natural water impurities, their behaviors, and normal concentration levels general order of predomination over one another, basic correlations among the correlative parameters and source to source variations in concentrations. An attempt has been taken to analyze groundwater samples collected from 14 unions of Nageshwari upazilaand the chemical analyses include the estimation of pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS) and major ionic constituents like $Ca^{2+}$, $Mg^{2+}$, $K^{+}$, $Na^{+}$, $P0_4^{3-}$, $SO_4^{2-}$and $HCO_3^-$

## 3.1 Collection and preparation of groundwater samples

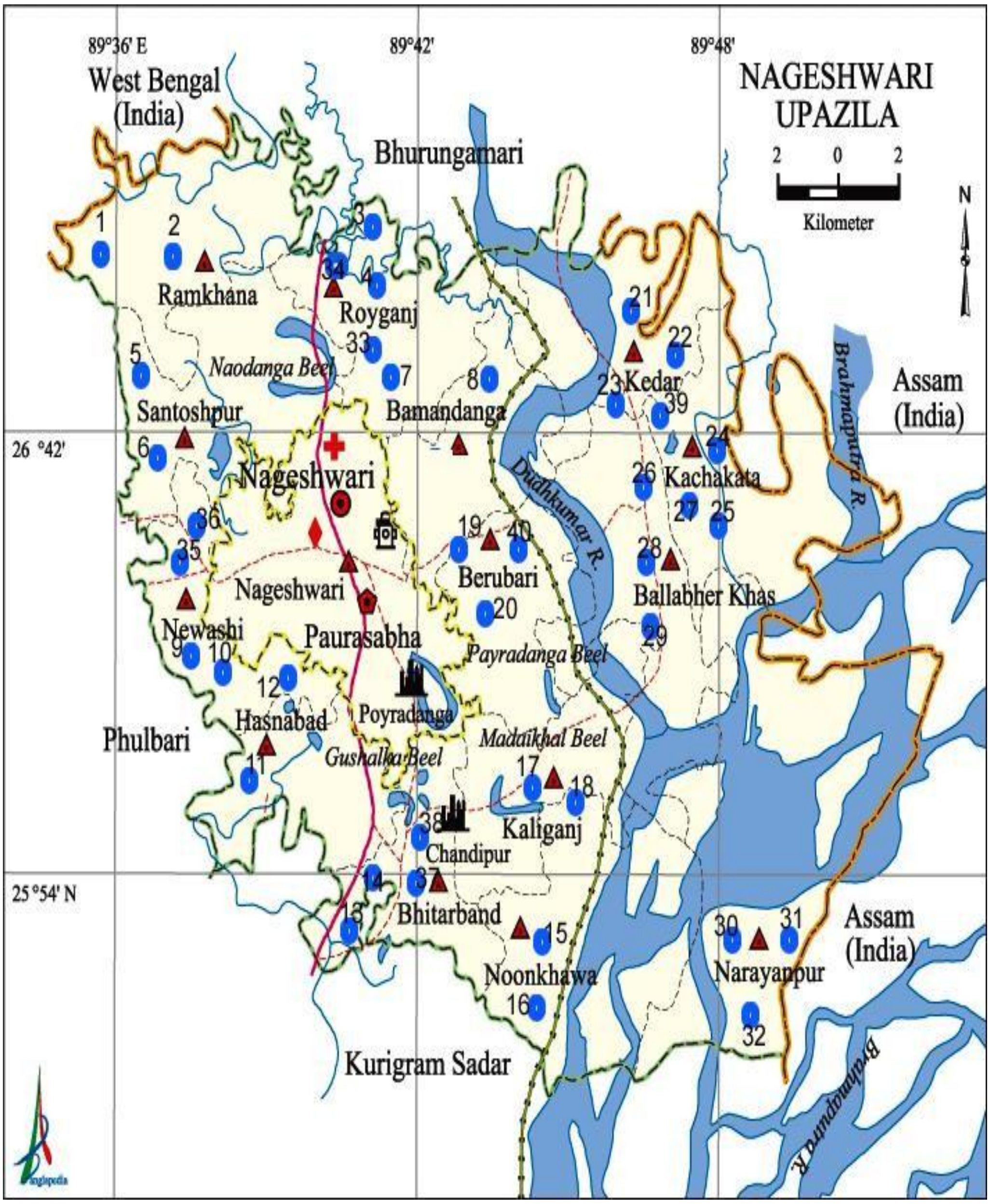
### 3.1.1 Site

Groundwater sampling sites were selected from 14 unions of Nageshwari upazila. Almost all soils of the region have medium inherent fertility with alluvial soils and some of the non-alluvial soils. The water holding capacity of most of these soils is low.

### 3.1.2 Collection of water samples

The ground water samples were collected from several unions of Nageshwari upazila. Water sample exactly fourty samples were randomly collected from shallow tube wells to cover most of the investigated area. These water samples were collected during 12 January 2025 to 26January, 2025. 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 two sources of waters were shown in Figure 3.1 and 3.2. The information of different water samples collected for analysis was mentioned in Table 3.1. Water samples were collected in 1 lit plastic bottles. These bottles were cleaned with hydrochloric acid (1:1) and then rinsed with tap water followed by rising with distilled water.

Before sampling, containers were again rinsed 3 to 4 times with water to be sampled and were sealed immediately to avoid exposure to air. During water sampling, all water samples were colorless, odorless, tasteless and also free from turbidity. Water samples were filtered with filter paper (Whatman No. 1) to remove undesirable solid and suspended materials before analysis. Samples were analyzed in the department of agricultural chemistry laboratory at HSTU, Dinajpur. The samples were analyzed as quickly as possible on arrival at the laboratory.




**Legend: ●Sampling sport**

**Figure 3.1 Map of Nageshwari upazila indicating the sampling sites.**

**Table 3.1: Information regarding water sampling sources**

| Sample no | Source | Union | Village | Depth (Feet) |
|---|---|---|---|---|
| 1 | Shallow Tube | Ramkhana | Nakharganj | 70 |
| 2 | Shallow Tube | Ramkhana | Kolaitary | 60 |
| 3 | Shallow Tube | Rayganj | Sonairkhamar | 70 |
| 4 | Shallow Tube | Rayganj | Pachim | 60 |
| 5 | Shallow Tube | Sontospur | Rayganj | 65 |
| 6 | Shallow Tube | sontospur | Gagla | 65 |
| 7 | Shallow Tube | Bamandanga | Sontospur | 55 |
| 8 | Shallow Tube | Bamandanga | Namahalla | 60 |
| 9 | Shallow Tube | Newashi | Pateshwari | 55 |
| 10 | Shallow Tube | Newashi | Moktarkuti | 65 |
| 11 | Shallow Tube | Hasnabad | Chakerkuti | 70 |
| 12 | Shallow Tube | Hasnabad | Hasnabad | 55 |
| 13 | Shallow Tube | Vitorbond | Alinkipur | 60 |
| 14 | Shallow Tube | Vitorbond | Velamari | 55 |
| 15 | Shallow Tube | Nunkhawa | Raypur | 55 |
| 16 | Shallow Tube | Nunkhawa | Char | 60 |
| 17 | Shallow Tube | Kaliganj | Nunkhawa | 70 |
| 18 | Shallow Tube | Kaliganj | Sarisuri | 55 |
| 19 | Shallow Tube | Berubari | Salmara | 55 |
| 20 | Shallow Tube | Berubari | Kaliganj | 60 |
| 21 | Shallow Tube | Kedar | Char brubari | 65 |
| 22 | Shallow Tube | Kedar | Miravita | 65 |
| 23 | Shallow Tube | Kedar | Teparkuthi | 60 |
| 24 | Shallow Tube | Kochakata | Kedar | 55 |
| 25 | Shallow Tube | Kochakata | Soulomari | 60 |
| 26 | Shallow Tube | Kochakata | Indrogar | 70 |
| 27 | Shallow Tube | Kochakata | Char soulomari | 65 |
| 28 | Shallow Tube | Bolloverkhas | Jinjira balarchar | 70 |
| 29 | Shallow Tube | Bolloverkhas | kochakata | 55 |
| 30 | Shallow Tube | Narayanpur | Bolloverkhas | 55 |
| 31 | Shallow Tube | Narayanpur | Methel | 75 |
| 32 | Shallow Tube | Narayanpur | Konnamoti | 60 |
| 33 | Shallow Tube | Rayganj | kaliganj | 65 |
| 34 | Shallow Tube | Newashi | Purbo | 55 |
| 35 | Shallow Tube | Rayganj | balarhat | 60 |
| 36 | Shallow Tube | Newashi | Hatiyarvita | 65 |
| 37 | Shallow Tube | Vitorbond | Purborayganj | 65 |
| 38 | Shallow Tube | Vitorbond | Bolditary | 55 |
| 39 | Shallow Tube | kedar | Mondoltari | 60 |
| 40 | Shallow Tube | Berubari | Digdari | 60 |

### 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:

3.2.1 Hydrogen ion concentration (pH)

3.2.2 Electrical conductivity (EC)

3.2.3 Total dissolved solids (TDS)

3.2.4 Ionic constituents

3.2.4.1 Calcium ($Ca^{2+}$)

3.2.4.2 Magnesium ($Mg^{2+}$)

3.2.4.3 Potassium ($K^{+}$)

3.2.4.4 Sodium ($Na^{+}$)

3.2.4.5 Bicarbonate ($HCO_3^{-}$)

3.2.4.6 Chloride ($Cl^{-}$)

3.2.4.7 Sulphate ($SO_4^{2-}$)

3.2.4.8 Phosphate ($PO_4^{3-}$)

### 3.2.1 Hydrogen ion concentration (pH)

The textural family of the soil ranges between silty clay to clay loam having highly acidic to the slightly alkaline reaction, and the soils are also slightly poor drained to poorly drained. Groundwater is an important source for irrigation, drinking, and household purposes in the area. Irrigation water can be classified as acid, neutral or alkaline. The degree of acidity or alkalinity of water can be described by a Ph value. The Ph values range from 0 to 14; any value below 7.0 is considered acid, a value of 7.0 is neutral and a pH above 7 is alkaline. The pH of water samples was 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, HSTU, Dinajpur.

### 3.2.2 Electrical Conductivity (EC)

Electrical conductivity (EC) has been used as a criterion to classify the drinking and irrigation waters (Erguvanli and Yuzer 1987). EC values during pre-monsoon and post monsoon range from 719 to 37,300 ls/cm. All samples exceeded the standard EC value (except 48) during pre-monsoon and post-monsoon. The enrichment of EC is liable to semiarid climate, nutrient enrichment, and high evaporation rate. Total dissolved solids (TDS) varied from The Electrical Conductivity of a system mainly 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, HSTU, 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). Total dissolved solids (TDS) varied from 345 to 19,490 mg/l and 422 to 18,755 mg/l in pre- and post monsoon with a mean value of 4829 and 4436 mg/l, respectively. As per TDS classification, 50 % of the wells were of brackish water type (TDS 1000) and 50 % wells were of freshwater (TDS\1000) (Freez and Cherry 1979).

### 3.2.4 Ionic Constituents

#### 3.2.4.1 Calcium ($Ca^{2+}$)

Complexometric titration was used for estimating the calcium from the water samples using disodium ethylene diamine tetra acetate ($Na_2H_2C_{10}H_{12}O_{28}N_2.2H_2O$) as a chelating agent. This analytical method was carried on eliminating possible interfering ions such as $Fe^{3+}$, $Mn^{2+}$, $Cu^{2+}$, $Zn^{2+}$, $Ni^{4+}$ and $PO_4^{3-}$ adding respective masking agents at pH 12 inpresence of calconindicator ($C_{20}H_{13}N_2NaO_5S$). High concentration of $Ca_2$ may be attributed to the landward saline water intrusion due to excessive withdrawal of water, lower river discharge rate and also from rock-weathering. 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).

#### 3.2.4.2 Magnesium ($Mg^{2+}$)

Groundwater during pre-monsoon is subjugated by $Mg_2$, which accounted for 98 % of total cations and anions. Magnesium was analyzed 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 tungastate ($CaWO_4$) 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 ($Fe^{3+}$, $Mn^{2+}$, $Cu^{2+}$, $Zn^{2+}$ and $PO_4^{3-}$) by the EDTA molecule in the reaction after Page *et al*.(1982).

#### 3.2.4.3 Potassium ($K^+$)

Potassium content was determined with the help of a flame emission spectrophotometer by using potassium filter. 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 768 nm is approximately proportional to the concentration of the elements potassium. The percent emission was recorded following the methods outlined by Golterman (1971) and Ghosh *et al*. (1983).

#### 3.2.4.4 Sodium ($Na^+$)

Sodium content was determined from water samples separately with the help of a flame emission spectrophotometer by using sodium 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 is approximately proportional to the concentration of the element sodium. The percent emission was recorded following the methods outlined by Golterman (1971) and Ghosh *et al*. (1983).

### 3.2.4.5 Bicarbonate ($HCO_3^-$)

$HCO_3$-and $CO_3^{2-}$ concentrations also varied within a long range but the anioncontribution (%) showed that first one is dominated in the study area. This might be due to the weathering of carbonate as well as dissolution of the carbonic acids (Kumar *et al*. 2007a,b).Bicarbonate concentration of water samples was 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 color complex at the end of titration. The bicarbonate was estimated titrimetrically after Chopra and Kanwar (1980) and Ghose *et al*.(1983). The reaction is mentioned below:

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

### 3.2.4.6 Chloride ($Cl^-$)

Chloride content of water sample has determinded by agentometric method of titration (Tandon, 1995 and APHA, 1998). Exactly 5 ml of wáter sample has taken in a porcelain dish followed by the addition of 5 to 6 drops of potassium chromate indicator. The test sample was titrated against silver nitrate (0.02N) solution. In neutral or slightly alkaline solution (pH=7-10), silver chloride (AgCl) was quantitatively precipitated before red silver chromate was formed**.** High concentration of Cl- may be attributed to the landward saline water intrusion due to excessive withdrawal of water, lower river discharge rate and also from rock-weathering.

### 3.2.4.11 Sulphate ($SO_4^{2-}$)

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 (HitachiU-2800) after 30 minutes of $BaCl_2$ addition al 425 nm wavelength following the methods of Wolf (1982).

### 3.2.4.12 Phosphate ($PO_4^{3-}$)

All samples were tested by colorimetric method to determine phosphorus. Phosphate was determined colorimetrically 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:

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

**3.3 Evaluation of water quality**

Use of poor water quality can create four types of problem, namely toxicity, water infiltration, salinity and miscellaneous (Ayers and westcot,1985). Whether a ground 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)**

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

**b) Hardness or Total Hardness ($H_T$)**

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

**c) Permeability Index (P.I)**

Permeability Index $$(\mathrm{P.I}) = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} x100$$

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

**e) Potential salinity =$Cl^-$+ $^{SO4}$ 2-/2**

**f) Gibbs ratio i(for anion) =Cl/(Cl + HCO3)**

**g) Gibbs ratio ii (for cation)=Na +K/(Na +K +Ca)**

Where, concentrations of ionic constituents for calculating all parameters in are meq $L^{-1}$ whereas in hardness is mg $L^{-1}$.

### 3.4 Statistical analysis

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

### 3.5 Checking concentration of analysis

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

#### 3.5.1 Anion-cation balance

Anion –cation balance means, the total sum of anion and cation must be balanced, because of all potables of water are electrically neutral. The unit of this term is $meqL^{-1}$. The acceptable percentage limit of this difference is 5-10%. The equation is,

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

# CHAPTER IV

# RESULTS AND DISCUSSION

Chemically and physically accessible, sufficient, safe and affordable water is needed in irrigation, drinking and industrial purposes. Water testing is initially judged the quality and extend of chemical, biological compounds related with soils and crops. So, the quality of water is equal importance to quantity. The chemical analysis of the groundwater samples is presented in Table 4.1. In the study area, major ionic constituents such as $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $K^{+}$, $P0_4^{3-}$, $SO_4^{2-}$, $Cl^{-}$ and $HCO_3^{-}$ were analyzed and these elements were present in variable amounts in the collected groundwater 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 worldwide by the scientists working on water quality. Different leading organizations also follow USEPA criteria such as FAO, UNICEF and USDA etc. The salient features of the experimental findings presented in the foregoing chapter have been described and discussed here in the light and support of relevant available research findings wherever applicable. The concentration of major ions ($Ca^{2+}$, $Mg^{2+}$, $Na^{+}$ and $K^{+}$) has been presented in Table 4.1 where the vertical bar diagrams indicated major ionic concentrations.

The recorded analytical all results have been described and discussed under the following headings:

## 4.1 Water Quality Assessment for irrigation

### 4.1.1 pH

The pH values of water samples that were collected from several unions of Nageshwari upazila. The pH is the indicator of acidity and alkalinity of water. If the pH is below 7.0 then it indicates acidity and above 7.0 it shows alkalinity. The pH of the solution is very important in plant nutrition and an out of range pH can lead to problems. In study area, the pH value of water sample was within the range of 5.88 to 7.15 while the average value was 6.44 (Table 4.2). The pH of water varied from 5.88 to 7.15 and indicated that the water samples were slightly acidic to slightly alkaline in reaction.  Out of 40 samples, 38 samples were below the neutral value □ 7 and were indicates acidic in nature and might be due to the presence of lower concentration of $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$ and $HCO_3^-$.

These 38 water samples would be suitable for acid loving crops. Out of 40 samples, 2 samples under the study showed higher pH values above the neutral value and were slightly alkaline in nature and this might be due to the presence of higher amount of $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$ 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 almost all water samples 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 210 to 1470 µS $cm^{-1}$ with the mean value of 508.875 µS $cm^{-1}$ (Table 4.2). The EC value of 24 samples were less than the mean value and rest 16 samples were higher than the average value out of 40 samples. The highest amount (1470 µS $cm^{-1}$) was recorded from the sample no. 22 and the lowest amount (210 µS $cm^{-1}$) was obtained from the sample no. 2 and 3. According to Willcox (1955) as reported in table no. 4.4 out of 40 samples were excellent for irrigation. According to the Richards (1968) as illustrated in Figure 4.1, all the groundwater samples under test were rated as “medium salinity” ($C_2$). High EC value reflected the higher amount of salt concentration which affect on irrigation water related to salinity hazard (Agarwal *et al*., 1982). Therefore, groundwater 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) of groundwater samples in the investigated area varied from 105 to 730 mg $L^{-1}$ with mean value of 254.125 mg $L^{-1}$ (Table 4.2). Out of the 40 samples, the TDS values of 24 samples were found bellow the mean value and the remaining 16 samples were found above the average value. The highest TDS value (730 mg $L^{-1}$) was detected in a Shallow Tube-wells (sample no. 22) and the lowest TDS value (105 mg $L^{-1}$) was detected in sample no. 2. Sufficient qualities of bicarbonate, sulphate and chloride are of $Ca^{2+}$, $Mg^{2+}$ and $Na^{+}$ caused high TDS values (Karanth, 1994). According to Freeze and Cherry (1979) as reported in table no.4.5, all the groundwater samples 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. The current investigation firmly indicated that the application of these water for irrigation uses would not affected the osmotic pressure of the soil solution and cell sap of the plants hence these waters are suitable for crop production at Nageshwari upazila. Khan (2019) as reported that, the amount of total dissolved solids (TDS) of ground water samples in the investigated area varied from 64 to 343 mg $L^{-1}$ with mean value of 159.58 mg $L^{-1}$.

#### 4.1.4 Ionic constituents

In present study, major ions like $Ca^{2+}$, $Mg^{2+}$, $K^{+}$, $Na^{+}$, $Cl^{-}$ 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 ($Ca^{2+}$)

The concentration of $Ca^{2+}$ was found within the range of 11.77 to 51.23 mg $L^{-1}$ with the mean value of 28.87 mg $L^{-1}$ (Table 4.1). Out of 40 samples, 23 samples were found below the mean value and the rest 17 samples were above the mean value.

The highest concentration (51.23 mg $L^{-1}$) was found samples no. 19. The lowest value (11.77 mg $L^{-1}$) was observed sample no.15. The concentration of $Ca^{2+}$ content in groundwater was largely dependent on the solubility of $CaCO_3$, $CaSO_4$ and rarely on $CaCl_2$ (Karanth, 1994). Irrigation water containing the 20-60 mg$L^{-1}$ $Ca^{2+}$ was normal range and suitable for irrigating crops plants as mentioned in table 4.4. On the basis of $Ca^{2+}$ content, the entire water samples can safely be used for irrigation and would not affect the soils.

##### 4.1.4.2 Magnesium ($Mg^{2+}$)

Groundwater samples were collected from Nageshwari upazila, $Mg^{2+}$ content was found within the range of 2.27 to 34.64 mg $L^{-1}$ with the mean value of 9.44 mg $L^{-1}$ (Table 4.1). Out of 40 samples, about 21 samples were found below the average value and the rest 19 Samples recorded above the mean value. The highest value 34.64 mg $L^{-1}$ of magnesium was found in sample no. 25 and the lowest value 2.27 mg $L^{-1}$ of magnesium was found in sample no. 26. In respect of $Mg^{2+}$ content, the range of 25-35 mg $L^{-1}$ is high and greater than 35 mg $L^{-1}$ is very high as mentioned in table 4.8. The area of this study, most of the groundwater samples were „suitable‟ for irrigation with respect of $Mg^{2+}$ content.

**Table 4.1: Chemical constituents of water collected from Shallow Tube-wells of several unions of Nageshwari Upazila**

| Sample No. | $Ca^{2+}$(mg/L) | $Mg^{2+}$(mg/L) | $Na^{+}$(mg/L) | $K^{+}$(mg/L) |
|---|---|---|---|---|
| 1 | 24.91 | 3.43 | 15.25 | 5.16 |
| 2 | 24.33 | 3.17 | 17.07 | 3.84 |
| 3 | 17.06 | 11.29 | 10.23 | 3.32 |
| 4 | 17.22 | 4.95 | 9.29 | 4.36 |
| 5 | 20.75 | 7.63 | 23.55 | 3.06 |
| 6 | 22.35 | 12.55 | 11.03 | 2.82 |
| 7 | 29.88 | 10.88 | 28.39 | 1.63 |
| 8 | 39.13 | 10.23 | 11.33 | 4.07 |
| 9 | 22.05 | 12.36 | 13.61 | 7.89 |
| 10 | 17.11 | 13.43 | 9.61 | 2.05 |
| 11 | 15.47 | 2.75 | 24.87 | 4.78 |
| 12 | 20.22 | 4.35 | 15.09 | 4.65 |
| 13 | 28.49 | 11.77 | 9.69 | 7.5 |
| 14 | 12.09 | 12.03 | 12.41 | 2.71 |
| 15 | 11.77 | 17.12 | 14.74 | 6.7 |
| 16 | 19.43 | 11.44 | 11.13 | 6.29 |
| 17 | 20.07 | 18.63 | 19.94 | 2.95 |
| 18 | 19.61 | 15.05 | 13.04 | 6.21 |
| 19 | 51.23 | 16.5 | 15.13 | 0.67 |
| 20 | 47.03 | 7.03 | 10.04 | 2.43 |
| 21 | 37.67 | 3.5 | 12.44 | 4.13 |
| 22 | 44.68 | 20.04 | 10.53 | 3.68 |
| 23 | 49.4 | 5.09 | 11.23 | 2.78 |
| 24 | 39.17 | 4.16 | 13.27 | 1.95 |
| 25 | 34.06 | 34.64 | 11.33 | 5.45 |
| 26 | 43.33 | 2.27 | 13.67 | 4.06 |
| 27 | 27.65 | 4.1 | 11.69 | 4.21 |
| 28 | 17.49 | 4.61 | 10.09 | 4.98 |
| 29 | 34.27 | 4.19 | 12.56 | 0.88 |
| 30 | 35.53 | 2.56 | 13.16 | 1.42 |
| 31 | 13.8 | 4.83 | 9.46 | 0.98 |
| 32 | 27.04 | 4 .00 | 9.38 | 3.34 |
| 33 | 36.21 | 4.75 | 13.91 | 4.71 |
| 34 | 43.48 | 8.94 | 11.13 | 6.14 |
| 35 | 38.61 | 14.35 | 13.44 | 2.54 |
| 36 | 22.31 | 4.58 | 11.34 | 0.73 |
| 37 | 36.75 | 12.05 | 9.3 | 1.92 |
| 38 | 24.61 | 4.57 | 10.35 | 2.45 |
| 39 | 45.1 | 12.07 | 12.06 | 2.61 |
| 40 | 23.54 | 16.04 | 10.73 | 4.06 |
| **Min** | **11.77** | **2.27** | **9.29** | **0.67** |
| **Max** | **51.23** | **34.64** | **28.39** | **7.89** |
| **Mean** | **28.8725** | **9.44825** | **13.16275** | **3.65275** |

#### 4.1.4.3 Sodium ($Na^+$)

Table 4.1 showed the $Na^{2+}$ content of collected groundwater samples from Nageshwari upazila. The concentration of $Na^{2+}$ in different water samples were within the range of 9.29 to 28.39 mg $L^{-1}$ and the mean value was 13.16 mg $L^{-1}$. About 62.5% values (25 samples) were below the mean and the remaining 27 % values (14 samples) were above the mean.

The recorded Na content in all the groundwater samples under test was far below this specified limit (Ayers and Westcot, 1985). Hence, as per $Na^{2+}$ 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 were within the range from 0.67 to 7.89 mg $L^{-1}$ with 3.65 mg $L^{-1}$ as mean value (Table 4.1). 50% values (20 samples) were below the mean and 50 % (20 samples) were above the mean value. According to Ayers and Westcot (1985), the acceptable limit of $K^+$ in irrigation water is 2.0 mg $L^{-1}$. The presence of higher quantity of $K^+$ in some groundwater 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 collected ground water samples had no significant influence on water quality for irrigation. The presence of higher K content in the groundwater might have beneficial effect as it acts as an essential nutrient element for plant growth and development.

**Table 4.2: Chemical constituents of water collected from Shallow Tube-wells of several unionsof Nageshwari upazila**

| Sample | pH | EC (µS cm-1) | (Temp.°C) | TDS | $Cl^-$ (mg/L) | $HCO_3^-$ | $SO_4^{2-}$ (mg/L) | $PO_4^{3-}$ |
|---|---|---|---|---|---|---|---|---|
| 2 | 6.89 | 210 | 19.7 | 105 | 0.93 | 58.94 | 3.53 | 1.43 |
| 3 | 6.3 | 210 | 19.7 | 135 | 7.63 | 83.81 | 2.03 | 1.55 |
| 4 | 6.74 | 410 | 19.7 | 205 | 6.07 | 72.05 | 1.73 | 0.17 |
| 5 | 6.45 | 570 | 19.7 | 285 | 3.68 | 87.69 | 10.38 | 0.09 |
| 6 | 6.76 | 650 | 19.7 | 325 | 7.65 | 73.62 | 4.38 | 0.59 |
| 7 | 6.77 | 570 | 19.7 | 280 | 16.45 | 44.04 | 2.13 | 1.67 |
| 8 | 6.67 | 530 | 19.7 | 265 | 21.43 | 71.63 | 2.73 | 1.43 |
| 9 | 6.57 | 640 | 19.7 | 320 | 9.68 | 51.01 | 0.48 | 0.61 |
| 10 | 6.55 | 670 | 19.7 | 330 | 0.59 | 80.83 | 3.23 | 1.05 |
| 11 | 6.64 | 220 | 19.7 | 110 | 6.58 | 30.94 | 1.63 | 1.67 |
| 12 | 6.31 | 245 | 19.7 | 120 | 0.98 | 27.41 | 2.18 | 1.74 |
| 13 | 6.2 | 235 | 19.7 | 115 | 3.48 | 70.82 | 12.78 | 1.02 |
| 14 | 6.24 | 230 | 19.7 | 115 | 7.81 | 60.61 | 2.73 | 1.43 |
| 15 | 6.09 | 675 | 19.7 | 335 | 2.74 | 25.62 | 15.23 | 0.9 |
| 16 | 6.15 | 1090 | 19.7 | 540 | 5.71 | 55.01 | 14.73 | 0.46 |
| 17 | 6.21 | 1260 | 19.7 | 635 | 13.76 | 88.13 | 15.03 | 0.84 |
| 18 | 6.26 | 1345 | 19.7 | 675 | 3.92 | 78.5 | 13.03 | 0.33 |
| 19 | 6.5 | 350 | 19.7 | 180 | 10.05 | 57.5 | 1.58 | 0.99 |
| 20 | 6.44 | 355 | 19.7 | 180 | 11.65 | 29.6 | 1.08 | 1.36 |
| 21 | 6.32 | 240 | 19.7 | 120 | 37.63 | 71.6 | 2.63 | 1.3 |
| 22 | 6.32 | 1470 | 19.7 | 730 | 15.07 | 78.5 | 15.03 | 0.84 |
| 23 | 6.46 | 315 | 19.7 | 160 | 14.42 | 65.78 | 0.88 | 1.11 |
| 24 | 6.33 | 295 | 19.7 | 145 | 11.53 | 50.39 | 1.98 | 1.49 |
| 25 | 6.3 | 265 | 19.7 | 130 | 8.93 | 58.6 | 2.08 | 1.61 |
| 26 | 6.84 | 245 | 19.7 | 125 | 17.92 | 67.19 | 0.18 | 0.23 |
| 27 | 6.48 | 245 | 19.7 | 125 | 12.46 | 43.16 | 0.32 | 0.41 |
| 28 | 6.42 | 250 | 19.7 | 125 | 23.45 | 86.85 | 2.18 | 1.74 |
| 29 | 6.5 | 245 | 19.7 | 125 | 14.64 | 37.73 | 2.23 | 1.8 |
| 30 | 6.24 | 1125 | 19.7 | 560 | 6.08 | 41.53 | 14.98 | 0.78 |
| 31 | 6.61 | 265 | 19.7 | 130 | 13.5 | 29.67 | 0.57 | 0.72 |
| 32 | 7.15 | 270 | 19.7 | 135 | 12.74 | 61.73 | 1.73 | 1.17 |
| 33 | 6.41 | 275 | 19.7 | 135 | 5.71 | 33.33 | 0.08 | 0.11 |
| 34 | 6.38 | 270 | 19.7 | 125 | 17.35 | 72.09 | 1.98 | 1.49 |
| 35 | 6.39 | 275 | 19.7 | 135 | 12.98 | 33.58 | 11.78 | 0.77 |
| 36 | 6 | 645 | 19.7 | 315 | 23.64 | 20.23 | 7.98 | 0.57 |
| 37 | 6.02 | 1275 | 19.7 | 640 | 13.67 | 71.28 | 0.58 | 0.73 |
| 38 | 5.88 | 240 | 19.7 | 115 | 15.74 | 34.24 | 7.28 | 0.13 |
| 39 | 6.42 | 625 | 19.7 | 310 | 23.76 | 83.34 | 15.58 | 0.53 |
| 40 | 6.34 | 810 | 19.7 | 405 | 11.89 | 77.63 | 8.83 | 0.7 |
| Min | 5.88 | 210 | 19.7 | 105 | 0.47 | 20.23 | 0.08 | 0.09 |
| Max | 7.15 | 1470 | 19.7 | 730 | 37.63 | 88.13 | 15.58 | 1.8 |
| Mean | 6.44 | 508.875 | 19.7 | 254.1 | 11.3593 | 57.82 | 5.242 | 0.944 |

#### 4.1.4.5 Chloride ($Cl^-$)

Table 4.2 showed the $Cl^-$content of collected groundwater samples from Nageshwari upazila. In all the groundwater samples, $Cl^-$ content varied from 0.47 to 37.63 mg $L^{-1}$ with the mean value of 11.36 mg $L^{-1}$ (Table 4.2). Out of 40 samples, 47.5% (19 samples) were less than the average value and the rest 52.5% (21 samples) were greater than that of the average value. According to Ayers and Westcot (1985), the acceptable limit of $Cl^-$ for irrigation water is 4.0 meq $L^{-1}$. 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.

#### 4.1.4.6 Sulphate ($SO_4^{2-}$)

Table 4.2 showed the $SO_4^{2-}$ content of collected groundwater samples from Nageshwari upazila. In all the groundwater samples, sulphate content varied from 0.08 to 15.58 mg $L^1$ with the mean value of 5.24 mg $L^{-1}$ (Table 4.2). Out of 40 samples, 67% (27 samples) were less than the average value and the rest 33% (13 samples) were greater than that of the average value. According to Ayers and Westcot (1985), the acceptable limit of $SO_4^{2-}$ for irrigation water is less than 20 mg $L^{-1}$. On the basis of this limit, all the water samples under investigation were not problematic for irrigation without any toxic effect on soils and crops grown in the area of this study. Khan (2019) as reported that, the ground waters, sulphate content varied from 0 to 11.72 mg $L^{-1}$ with the mean value of 1.97 mg $L^{-1}$.

#### 4.1.4.7 Phosphate ($PO_4^{3-}$)

Table 4.2 showed the $P0_4^{3-}$ content of collected groundwater samples collected from Nageshwari upazila. The phosphorus content of all collected groundwater samples varied from 0.09 to 1.80 mg $L^{-1}$ with the mean value of 0.94 mg $L^{-1}$ (Table 4.2). Out of the 40 samples, about 52% samples (21 samples) were less than the mean value and the rest 48% samples (19 samples) were higher then the mean value. According to Ayers and Westcot (1985), the acceptable limit of $PO_4^{3-}$ for irrigation water is 0-2.0 mg $L^{-1}$. The status of $PO_4^{3-}$ of all tested groundwater samples were found within the recommended limit. Khan (2019) as reported that, the phosphorus content of all collected ground waters varied from 0 to .02 mg $L^{-1}$ with the mean value of 0.01 mg $L^{-1}$.

#### 4.1.4.8 Bicarbonate ($HCO_3^-$)

Table 4.2 showed the $HCO_3^-$content of collected groundwater samples from Nageshwari upazila. The concentration of $HCO_3^-$ in water samples was within the range of 20.23 to 88.13 mg $L^{-1}$ and the mean value was 57.81 mg $L^{-1}$ (Table 4.2). Out of 40 samples, 45% (18 samples) were below the mean value and rest 55% (22 samples) were above the mean value. According to Ayers and Westcot (1985), the acceptable limit of $HCO_3^-$ for irrigation water is 1.5 meq$L^{-1}$. In respect of $HCO_3^-$ content, all groundwater samples were suitable for irrigation because $HCO_3^-$ content were within the recommended limit as mentioned in table 4.5. Khan (2019) as reported that, the concentration of $HCO_3$ in water samples was within the range of 0.8 to 3.6 mg $L^{-1}$ and the mean value was 1.69 mg $L^{-1}$.

## 4.2 Groundwater Quality Determining Indices

### 4.2.1 Sodium Adsorption Ratio (SAR)

Table 4.3 showed the computed SAR of collected groundwater samples from Nageshwari upazila. The computed Sodium Adsorption Ratio (SAR) of groundwater samples was within the range of 0.26 to 1.14 meq/L with average value of 0.44 meq/L (Table 4.3). The 75% samples (30 samples) were found below the average value and the rest 25% samples (10 samples) were more than the average value (>0.44). On the basis of SAR, Todd (1980) categorized irrigation waters into 4 groups as shown in Table 4.6. Considering this classification, all the groundwater samples were excellent in irrigation. The present investigation expressed that a good proportion of $Ca^{2+}$ and $Mg^{2+}$ existed in water samples which was suitable for good structure and tilth condition of soil also would improve the soil permeability. The irrigation water with SAR less than 1 might not be harmful for agricultural crops (Todd, 1980). All the groundwater samples used for irrigation were also classified on the basis of alkalinity hazard as diagrammatically in Figure 4.1 (Richards, 1968). According to this classification, all samples were rated as “low” alkalinity hazard (C1SI) class for irrigation as per SAR (Figure 4.1).

**Table 4.3: Evaluation of water quality of water samples**

| Sample No. | SAR | SSP | PI | PS | Hardness | Gibbs Ratio(A) | Gibbs Ratio(C) | Kelly's Ratio |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.56 | 28.5 | 70.03 | 0.02 | 76.34 | 0.02 | 0.39 | 0.43 |
| 2 | 0.64 | 31.97 | 77.61 | 0.06 | 73.82 | 0.03 | 0.41 | 0.5 |
| 3 | 0.39 | 19.14 | 72.23 | 0.24 | 88.94 | 0.14 | 0.38 | 0.25 |
| 4 | 0.39 | 22.57 | 88.87 | 0.19 | 63.35 | 0.13 | 0.37 | 0.32 |
| 5 | 0.88 | 36.89 | 82.41 | 0.21 | 83.16 | 0.07 | 0.52 | 0.61 |
| 6 | 0.37 | 17.66 | 59.71 | 0.26 | 107.33 | 0.15 | 0.33 | 0.22 |
| 7 | 0.88 | 33.57 | 57.33 | 0.49 | 119.31 | 0.39 | 0.46 | 0.51 |
| 8 | 0.32 | 14.46 | 47.74 | 0.64 | 139.77 | 0.34 | 0.23 | 0.18 |
| 9 | 0.47 | 20.22 | 55.29 | 0.28 | 105.8 | 0.25 | 0.42 | 0.28 |
| 10 | 0.35 | 17.09 | 65.58 | 0.05 | 97.84 | 0.01 | 0.35 | 0.21 |
| 11 | 1.15 | 49 | 86.06 | 0.2 | 49.95 | 0.27 | 0.61 | 1.08 |
| 12 | 0.6 | 30.53 | 65.35 | 0.05 | 68.39 | 0.06 | 0.43 | 0.48 |
| 13 | 0.3 | 13.96 | 53.02 | 0.23 | 119.48 | 0.08 | 0.3 | 0.18 |
| 14 | 0.51 | 24.35 | 71.57 | 0.25 | 79.55 | 0.18 | 0.5 | 0.34 |
| 15 | 0.56 | 22.66 | 48.53 | 0.24 | 99.62 | 0.16 | 0.58 | 0.32 |
| 16 | 0.4 | 18.83 | 59.51 | 0.32 | 95.48 | 0.15 | 0.4 | 0.25 |
| 17 | 0.65 | 24.78 | 60.44 | 0.55 | 126.56 | 0.21 | 0.48 | 0.34 |
| 18 | 0.45 | 19.15 | 60.73 | 0.25 | 110.73 | 0.08 | 0.43 | 0.25 |
| 19 | 0.36 | 14.26 | 35.45 | 0.3 | 195.73 | 0.23 | 0.21 | 0.17 |
| 20 | 0.27 | 12.7 | 33.59 | 0.34 | 146.4 | 0.41 | 0.18 | 0.15 |
| 21 | 0.38 | 19.17 | 59.8 | 1.1 | 108.53 | 0.48 | 0.26 | 0.25 |
| 22 | 0.26 | 10.27 | 36.5 | 0.59 | 193.86 | 0.25 | 0.2 | 0.12 |
| 23 | 0.3 | 14.14 | 45.14 | 0.42 | 144.37 | 0.28 | 0.18 | 0.17 |
| 24 | 0.4 | 19.68 | 51.55 | 0.35 | 114.98 | 0.29 | 0.24 | 0.25 |
| 25 | 0.28 | 9.43 | 28.98 | 0.28 | 227.17 | 0.21 | 0.27 | 0.11 |
| 26 | 0.4 | 19.46 | 55.72 | 0.51 | 117.63 | 0.32 | 0.24 | 0.25 |
| 27 | 0.41 | 21.72 | 60.45 | 0.36 | 85.94 | 0.33 | 0.31 | 0.29 |
| 28 | 0.42 | 24.04 | 96.14 | 0.69 | 62.63 | 0.32 | 0.39 | 0.35 |
| 29 | 0.4 | 20.75 | 51.08 | 0.44 | 102.85 | 0.4 | 0.25 | 0.26 |
| 30 | 0.42 | 22.02 | 54.54 | 0.33 | 99.32 | 0.2 | 0.26 | 0.29 |
| 31 | 0.44 | 26.9 | 73.73 | 0.39 | 54.3 | 0.44 | 0.39 | 0.38 |
| 32 | 0.33 | 18.72 | 67.54 | 0.38 | 84 | 0.26 | 0.27 | 0.24 |
| 33 | 0.43 | 20.63 | 47.81 | 0.16 | 110 | 0.23 | 0.29 | 0.27 |
| 34 | 0.3 | 13.59 | 46.17 | 0.52 | 145.35 | 0.3 | 0.23 | 0.17 |
| 35 | 0.37 | 15.48 | 35.74 | 0.49 | 155.36 | 0.4 | 0.25 | 0.19 |
| 36 | 0.43 | 24.54 | 53.71 | 0.76 | 74.55 | 0.67 | 0.31 | 0.33 |
| 37 | 0.26 | 12.27 | 45.76 | 0.4 | 141.28 | 0.25 | 0.2 | 0.14 |
| 38 | 0.38 | 21.18 | 58.18 | 0.53 | 80.26 | 0.44 | 0.29 | 0.28 |
| 39 | 0.32 | 13.61 | 44.73 | 0.84 | 162.24 | 0.33 | 0.21 | 0.16 |
| 40 | 0.34 | 15.13 | 53.51 | 0.43 | 124.61 | 0.21 | 0.33 | 0.19 |
| **Min** | 0.26 | 9.43 | 28.98 | 0.02 | 49.95 | 0.01 | 0.18 | 0.11 |
| **Max** | 1.15 | 49 | 96.14 | 1.1 | 227.17 | 0.67 | 0.61 | 1.08 |
| **Mean** | 0.44 | 20.88 | 57.95 | 0.38 | 110.92 | 0.25 | 0.33 | 0.29 |
| **Std** | 0.18 | 7.77 | 15.36 | 0.22 | 39.45 | 0.14 | 0.11 | 0.17 |

### 4.2.2 Soluble Sodium Percentage (SSP)

Table 4.3 showed the computed SSP of collected groundwater samples from Nageshwari upazila. The soluble Sodium Percentage (SSP) of all 40 water samples varied from 9.43 to 49%. The obtained mean value was 20.86 (Table 4.3). About 60% (24 samples) values were below the mean and 40% (16 samples) were above the mean value. The standard deviation and co-efficient of variation were 7.77 respectively. According to the water classification proposed by Wilcox (1955), 21 collected water samples were classified as "excellent",18 samples were classified as "good" and 1 sample was classified as "permissible" reported in Table 4.4. In the study area, groundwater samples might safely be applied for irrigating agricultural crops.

### 4.2.3 Total Hardness ($H_T$)

Table 4.3 showed the computed $H_T$ of collected groundwater samples from Nageshwari upazila. The Total Hardness ($H_T$) of water samples was within the range of 49.95 to 227.174 mg $L^{-1}$ with a mean value of 110.919 mg $L^{-1}$(Table 4.3). The standard deviation and Coefficient of variance 39.44 respectively. About 60% values (24 samples) were found below the mean and 40% (16 samples) were above the mean value. Sawyer and McCarty (1967) classified irrigation water into 4 classes based on Hardness as mentioned in Appendix IV. According to this classification, 7 samples were soft, 28 samples were moderately hard and 5 sample were hard. Hardness resulted due to presence of appreciable amount of divalent cations like $Ca^{2+}$ and $Mg^{2+}$ (Todd, 1980).

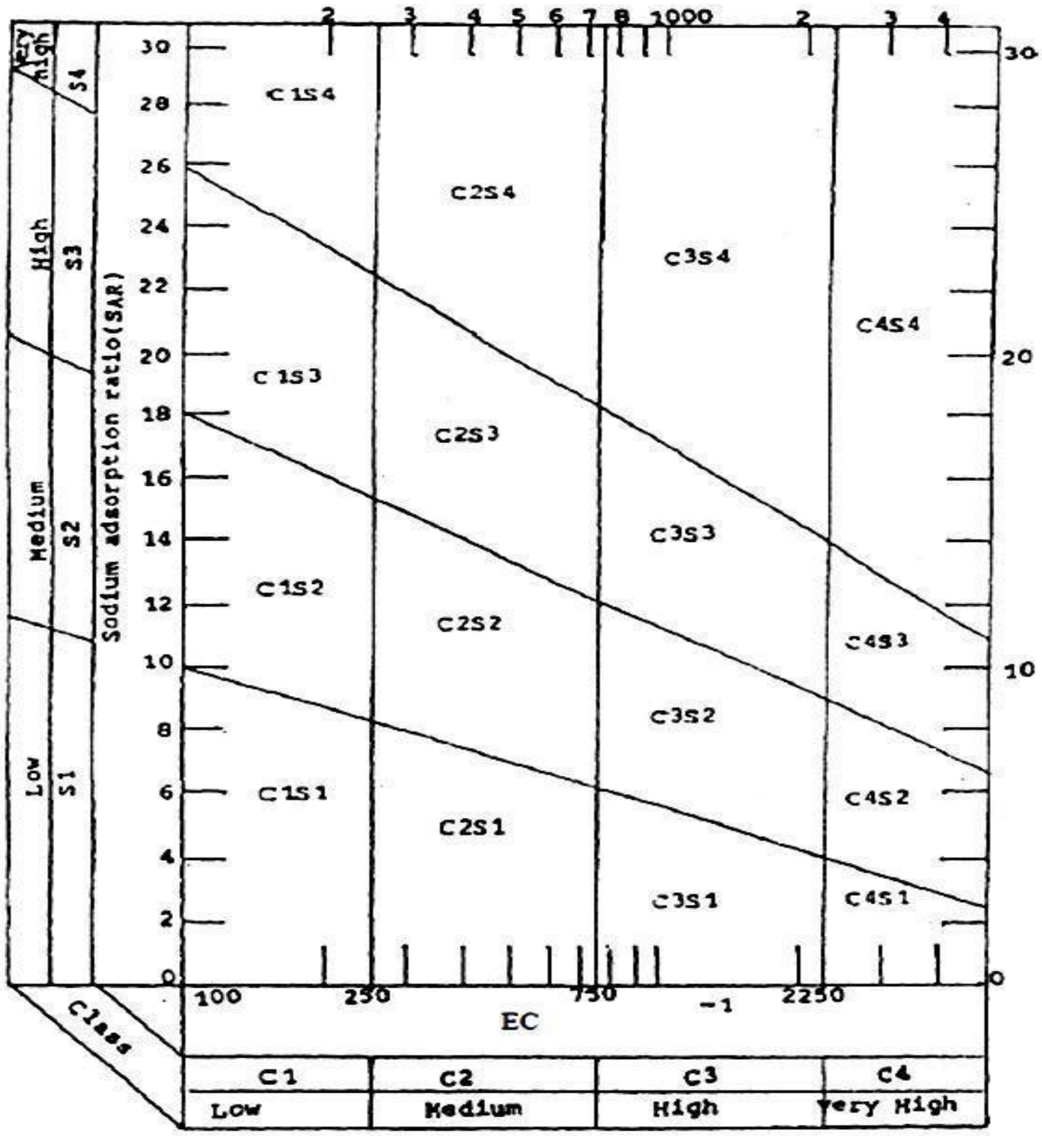



**Figure 4.1: Diagram for classification of irrigation waters (Richards, 1968)**

### 4.2.4 Permeability Index and Potential Salinity

The range of the value of Permeability Index (PI) for all water samples varied from 28.97 to 96.14 (Table 4.3). The average value of this term was 57.94 (Table 4.3). The values of 19 samples were above from the mean value and the rest 21 samples were below from the mean value. Potential Salinity was varied from 0.015 to 1.103 and mean value was 0.379. The values of 17 samples were above from mean value and 22 samples were below from the mean value. Permeability Problem occurs when normal infiltration rate of soil is appreciably reduced and hinders moisture supply to crops which is responsible for two most water quality factors as salinity of water and its sodium content relative to calcium and magnesium. Highly saline water increases the infiltration rate. Relative proportions of other different cations or balance of some cations and anions defined by SAR, SSP, KR, MAR, TH and RSBC etc. also the indicators of permeability problem.

### 4.2.5 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 meq $L^{-1}$. Kelly‟s Ratio is used to find whether groundwater is suitable for irrigation or not. Sodium measured against calcium and magnesium was considered by Kelly (1951) for calculating Kelly‟s Ratio. Groundwater having Kelly‟s Ratio more than one (1) is generally considered as unfit for irrigation. The Kelly‟s ratio for all water samples were ranged from 0.11 to 1.08 with the mean value 0.29 (Table 4.3). Therefore, according to Kelly‟s Ratio, most of the water samples were suitable for irrigation.

**Table 4.4: Guidelines for nutrient concentrations in irrigation water (mg$L^{-1}$)**

| **Macronutrient** | **Low** | **Normal** | **High** | **Very High** |
|---|---|---|---|---|
| Phosphorus | <0.01 | 0.1-0.4 | 0.4-0.8 | >0.8 |
| Potassium | <5 | 5-20 | 20-30 | >30 |
| Calcium | <20 | 20-60 | 60-80 | >80 |
| Magnesium | <10 | 10-25 | 25-35 | >35 |
| Sulfur | <10 | 10-30 | 30-60 | >60 |
| Micronutrient | Acceptable range | | Suggested maximum concentration | |
| Iron | 2.4-4.0 | | 5.0 | |
| Manganese | <0.2 | | 0.2 | |
| Copper | <0.2 | | 0.2 | |
| Zinc | <0.3 | | 2.0 | |

Guidelines based on the suggestions of Duncan, R.R., R.N. Carrow, and M. Huck. 2000. Understanding Water Quality and Guidelines to Management. USGA Green Section Record. September-October, PP.14-24.

**Table 4.5: Guidelines for nutrient concentrations in irrigation water ($mgL^{-1}$)**

| Elements | Symbol | For waters used continuously on all soils |
|---|---|---|
| Aluminium | Al | 5.00 mg $L^{-1}$ |
| Arsenic | As | 0.10 mg $L^{-1}$ |
| Berylium | Be | 0.10 mg $L^{-1}$ |
| Boron | B | <0.75 mg $L^{-1}$ |
| Bicarbonate | HCO3 | 1.50 meq $L^{-1}$ |
| Cadmium | Cd | 0.01 mg $L^{-1}$ |
| Carbonate | $CO_3$ | 0.10 meq $L^{-1}$ |
| Chromium | Cr | 0.10 mg $L^{-1}$ |
| Chloride | Cl | 4.0 meq $L^{-1}$ |
| Cobalt | Co | 0.05 mg $L^{-1}$ |
| Copper | Cu | 0.20 mg $L^{-1}$ |
| Fluoride | F | 1.00 mg $L^{-1}$ |
| Iron | Fe | 5.00 mg $L^{-1}$ |
| Lead | Pb | 5.00 mg $L^{-1}$ |
| Manganese | Mn | 0.20 mg $L^{-1}$ |
| Molybdenum | Mo | 0.01 mg $L^{-1}$ |
| Phosphate phosphorus | $PO_4$-P | 0-2.0 mg $L^{-1}$ |
| Nickel | Ni | 0.20 mg $L^{-1}$ |
| Potassium | K | 0-2.0 mg $L^{-1}$ |
| Selenium | Se | 0.02 mg $L^{-1}$ |
| Sulphate | $SO_4$ | 0-20 mg $L^{-1}$ |

Source: Ayers, R.S. and Westcot, D.W. 1976. Water Quality for Agriculture, FAO Irrigation and Drainage Paper 29, p.81.

**Table 4.6: Quality classification and suitability assessment of water samples for irrigation**

| Sample No. | EC | TDS | SAR | SSP | HT |
|---|---|---|---|---|---|
| 1 | Ex. | Fre | Ex. | Good | Moderate |
| 2 | Ex. | Fre | Ex. | Good | Soft |
| 3 | Ex. | Fre | Ex. | Ex. | Moderate |
| 4 | Good | Fre | Ex. | Good | Soft |
| 5 | Good | Fre | Ex. | Good | Moderate |
| 6 | Good | Fre | Ex. | Ex. | Moderate |
| 7 | Good | Fre | Ex. | Good | Moderate |
| 8 | Good | Fre | Ex. | Ex. | Moderate |
| 9 | Good | Fre | Ex. | Good | Moderate |
| 10 | Good | Fre | Ex. | Ex. | Moderate |
| 11 | Ex. | Fre | Ex. | Permi. | Soft |
| 12 | Ex. | Fre | Ex. | Good | Soft |
| 13 | Ex. | Fre | Ex. | Ex. | Moderate |
| 14 | Ex. | Fre | Ex. | Good | Moderate |
| 15 | Good | Fre | Ex. | Good | Moderate |
| 16 | Permi. | Fre | Ex. | Ex. | Moderate |
| 17 | Permi. | Fre | Ex. | Good | Moderate |
| 18 | Permi. | Fre | Ex. | Ex. | Moderate |
| 19 | Good | Fre | Ex. | Ex. | Hard |
| 20 | Good | Fre | Ex. | Ex. | Moderate |
| 21 | Ex. | Fre | Ex. | Ex. | Moderate |
| 22 | Permi. | Fre | Ex. | Ex. | Hard |
| 23 | Good | Fre | Ex. | Ex. | Moderate |
| 24 | Good | Fre | Ex. | Ex. | Moderate |
| 25 | Good | Fre | Ex. | Ex. | Hard |
| 26 | Ex. | Fre | Ex. | Ex. | Moderate |
| 27 | Ex. | Fre | Ex. | Good | Moderate |
| 28 | Good | Fre | Ex. | Good | Soft |
| 29 | Ex. | Fre | Ex. | Good | Moderate |
| 30 | Permi. | Fre | Ex. | Good | Moderate |
| 31 | Good | Fre | Ex. | Good | Soft |
| 32 | Good | Fre | Ex. | Ex. | Moderate |
| 33 | Good | Fre | Ex. | Good | Moderate |
| 34 | Good | Fre | Ex. | Ex. | Moderate |
| 35 | Good | Fre | Ex. | Ex. | Hard |
| 36 | Good | Fre | Ex. | Good | Soft |
| 37 | Permi. | Fre | Ex. | Ex. | Moderate |
| 38 | Ex. | Fre | Ex. | Good | Moderate |
| 39 | Good | Fre | Ex. | Ex. | Hard |
| 40 | Permi. | Fre | Ex. | Ex. | Moderate |

***Note: Ex=Excellent, Fre=Fresh**

## 4.3 Water quality rating and suitability of groundwater samples for irrigation usage

The pH value of water sample was within the range of 6.97 to 7.05 while the average value was 7.02 (Table 4.2). Out of 40 samples, the pH of 22 samples was varied from 6.97 to 7.02 and the rest 18 samples were varied from 7.02 to 7.05. The pH of water varied from 6.97 to 7.05 and indicated that the waters were slightly acidic to slightly alkaline. Out of 40 samples, 22 samples were below the mean value and were slightly acidic in nature and might be due to the presence of lower concentration of $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$ and $HCO_3^{-}$. These 22 water samples would be suitable for acid loving crops. The remaining 18 samples under the study showed higher pH values above the mean value and were slightly acidic and slightly alkaline in nature and this might be due to the presence of higher amount of $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$ and $HCO_3^{-}$. Almost all the water samples were within the recommended value. 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 dolomite limestone put into the substance and substrate component themselves, 2) the alkalinity of irrigation water, 3) the acidity or basically of the fertilizer used during crop production.

The amount of Total Dissolved Solids (TDS) of groundwater samples in the investigated area varied from 60.18 to 240.18 mg $L^{-1}$ with mean value of 96.54 mg $L^{-1}$(Table 4.2). According to Carroll (1962) and Freeze and Cherry (1979), water quality divided into four groups on the basis of TDS (Appendix II). By as per this suitability rating, all the collected groundwater samples were considered as fresh for irrigation. Because TDS values of all water samples were less than 1000 mg $L^{-1}$ (Appendix II).

Table 4.6 showed that Sodium Adsorption Ratio (SAR) for all groundwater samples were excellent for irrigation indicated in depicted in Appendix III.

Sawer and McCarty (1967) classified water into four groups on the basis of Hardness (Appendix IV). In the present study, 16 samples were soft, and 24 samples were moderately hard for irrigation usage.

### 4.4 Salient Features of the Present Investigation

It is evident from the above discussion that out of the 40 samples, all the groundwater samples under analyzed were found "suitable" for irrigation. Considering all the criteria of suitability evaluation, all the tested water samples were safe for irrigation usage but it should be monitored regularly for better water management for maintaining the crop and soil health. Some water samples contained appreciable amount of $Ca^{2+}$ and $Mg^{2+}$. Those water samples would be beneficial for acidic soil and crop.

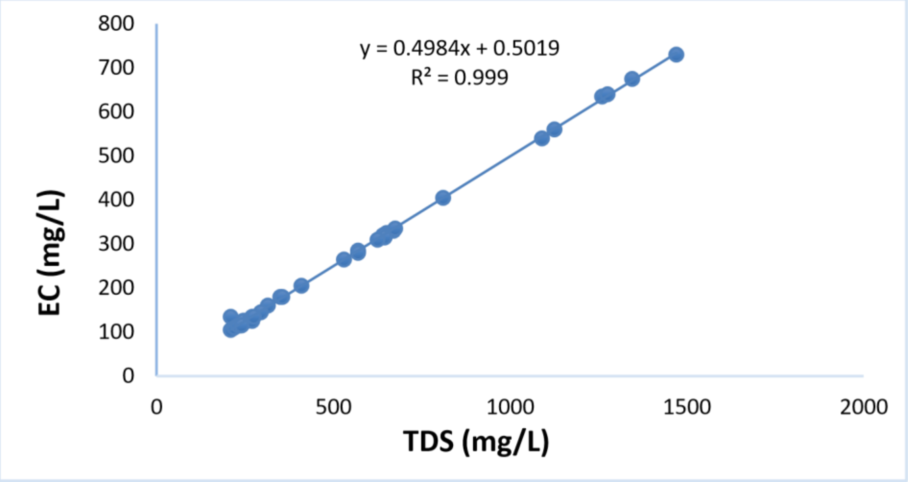



**Figure 4.2 Relationship between EC and TDS**

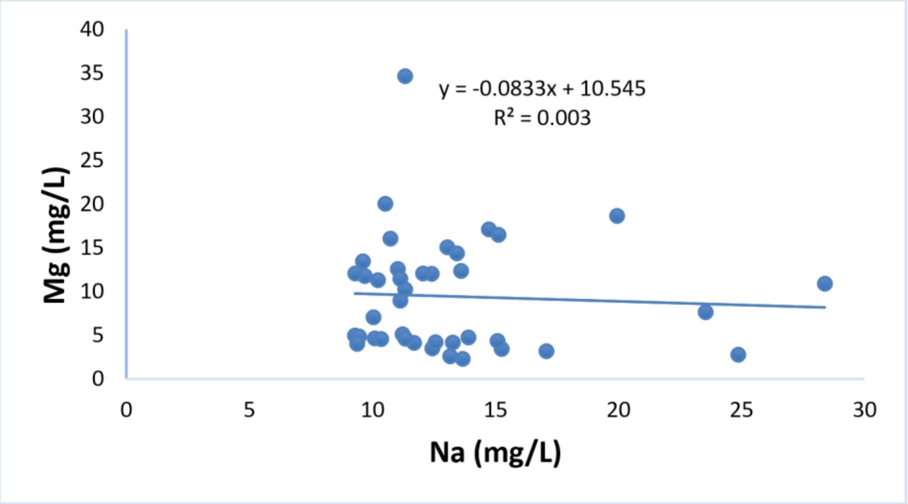



**Figure 4.3 Relationship between Na and Mg**

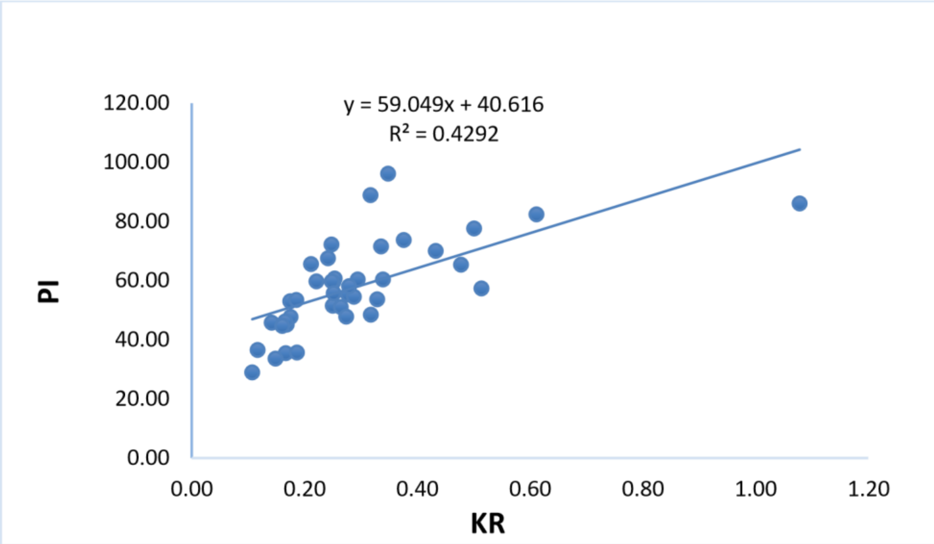



**Figure 4.4 Relationship between Permeability Index and Kelly's Ratio**

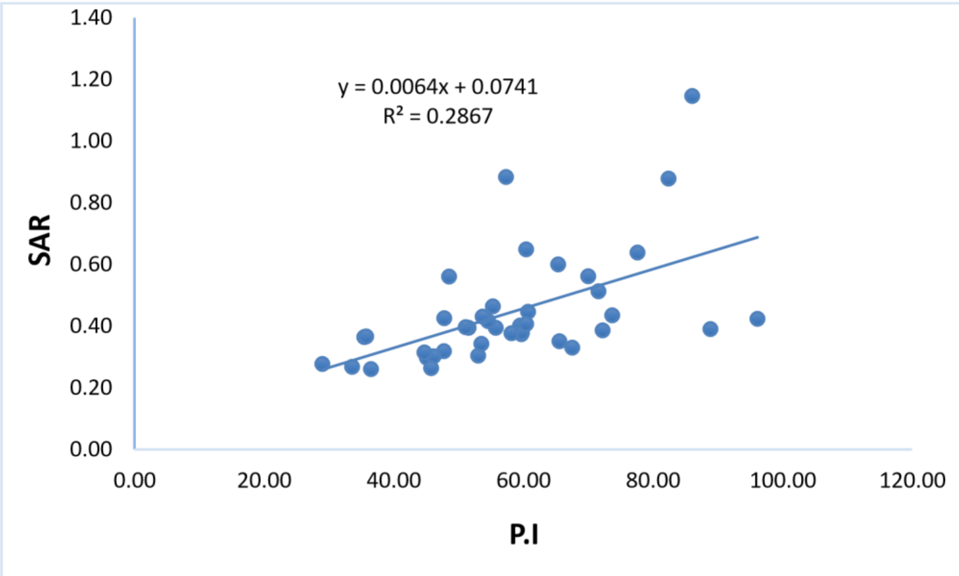



**Figure 4.5 Relationship between Permeability Index and Sodium Adsorption Ratios**

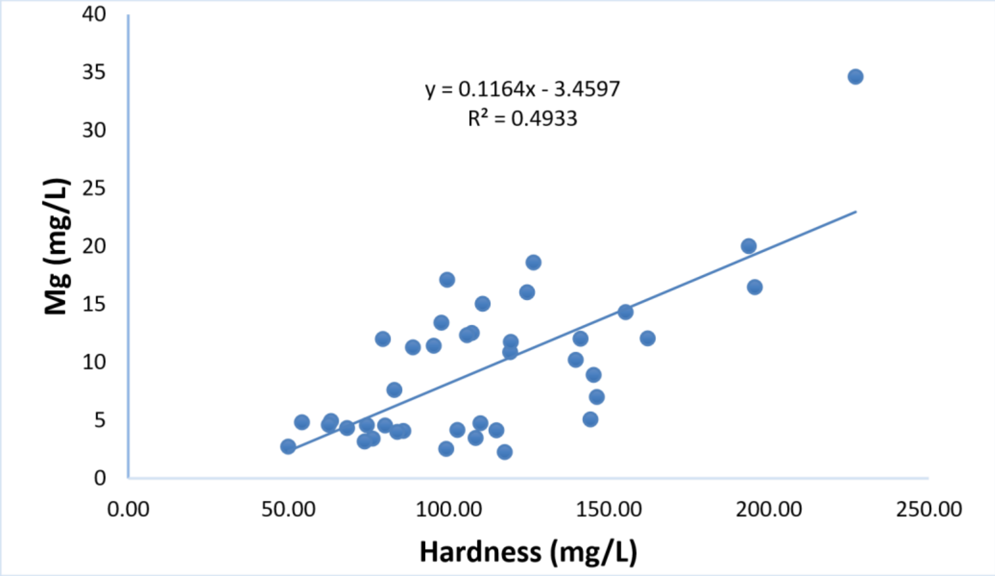



**Figure 4.6 Relationship between Mg and Hardness**

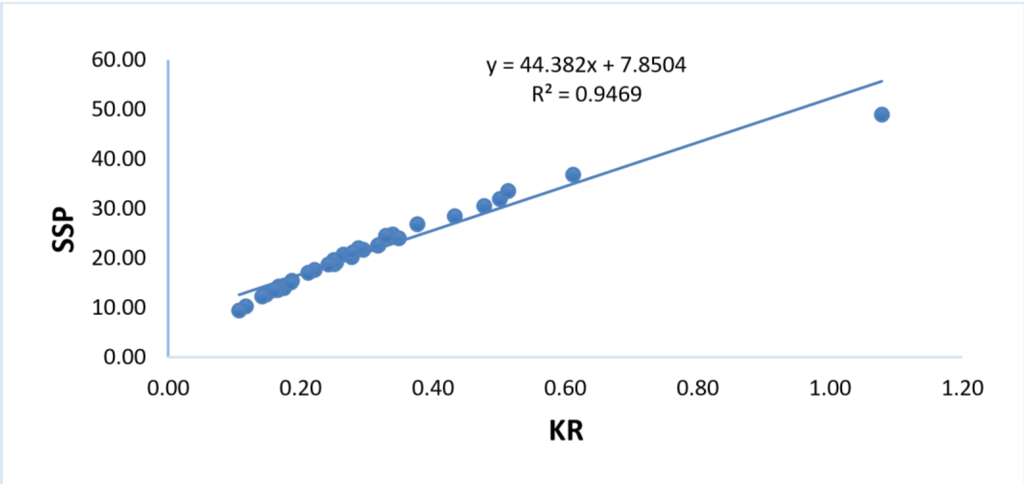



**Figure 4.7 Relationship between Soluble Sodium Percentage and Kelly's Ratio**

# CHAPTER V

# SUMMARY AND CONCLUSION

The study was conducted to assess the status of groundwater quality at Nageshwari upazila of Kurigram District, Bangladesh.

Totally 40 groundwater samples were collected from Shallow Tube-wells at different locations to investigate the chemical composition of water and also to classify them according to their quality and comparative suitability for irrigation purpose.

The concentrations of total cations and total anions under study were within the safe limit for soil and crops. The research work was accomplished to assess the extent of water quality and to predict the suitability and acceptability for irrigation purposes. In order to assess the suitability classes for irrigation purposes, the waters were analyzed for pH, EC, TDS, $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $K^{+}$, $PO_4^{3-}$, $HCO_3^{-}$, $SO_4^{2-}$ and $Cl^{-}$.

On the basis of pH values almost all the water samples were recommended for irrigation and have a great impact on crop production. The pH value was 5.88 to 7.15 with mean value 6.44. The EC value was 210 to 1470 with mean value 508 $\mu Scm^{-1}$. The amount of Total Dissolved Solids (TDS) of groundwater samples in the investigated area varied from 105 to 730 mg $L^{-1}$ with mean value of 254.12 mg $L^{-1}$. The concentration of $Ca^{2+}$ was found within the range of 11.77 to 51.23 mg $L^{-1}$ with the mean value of 24.87 mg $L^{-1}$. Groundwater samples were collected from Nageshwari upazila, $Mg^{2+}$ content was found within the range of 2.27 to 34.64 mg $L^{-1}$ with the mean value of 9.44 mg $L^{-1}$. The concentration of $Na^{2+}$in different water samples were within the range of 9.29 to 28.39 mg $L^{-1}$ and the mean value was 13.16 mg $L^{-1}$. The concentration of $K^{+}$ in the collected water samples was within the range from 0.67 to 7.89 mg $L^{-1}$ with 3.65 mg $L^{-1}$ as mean value. In all the groundwater samples, sulphate content varied from 0.08 to 15.58 mg $L^{-1}$ with the mean value of 5.24 mg $L^{-1}$. The phosphorus content of all collected groundwater samples varied from 0.09 to 1.8 mg $L^{-1}$ with the mean value of 0.94 mg $L^{-1}$. The concentration of $HCO_3^{-}$ in water samples was within the range of 20.23 to 88.13 mg $L^{-1}$ and the mean value was 57.81 mg $L^{-1}$. The computed Sodium Adsorption Ratio (SAR) of groundwater samples was within the range of 0.26 to 1.15 meq/L with average value of

0.44 meq/L. The soluble Sodium Percentage (SSP) of all 40 water samples varied from 9.43 to 49%. The obtained mean value was 20.88 (Table 4.3). The Total Hardness ($H_T$) of water samples was within the range of 49.95 to 227.17 mg $L^{-1}$ with a mean value of 110 mg $L^{-1}$. The range of the value of Permeability Index (PI) for all water samples varied from 28.98 to 96.14. The average value of this term was 57.95. The Kelly‟s ratio for all water samples were ranged from 0.11 to 1.08 with the mean value 0.29.

In respect to EC, 12 samples were excellent, 21 samples were good and 7 samples were permissible for irrigation purposes. As regards to SSP, 21 samples were „excellent‟ and 18 samples were good and 1 sample was permissible for irrigation. All the collected samples were considered as „fresh‟ for irrigation in respect to TDS. For hardness, 7 samples were soft, 28 samples were moderately hard and 5 samples were hard for irrigation.

On the basis of Ca, Mg, Na and K content, the entire water samples can safely be used for irrigation and would not affect the soils. The status of Cl, $PO_4$ and $HCO_3$ were found within the recommended limit. Sodium adsorption ratios (SAR) for all ground water samples were „excellent‟ for irrigation. All the water samples were classified as „excellent‟ (SSP<20%). For hardness, 7 samples were soft, 28 samples were moderately hard and 5 samples were hard for irrigation. In the study area, most of the groundwater might safely be applied for irrigating agricultural crops.

The correlation among the 12 parameters for water quality factors viz., pH, EC, TDS, Ca, Mg, Na, K, Cl, $HCO_3$, $SO_4$, Hardness and Kelly‟s Ratio were studied. The relationships between water quality factors viz., pH, EC, TDS, Ca, Mg, Na, K, Fe, Mn, Cu, Cl, $HCO_3$, $SO_4$, Hardness and Kelly‟s Ratio were studied. Among the combinations, pH vs EC, EC vs TDS, EC vs Mg, EC vs K, EC vs Cl, EC vs Hardness, EC vs Kellys Ratio, TDS vs Mg, TDS vs K, TDS vs CL, TDS vs $SO_4$, TDS vs Hardness, TDS vs Kelly‟s Ratio, Ca vs Hardness, Ca vs Kelly‟s Ratio, Mg vs Cl, Mg vs Hardness, Mg vs Kelly‟s Ratio, K vs $SO_4$, Cl vs Hardness, $SO_4$ vs Hardness, Hardness vs Kelly‟s Ratio showed significant correlation at 1% and 5% level of significance.

Ground water samples were found suitable for irrigated agriculture with some exception. Most of the waters were suitable for irrigation purposes based on pH, TDS, EC, Ca, Mg, Na, K, $PO_4$, $SO_4$ and Cl.

Therefore, we can concluded that the quality of groundwater in the study area was almost permissible and good for irrigation purposes based on their physical and chemical properties analysis.

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# APPENDICES

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

| Water class | Percent Sodium | Electrical Conductance (EC), µS $cm^{-1}$ |
|---|---|---|
| Excellent | <20 | <250 |
| Good | 20-40 | 250-750 |
| Permissible | 40-60 | 750-2000 |
| Doubtful | 60-80 | 2000-3000 |
| Unsuitable | >80 | >3000 |

**Appendix II: 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 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 $mgL^{-1}$, as $CaCO_3$ |
|---|---|
| Soft | 0-75 |
| Moderately hard | 75-150 |
| Hard | 150-300 |
| Very hard | >300 |

**Appendix V: Irrigation water classification based on RSC (1950)**

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