

**ASSESSMENT OF IONIC TOXICITY OF WATER SOURCES
AND THEIR SUITABILITY FOR IRRIGATION, DRINKING,
LIVESTOCK AND INDUSTRIAL USES**

BY

MD. SIRAJUL ISLAM KHAN
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**Submitted to the Faculty of Agriculture,
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**DEPARTMENT OF AGRICULTURAL CHEMISTRY
SHER-E-BANGLA AGRICULTURAL UNIVERSITY
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CERTIFICATE



This is to certify that the thesis entitled as, "ASSESSMENT OF IONIC TOXICITY OF WATER SOURCES AND THEIR SUITABILITY FOR IRRIGATION, DRINKING, LIVESTOCK AND INDUSTRIAL USES" submitted to the DEPARTMENT OF AGRICULTURAL CHEMISTRY, Sher-e-Bangla Agricultural University, Dhaka in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE (M.S.) in AGRICULTURAL CHEMISTRY, embodies the results of a piece of bona fide research work carried out by MD. SIRAJUL ISLAM KHAN, Registration. No. 00651, under my supervision and guidance. No part of this thesis has been submitted for any other degree or diploma in any other institution.

I further certify that any help or sources of information received during the course of this investigation have been duly acknowledged.

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Dedicated to
My
Beloved Parents



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*Place: Dhaka
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Md. Sirajul Islam Khan

ABSTRACT

The study was conducted to assess of the degree of ionic toxicity and classify of waters on the basis of standard criteria for irrigation, drinking, livestock, poultry, aquaculture and industrial purposes of 41 ground water sources in Kushtia district. The chemical analysis included pH , electrical conductivity (EC), total dissolved solids(TDS) and major ionic constituents like Ca, Mg, K, Na, Fe, Mn, B, As, Cu, PO₄, CO₃, HCO₃, SO₄ and Cl. sodium adsorption ratio(SAR), soluble sodium percentage(SSP), residual sodium carbonate(RSC) and hardness(H_T) were also calculated. The pH (6.53 to 7.63) showed slightly acidic to slightly alkaline. The TDS was rated as 'fresh water'. EC and SAR were 'medium' and 'high salinity' (C2 and C3) classes and 'low alkali hazard' (S1) class, combinedly expressed as C2S1 and C3S1. SSP was of 'excellent', 'good' and 'permissible' categories. Waters were free from RSC and belonged to 'suitable' category for irrigation. The waters were classified as 'hard', 'very hard' and 'medium hard' based on hardness (H_T).The toxicities of B, Mn and Cl were not found in the study area for irrigation but HCO₃, CO₃, Fe and As toxicities were found in some sources. Iron content of 22 samples was 'unsuitable' for drinking, livestock, poultry and 8 samples were unsuitable for aquaculture usage. Manganese content of 40 samples was 'suitable' for drinking and livestock consumption. Both Fe and Mn content of all samples were 'problematic' for industrial usage. Arsenic status of 37 water samples was 'suitable' for drinking and 39 for livestock consumption. Chloride of 35 samples was 'toxic' for livestock but all samples were 'unfit' for aquaculture. Sulphate of all samples was 'suitable' for drinking, livestock, poultry, aquaculture and industrial usage. The relationship of SAR vs SSP and SSP vs RSC indicated significant positive correlation while SSP vs H_T and RSC vs H_T combination revealed negative significant correlation. To the contrary, the relationship between pH vs. SAR, pH vs. H_T, EC vs. TDS, EC Vs SSP, EC vs. H_T, H_T vs. TDS, EC vs. SSP and EC vs. RSC, were found insignificant. Among the major ionic constituents remarkable significant correlation existed between Ca vs. Mg; Ca vs. Mn , Ca vs. Cu, Mg vs. K, Mg vs. Mn , Mg vs. Cu , Na vs. Fe, Na vs. Mn , Na vs. Cu , K vs. Cu , Na vs. B , Fe vs. Cu , Cl vs. Mn , Mn vs. SO₄, Cu vs. B and Cu vs. SO₄.

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LIST OF ABBREVIATIONS

Abbreviation	Full word
TDS	Total Dissolved Solids
BARI	Bangladesh Agricultural Research Institute
BAU	Bangladesh Agricultural University
BBS	Bangladesh Bureau of Statistics
BINA	Bangladesh Institute of Nuclear Agriculture
CV	Coefficient of variation
EC	Electrical Conductivity
SAR	Sodium Adsorption Ratio
SSP	Soluble Sodium Percentage
RSC	Residual Sodium Carbonate
AAS	Atomic Absorption Spectrophotometer
PAR	Potassium Adsorption Ratio
DTW	Deep Tubewell Water
FAO	Food and Agriculture Organization
Fig.	Figure
STW	Shallow Tubewell Water
HTW	Hand Tubewell Water
i.e.	Id est (that is)
IW	Irrigation Water
LSD	Least significant difference
SD	Standard Deviation
USEPA	United States Environmental Protection Agency
H _T	Hardness
VH	Very Hard
SAU	Sher-e-Bangla Agricultural University
MH	Moderately Hard
Viz.	Videlicet (namely)
Unit	
dS cm ⁻¹	Deci Siemens per meter
%	Percentage
°C	Degree Celsius
cm	Centimeter
g	Gram
Me L ⁻¹	Milli equivalent per Litre
Mg L ⁻¹	Milli gram per Litre
R ²	Co-efficient of Determination
m	Meter
r	Correlation of Coefficient
μS m ⁻¹	Micro Siemens per metre

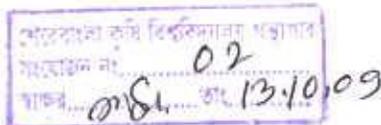




CHAPTER 1

INTRODUCTION





CHAPTER I INTRODUCTION

Water quality is a prime factor for successful crop production. Because the quality of water for irrigation usually depends on its chemical characteristics. If low quality of water is used for irrigation, toxic elements may accumulate in the soils as well as plants and deteriorates soil properties which adversely affects on crop production and plant consumers. Besides, its use as irrigation, its utility is equally important for drinking, livestock, poultry, aquaculture and industrial purposes. Thus, water quality assessment is the most significant aspect of water management irrespective of its uses. Water found in different conditions in nature is not pure in the chemical sense. All types of water contain variable amounts and different species of cations and anions, hence the concentration and composition of dissolved constituents in water is an important consideration concerning its quality. Among them, the principal soluble constituents are Ca, Mg, Na and K as cations and Cl, SO₄, CO₃ and HCO₃ as anions. Beside these, Cu, PO₄, Mn, Fe, As, B, Zn, Si and F are present in minor amounts. Out of the soluble constituents, Ca, Mg, Na, Cl, SO₄, HCO₃ and B are of prime importance in judging the water quality for irrigation (Michael, 1978), especially for rice. Some of these ions are more or less beneficial to plant growth and are also harmful to plant growth beyond the safe limit. Certain soluble ions at relatively high concentrations have a direct toxic effect on sensitive crops. According to Bohn *et al.*, (1985) the concentrations of these toxic ions in irrigation water are particularly important because many crops are susceptible to even extremely low concentrations of these elements. Moreover, specific water may be suitable for irrigation purpose but may not be suitable for drinking, livestock, poultry, aquaculture and industrial uses due to the presence of some other ions at toxic level. Toxic elements for drinking water are As, Cd, Cl, Cr, Pb, Hg, Fe, Mn and Zn. The troublesome ions for industrial process waters are SO₄, Cl, Fe, Mn etc. and As, B, Cd, Cu, Pb, Mn, Hg, and Fe are also toxic to livestock consumption (AWWA, 1971 and ESB, 1972). In the global water resources, about 97.2% is salt water mainly in oceans, and only 2.8% is available as fresh water. Out of 2.8%, about 2.2% is available as surface water and 0.6% as ground water (Raghunath, 1987). At present, nearly one fifth of all water used in the world is obtained from ground water resources. Agriculture is the greater user of water accounting

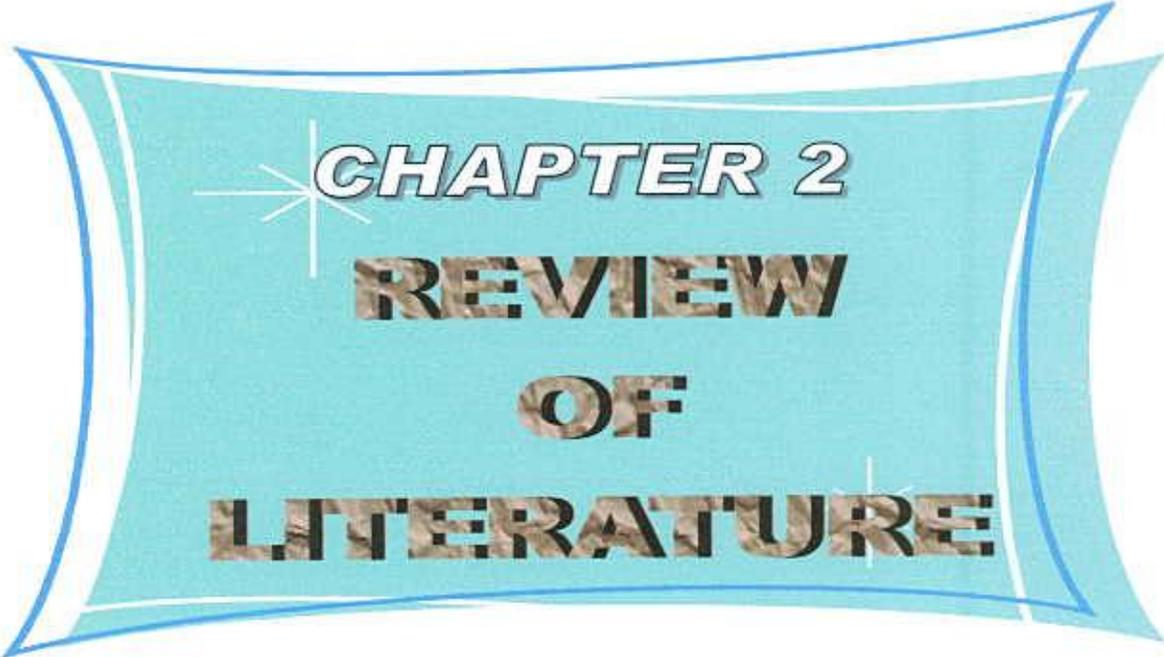
for 80% of all consumption. The discovery of arsenic in the ground water of Bangladesh is posing a major threat to people's livelihood in the country. More than 90% of the ground water is used for irrigation although 95% of the population relies on this as the source of drinking water. A recent study of WHO revealed that about 80 million people of 59 districts are at high risk of deadly arsenic poisoning (Hossain *et al.*, 2000). However, arsenic concentration of ground water has recently been realized as a global problem. The quality of water is generally judged by its total salt concentrations and the relative proportions of ions. The chemical composition of water is very important criterion to evaluate its suitability for irrigation, drinking, livestock, poultry, aquaculture and industrial uses. In this context, it becomes a crying need to conduct field level investigations of the existing water management practices in rural areas of Bangladesh.

Some studies of the quality of water in some selected areas of Bangladesh namely Dinajpursadar, Kalihati, Madhupur, Pangsha, Shahzadpur, Jamalpur, Gazipur, Meherpur, Phulpur, Trishal, Muktagacha, Matiranga, Sherpur and Pabna sadar upazilla has been conducted (Zaman *et al.*, 2000). Most of the chemical analysis of these investigation included p^H , EC, Ca, Mg, CO_3 , HCO_3 , Cl, Na, and K. But little attention has been given to the concentration of micronutrients, heavy metals and toxic elements (Cu, Mn, Zn, Fe, As, Cr, Pb, Hg, Cd etc.). Now-a-days, analyses of water from ground water sources to determine the toxic elements are very important for irrigating crops, domestic uses, drinking, poultry, aquaculture and industrial usage. Unfortunately, there is no laboratory for systematic investigation of the water quality in Bangladesh.

For the formulation of a baseline data, an investigation was conducted to assess the groundwater quality for irrigation, drinking, livestock, poultry, aquaculture and industrial usage in Kushtia district. In the study area, there were different water sources, in which waters of shallow tube-well were mainly applied for irrigation. The cropping sequences like HYV rice, vegetables and rabi crops were also found to be cultivated. Some tube-well waters were usually being used for drinking, livestock, poultry, aquaculture and industrial usage. But there is no systemic organization to assess the extent of ground water quality at field level. Keeping all these above facts in mind, this area was selected to assess the degree of pollutant in ground water with the following objectives:

- i) To analyze waters for the determination of chemical constituents present therein.

- ii) To assess the degree of ionic toxicity of water samples
- iii) To classify the water on the basis of standard criteria as regards to suitability for irrigation, drinking, livestock and industrial usage and
- iv) To predict the future recommendations for water usage effectively.



CHAPTER 2
REVIEW
OF
LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

Water is a universal solvent and contains variable quantities of inorganic and organic substances. Sometimes, suspended and colloidal materials are also found in it. It is necessary to determine the quality of water and its suitability for, irrigation, drinking and industrial usage. Few research works have been conducted on these perspectives at home and abroad. An attempt has been made in this chapter to review the pertinent research information related to water pollution or quality assessment. The research reports are mentioned here under the following heads:

2.1 Water quality on the basis of pH

It is an important parameter for ascertaining the reactivity character of water.

Acharya *et al.* (2008) found that the pH value ranges between 8.0 and 9.4 in the ground water of Bhiloda taluka of Sabarkantha district (North Gujarat), India. It was observed that 76% of the water samples lied in the range of 6.5 – 8.5 prescribed by Bureau of Indian Standards. Islam *et al.* (2003) stated that pH varies from 6.72 to 7.54 in the ground water sample of Matiranga Upazilla under Khagrachari Hill District of Bangladesh. Are fin (2002) stated that the pH values of ground water samples in sadar upazila under Pabna district varied from 7.5 to 8.2. The pH values of the ground water of Sherpur upazila under Bogra district ranged from 4.2 to 8.8(Rahman, 2001). Singh *et al.* (2001) reported that the pH values of irrigation water samples of Chirawa Block Jhunjhunu district varied from 7.1 to 8.2. Siddique (2000)reported that the pH of ground water samples of Atrai upazila under Naogaon district was found within the limited of 6.88 to 9.84.The pH values of water samples in Tongi aquifers were within the range of 6.69 to 7.63 indicating slightly acidic to alkaline in nature Sen *et al.*, 2000). The pH values of ground waters collected from Sherpur sadar under Old Brahmaputra Floodplain ranged from 7.64 to 8.90 indicating slightly alkaline to alkaline in nature (Hoque, 2000). Jesmin (2000) found that the pH values of ground water in Gaibandha aquifers ranged from 6.73 to 8.66 reflecting “Slightly” acidic to alkaline in nature. The pH value of water samples collected from Bagmara, Mahadebpur and Nachoul upazilas varied from 7.48 to 9.44, 6.74 to 9.33 and 6.8 to 8.2, respectively (Zaman, 2000).

Nizam (2000) collected 103 water samples from 11 unions of Bhaluka upazilla under Mymensingh district and reported that pH values were within the range of 2.80 to 10.30 indicating acidic to alkaline in nature. Mitra and Gupta (1999) observed that the pH of tubewell water during monsoon and winter seasons were within the range from 7.4 to 7.6, respectively. Hussain and Ahmed (1999) reported that the pH values of groundwater samples of Muktagacha aquifer ranged from 7.5 to 8.5. Lal *et al.* (1998) observed that the pH values of underground irrigation waters of Bikaner district in Rajasthan Pradesh were within the limit of 8.0 to 9.0. Alamgir *et al.* (1999) stated that the pH values in ground waters of Madhupur Tract varied within the limit of 5.0 to 8.0 showing acidic to alkaline in nature. All of the surface and ground water samples collected from Northern and Eastern Piedmont plains, varied from 5.20 to 8.41 revealing acidic to alkaline in nature and most of the water samples were not problematic for irrigating agricultural crops (Ali, 1999). Sarker (1997) obtained that the pH value of surface and ground waters of Naryanganj aquifers ranged from 6.8 to 8.6. Ali (1997) revealed that the pH value of ground water of Nachoul upazila at High Barind Tract fluctuated from 6.8 to 8.2. Anil-Sood *et al.* (1998) reported that the pH value of underground waters varied from 7.6 to 8.8 indicating alkalinity of water. Helaluddin (1996) found that the pH values of 88 samples of surface and ground waters collected from the different locations of Khagrachari Hill Tract were found to vary from 4.02 to 7.54 showing acidic to 'slightly' neutral.

2.2 Water quality on the basis of Electrical Conductivity

Acharya *et al.* (2008) found that the maximum electrical conductivity (EC) was $742 \mu\text{S cm}^{-1}$ (at Sunokh) and the minimum EC was $231 \mu\text{S cm}^{-1}$ (at Jinava) in the ground water of Bhiloda taluka of Sabarkantha district (North Gujarat), India. The result indicates that almost all the water samples are within the permissible limits of $650 \mu\text{S cm}^{-1}$ except at sampling locations *viz.* Sunokh ($642 \mu\text{S cm}^{-1}$), Madhtimba ($739 \mu\text{S cm}^{-1}$), Padara ($1304 \mu\text{S cm}^{-1}$) and Jayla ($781 \mu\text{S cm}^{-1}$). Sarfraz and *et al.* (2007) carried out a research study to determine the Electrical Conductivity (EC) in metal-polluted irrigation water from a Nullah Dek at Thatta Wasiran in Sheikhpura District (Pakistan) over a period of time. Water samples were collected during rice crop (cv. Super Basmati and Basmati 385) growth at 15-day intervals from 3 August to 1 November 2002. The results showed that Nullah Dek water had an $\text{EC} > 100 \mu\text{S cm}^{-1}$ which was hazardous for crops. Mostafa *et al.* (2006) stated that agricultural drainage water (DW) and sewage water (SW) used for



irrigation has an electrical conductivity between 98 and 1680 $\mu\text{S cm}^{-1}$ in El-Sharkia Governorate, Egypt.

Islam *et al.* (2003) stated that Electrical Conductivity values were between 52 to 300 $\mu\text{S cm}^{-1}$ in the ground water sample of Matiranga Upazilla under Khagrachari Hill District of Bangladesh. Arefin (2002) reported that the EC values of groundwater samples in sadar upazila under Pabna district varied from 47 to 90 $\mu\text{S cm}^{-1}$. Rahman (2001) stated that the EC values of ground water samples of Sherpur upazila in Bogra ranged from 242.8 to 670.8 $\mu\text{S cm}^{-1}$. The EC of ground samples collected from 69 villages of Atrai upazila under Naogaon district varied from 366.96 to 733.92 $\mu\text{S cm}^{-1}$ and all the ground waters under test were 'medium salinity' hazard class (Siddique, 2000). The EC value of ground waters collected from Sherpur sadar upazila under Sherpur district varied from 174 to 522 $\mu\text{S cm}^{-1}$ and all waters under investigation were under 'low to medium salinity' class (Hoque, 2000). Sen *et al.* (2000) conducted an investigation to determine water quality for irrigation at Tongi aquifer under the district of Gazipur and found that the EC values of surface and ground water samples varied from 185 to 992 $\mu\text{S cm}^{-1}$ reflecting 'low to high salinity' hazard. Jesmin (2000) reported that the EC values of ground water in Gaibandha aquifer varied from 274 to 1465 $\mu\text{S cm}^{-1}$ showing 'medium to high salinity' hazard of waters. Zaman and Majid (2000) reported that the EC values of ground waters of Madhupur sadar under Tangail district ranged from 340 to 980 $\mu\text{S cm}^{-1}$ indicating 'medium to high salinity' of water. The EC values of ground waters of Mahadebpur upazila under the district of Naogaon and Bagmara and Nachoul upazilas under the district of Rajshahi fluctuated from 256 to 1334, 235 to 1682 and 285 to 780 $\mu\text{S cm}^{-1}$, respectively (Zaman, 2000). Nizam (2000) found that the EC value of surface and ground water samples collected from 11 unions of Bhaluka upazila under Madhupur Tract ranged from 244.64 to 822.88 $\mu\text{S cm}^{-1}$ indicating 'low to high salinity' hazard of water. Hussain and Ahmed (1999) found that the EC value of ground waters collected from Muktagacha aquifer varied from 246 to 416 $\mu\text{S cm}^{-1}$ showing 'low to medium salinity' hazard. Mitra and Gupta (1999) showed that the tubewell waters during monsoon and winter seasons were 0.46 and 0.52 $\mu\text{S cm}^{-1}$, respectively. Gumtang *et al.* (1999) conducted a study from October 1994 to March 1996 to assess ground water dynamics and quantity in reaction to land use and farm input of nitrogen fertilizer in a highly diversified and intensive agricultural area at Magnuang, Batac Iicos Norte. They reported that the EC of all the varied from 70 to 300 $\mu\text{S cm}^{-1}$, which exceeded the FAO threshold quality for irrigation

but were not related to the farm management practices. The EC values of the water samples of Kokia, Kolayat and Loonkaransor under Bikaner district of Rajasthan Pradesh in India were found to range from 10.0 to 60.1, 80.0 to 100.3, 230 to 790 and 770 $\mu\text{S cm}^{-1}$, respectively (Lal *et al.*, 1998). Umeki *et al.* (1998) reported that the electrical conductivity (EC) of water increased by treating with 100g granite L^{-1} of desalinated water. Sarker (1997) reported that the EC values of surface and ground water samples of Naryangang aquifers varied from 164 to 1894 $\mu\text{S cm}^{-1}$ reflecting 'low to high salinity' hazard for irrigating agricultural crops.

2.3 Water quality on the basis of Total Dissolved Solids

Acharya *et al.* (2008) found that the total dissolved solids (TDS) of the ground water samples ranged from 145 mg L^{-1} to 1910 mg L^{-1} of Bhiloda taluka of Sabarkantha district (North Gujarat), India. Islam *et al.* (2003) stated that total dissolved solid (TDS) values were between 35-200 mg L^{-1} in the ground water sample of Matiranga upazilla under Khagrachari Hill district of Bangladesh. The TDS values of ground water in sadar upazila under Pabna district varied from 336.26-671.89 mg L^{-1} (Arefin, 2002). Rahman (2001) reported that the TDS values ranged from 194.6 to 458.5 mg L^{-1} in ground water in selected aquifers of Bogra. Siddique (2000) revealed that the TDS values of ground waters at Atrai upazila under Naogaon district ranged from 242.19 to 479.17 mg L^{-1} . Sen *et al.* (2000) reported that the TDS values of some surface and ground waters collected from Tongi aquifers varied from 123 to 675 mg L^{-1} showing 'freshwater' in quality. The TDS values of ground waters collected from Sherpur sadar under Sherpur district varied within the limit of 112 to 358 mg L^{-1} reflecting 'freshwater' in quality (Hoque, 2000). Jesmin (2000) measured TDS value of ground waters in Gaibandha aquifer and found that TDS values varied from 192 to 1000 mg L^{-1} . The TDS values of surface groundwater samples collected from 11 unions of Bhaluka upazila under Mymensingh district were within the range of 26.00 to 660.00 mg L^{-1} (Nizam, 2000). The TDS value of groundwater at Tripura in India ranged from 1500 to 8000 mg L^{-1} (Senthilnathan and Azeez, 1999). Quddus and Zaman (1996) showed that the TDS values of some surface and ground waters collected from some villages of Meherpur sadar under the district of Meherpur ranged from 282 to 461 mg L^{-1} . The TDS values of ground waters of Nachoul at High Barind Tract varied from 185 to 546 mg L^{-1} and all the waters under study were classified as 'fresh' and 'brackish' waters (Sarker, 1997). Surface and ground water samples of Shahzadpur under

Sirajgong district contained TDS within the limit of 342 to 550 mg L⁻¹ reflecting 'freshwater' in quality (Zaman and Rahman, 1996).

2.4 Water quality on the basis of Calcium, Magnesium, Sodium and Potassium

Acharya *et al.* (2008) found that potassium (K) in the ground water ranges from 0.00 me L⁻¹ (Jinava) to 0.03 me L⁻¹ (Bhatera) of Bhiloda taluka of Sabarkantha district (North Gujarat), India. These authors also also found that the sodium content of the ground waters of Bhiloda taluka of Sabarkantha district (North Gujarat), India ranges from 0.5 me L⁻¹ (Jinava) to 32.87 me L⁻¹ (Sunokh). About 61% of the water samples show sodium higher than the permissible limit of 50 ppm (9 me L⁻¹) in irrigation water prescribed by BIS (Bangladesh Institute of Statistics) (1983). Arefin (2002) stated that calcium, magnesium, sodium and potassium contents in groundwater in sadar upazila under Pabna district varied from 0.8 to 3.8, 1.5 to 4.30, and 0.14 to 0.6 me L⁻¹, respectively. Ca, Mg, K and Na contents in groundwater sources of Sherpur upazila under Bogra district ranged from 0.5 to 2.5, 0.8 to 3.6, trace to 2.22 and 0.1 to 1.36 me L⁻¹, respectively (Rahman, 2001). Hoque (2000) reported that Ca, Mg, Na and K contents in all waters of Sherpur sadar under Sherpur district ranged from 0.5 to 2.0, 0.4 to 2.0, 0.006 to 0.421 and 0.097 to 2.260 me L⁻¹, respectively.

Sen *et al.* (2000) found that in Tongi aquifers the concentrations of Ca, Mg, Na and K in water samples varied from of 0.50 to 3.21, 0.70 to 5.13, 0.20 to 2.28 and 0.12 to 0.59 me L⁻¹, respectively. The contents of Ca, Mg, Na and K in groundwater samles collected from Gaibandha sadar under Gaibandha district varied from 0.72 to 3.01, 1.80 to 6.80, 0.06 to 0.74 and 0.45 to 6.47 me L⁻¹, respectively (Jesmin, 2000). Siddique (2000) analyzed 88 surfaces and ground water samples collected from Atrai upazila under Naogaon district and recorded that the amounts of Ca, Mg, Na and K ranged from 0.50 to 2.20, 0.70 to 4.10, 0.11 to 1.13 and 0.012 to 0.80 me L⁻¹, respectively. Nizam (2000) showed that Ca, Mg, Na and K contents in surface and groundwater samples collected from Bhaluka upazila under Mymensingh district varied from 0.10 to 2.80, 0.40 to 4.40, trace to 0.077 and 0.086 to 0.33 me L⁻¹, respectively.

Zaman (2000) stated that Ca content in ground waters of Bagmara, Mahadebpur and Nachoul upazilas ranged from 0.08 to 4.00, 0.20 to 3.60 and 1.50 to 3.50 me L⁻¹, respectively. During monsoon season Ca, Mg, Na and K contents in tube-well waters in

vegetables growing area around Calcutta were 8.0, 3.4, 1.3 and 0.5 me L⁻¹, respectively (Mitra and Gupta, 1999). Hussain and Ahmed (1999) reported that the respective concentrations of Ca, Mg, Na and K in groundwater samples collected from Muktagacha under Mymensingh district varied from 0.20 to 1.50, 0.63 to 1.73, 0.35 to 4.09 and 0.021 to 0.056 meL⁻¹ with the mean values of 1.10, 1.09, 1.86 and 0.039 me L⁻¹. The concentrations of Ca + Mg and Na in ground water samples collected from Bathinda district of Punjab in India varied from 1.30 to 47.30 and 3.00 to 90.10 me L⁻¹, respectively (Anil-Sood *et al.* 1998).

2.5 Water quality on the basis of Iron, Manganese and Copper

Sarfraz *et al.* (2007) carried out a research study to determine the metals in metal-polluted irrigation water from a nullah and those in soils over a period of time. The effect of metals on rice yield and metal concentrations in rice grain and straw was also studied. Two sites (I and II) were selected on the bank of Nullah Dek at Thatta Wasiran in Sheikhpura District (Pakistan), with two rice varieties (cv. Super Basmati and Basmati 385), at both sites. Water samples were collected during rice crop growth at 15-day intervals from 3 August to 1 November 2002. Mn, Cd and Sr were within the safe limits in the water.

The concentrations of Fe and Mn in groundwater of sadar upazila under Pabna district were within the range of 0.02 to 0.488 and 0.008 to 0.403 me L⁻¹, respectively (Arefin, 2002). Rahman (2001) showed that the collected groundwater samples of Sherpur upazila of Bogra district contained Fe and Mn within the ranged of 0.07 to 1.25 and 0.01 to 0.81 me L⁻¹, respectively. In Tongi aquifers, the concentrations of Fe and Mn in surface and ground water samples varied from trace to 0.09 and trace to 0.30 mgL⁻¹, respectively (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 Fe and Mn in those areas ranged from 0.05 to 0.90 and 0.50 to 0.58 mg L⁻¹, respectively.

Jesmin (2000) found that the respective concentrations of Fe and Mn in groundwater samples collected from Gaibandha aquifer varied from 0.15 to 1.00 and 0.03 to 0.10 mg L⁻¹, respectively. Siddique (2000) revealed that the amounts of Fe and Mn in water samples collected from Atrai upazila under Naogaon district ranged from 0.10 to 0.42 and trace to 0.24 mg L⁻¹, respectively. Nizam (2000) analyzed 20 water samples collected from different sources of two unions of Bhaluka upazila under Mymensingh district and reported

that the most of the water samples were 'unsuitable' for drinking livestock consumption due to the presence of higher amounts of iron ($\text{Fe} = 0.35\text{-}3.11 \text{ mg L}^{-1}$) and manganese ($\text{Mn} = 0.091 - 0.347 \text{ mg L}^{-1}$). An experiment was performed by Zaman (2000) to evaluate the quality of groundwater collected from Bagmara, Mahadebpur and Nachoul upazilas in Barind area. He found that the concentration of Fe in those areas varied from 0.005 to 0.390, 0.010 to 3.722 and trace to 0.44 mg L^{-1} , respectively but the content of Mn in those areas also ranged from 0.0020 to 0.197, 0.005 to 0.567 and 0.007 to 0.102 mg L^{-1} , respectively. The concentrations of Fe and Mn in groundwater of Madhupur Tract were within the range of 0.90 to 0.24 and 0.70 to 0.22 mg L^{-1} , respectively (Alamgir *et al.*, 1999). Hussain and Ahmed (1999) analyzed groundwater of Muktagacha thana under Mymensingh district and found that the concentrations of Fe and Mn in groundwater samples ranged from 0.01 to 0.06 and 0.02 to 0.86 mg L^{-1} , respectively.

Rahman (2000) stated that the collected surface and ground water contained Cu within the range of 0.029 to 0.063 mg L^{-1} , respectively. Quddus and Zaman (1996) reported that the concentrations of Cu surface and groundwater of some villages in Meherpur sadar varied from traces to 0.1 mg L^{-1} respectively. Helaluddin (1996) analyzed 88 ground and surface water samples of Khagrachari district and found the concentration of Cu was ranged from trace to 0.05 mg L^{-1} respectively. Maximum recommended concentration of Cu in irrigation water was 0.20 mg L^{-1} respectively (Ayers and Westcot, 1985). Quddus (1996) indicated that the concentration of Cu in surface and ground waters of Meherpur, Sadar thana varied from trace to 0.05 mg L^{-1} respectively (Quayum, 1995). Mohidudin (1995) showed that the collected irrigation water samples of Pangsha thana of Rajbari district contained Cu within the range of 0.01 to 0.06 mg L^{-1} respectively. The concentration of Cu in ground waters of Phulpur thana under Mymensingh district was the range of 0.01 to 0.03 mg L^{-1} respectively (Shahidullah, 1995).

2.6 Water quality on the basis of Phosphate, Sulphate, Boron, Chloride and Fluoride

Siddique (2000) assessed the ground water quality of Atrai upazila under Naogaon district and found that the contents of phosphate varied from trace to 2.19 mg L^{-1} . The concentration of phosphate in surface and ground water samples collected from Tongi thana under the district of Gazipur ranged from trace to 0.05 mg L^{-1} (Sen *et al.*, 2000). Groundwater samples collected from Gaibandha aquifer contained small amount (trace- 1.10 mg L^{-1}) of phosphate (Jesmin, 2000). The content of PO_4 in surface and groundwater

samples collected from Bhaluka upazila under Mymensingh district varied from trace to 0.47 mg L^{-1} (Nizam, 2000). In Northern and Eastern Piedmont Plains, surface and groundwater samples contained small amount (0.001 to 0.012 mg L^{-1}) of phosphate (Ali, 1999). Hussain and Ahmed (1999) analyzed groundwater samples of Muktagacha aquifers in Mymensingh district and found that the content of phosphate was within the limit of 0.10 to 1.40 mg L^{-1} . Mitra and Gupta (1999) analyzed tube-well waters of vegetables area around Calcutta and found that the content of PO_4 during both monsoon and winter seasons was 0.02 mg L^{-1} . The obtained concentration of PO_4 in groundwater samples collected from Shahzadpur under the district of sirajgang had no remarkable influence on water quality (Zaman and Rahman, 1996). In Tista Floodplains, the concentration of PO_4 in water samples ranged from 0.03 to 0.73 mg L^{-1} (Shamsuzzaman, 1997). Sarker (1997) revealed that all the water samples collected from Naryanganj aquifers contained small amount (0.005 to 2.12 mg L^{-1}) of PO_4 .

Boron content was found to vary from trace to 0.39 mg L^{-1} in groundwater sources of sadar upazila under Pabna district (Arefin, 2002). Rahman (2001) reported that the boron concentration in groundwater of Sherpur upazila under Bogra district varied from 0.1 to 0.52 mg L^{-1} . The concentration of B in surface and ground water collected from Old Bramaputra Floodplain ranged from 0.02 to 0.45 mg L^{-1} exhibiting no toxicity for irrigation (Hoque, 2000). An experiment was conducted by Sen *et al.* (2000) to evaluate the water quality of Tongi aquifers and found that B concentration varied from 0.006 to 0.067 mg L^{-1} and all the waters were 'excellent' in quality for irrigation. Jesmin (2000) showed that all the ground waters collected from Gaibandha aquifers contained small amount of B (0.04 TO 1.19 mg L^{-1}). Siddique (2000) found that B concentration in surface and groundwater of Lower Atrai Basin ranged within the limit of 0.009 to 0.54 mg L^{-1} causing no B toxicity for sensitive crops. Nizam (2000) stated that B content in surface and 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 B ranged from 0.10 to 0.20 mg L^{-1} and these waters were not problematic for irrigating agricultural crops. Sarker (1997) showed that B content in Naryanganj aquifers ranged from 0.06 to 0.62 mg L^{-1} . The concentration of B in groundwater of Nachoul thana under High Barind area was within the range of 0.03 to 0.53 mg L^{-1} as reported by Ali (1997). Quddus and Zaman (1996) reported that B content in surface and groundwater in some villages of Meherpur

sadar under Meherpur district ranged from 0.10 to 0.63 mg L⁻¹. The amount of B in surface and groundwater 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 B content in groundwater of Pansha thana under Rajbari district varied from 0.08 to 0.45 mg L⁻¹. The content of B in water samples collected from Ghatail thana under Tangail district was within the range of 0.01 to 0.45 mg L⁻¹ and all waters were 'excellent' to 'good' in quality for irrigation usage (Razzaque, 1995). An investigation was conducted by Quayum (1995) to evaluate the quality of groundwater collected from Gazipur sadar under Gazipur district and showed that B concentration varied from 0.15 to 0.54 mg L⁻¹.

Acharya *et al.* (2008) recoded high sulfate content of 3.0, 1.3 and 0.8 me L⁻¹ in the ground water at Vijapur, Jayla and Khokhara, respectively of Bhiloda taluka of Sabarkantha district (North Gujarat), India. Acharya *et al.* (2008) also observed that fluoride content of groundwater samples of the study areas of Bhiloda taluka of Sabarkantha district (North Gujarat), India ranges from 0.20 to 1.10 ppm. Maximum allowable limit is 1.5 ppm (WHO, 1984). It is under permissible limit. They also observed that around 53% of the ground water samples of Bhiloda taluka of Sabarkantha district (North Gujarat), India have chlorides higher than the permissible limit of 10.0 me L⁻¹. The highest concentration of chlorides was recorded in padara (19.5 me L⁻¹) and the lowest at Bhatara (1.00 me L⁻¹).

The concentration of SO₄ and Cl in ground water in sadar upazila under Pabna district was within the range of 0.14 to 5.48 mg L⁻¹ and 0.8 to 1.4 me L⁻¹, respectively (Arefin, 2002). Rahman (2001) revealed that the collected groundwater samples of Sherpur upazila under Bogra district contained SO₄ and Cl within the range of trace to 10.30 mg L⁻¹ and 0.40 to 2.40 me L⁻¹, respectively. Sen *et al.* (2000) found that the surface and groundwater samples in Tongi under the district of Gazipur contained SO₄ within the limit of trace to 11.00 mg L⁻¹ and also contained Cl varying from 0.80 to 4.80 me L⁻¹. In all the groundwater and surface waters of Madhupur Tract, Cl content of tube-well water used for irrigating during monsoon and winter seasons were 45.6 and 55.2 mg L⁻¹, respectively and Cl concentration of sewage-water used for irrigation during monsoon and winter seasons were 155 and 212 mg L⁻¹, respectively. Hussain and Ahmed (1999) stated that the concentration of Cl in groundwater samples of Muktagacha aquifers ranged from 0.20 to 0.70 meL-1 having the mean value of 0.44 me L⁻¹. Islam *et al.* (1998) recorded that Cl

content within the range of 21.30 to 85.20 me L⁻¹ in most of the water samples collected from Dhaka city. Alamgir *et al.* (1999) reported that the concentrations of Cl and so₄ in groundwaters of madhupur tract were found within the range of 8.50 to 45.10 and 14.50 to 40.40 mg L⁻¹, respectively. Zaman (2000) revealed that Cl content of groundwaters collected from Bagmara, Mahadebpur and Nachoul upazilas ranged from trace, 4.22 to 5.40 and 0.78 to 1.78 me L⁻¹, respectively

2.7 Water quality on the basis of Carbonate and Bicarbonate

Acharya *et al.* (2008) found that the values of HCO₃ in the ground water samples of Bhiloda taluka of Sabarkantha district (North Gujarat), India varied from 2.90 to 15.00 me L⁻¹. The lowest value of 2.90 me L⁻¹ was observed in the water sample obtained from Jinava where as the highest value of 15.00 me L⁻¹ was observed in Jayla Village. All the samples are far below than the permissible limit of 120 me L⁻¹.

Arefin (2002) observed that in Sadar upazila under Pabna district, the amount of CO₃ in ground in all the ground waters were not detected and HCO₃ concentration was within the range of 3.5-7 me L⁻¹. Rahman (2001) found that the concentration of HCO₃ varied from 1.5 to 4.5 me L⁻¹. The concentrations of CO₃ and HCO₃ in surface and ground waters ranged from 0.05 to 1.50 me L⁻¹ and 0.60 to 3.50 meL⁻¹, respectively (Hoque, 2000). The concentration of HCO₃ ranged from 0.80 to 6.20 me L⁻¹ and this anion was dominant in groundwater as compared to surface water in Tongi under Gazipur (Sen *et al.* 2000).

Jesmine (2000) observed that the amount of CO₃ in all the ground waters in Gaibandha aquifers was not detected and HCO₃ concentration was within the range of 1.50 to 6.00 mg L⁻¹. Siddique (2000) carried out an experiment by collecting surface and groundwater samples from Lower Atrai Basin and found that only 3 samples under study small amount of carbonate (CO₃ = 0.50 to 0.80 me L⁻¹) but the rest samples under study were free from CO₃ but HCO₃ content of all the samples ranged from 0.50 to 5.50 me L⁻¹. Zaman (2000) observed that the amount of HCO₃ ion in ground waters of Bagmara, Mahadebpur and Nachoul upazilas ranged from trace to 1.20, 1.00 to 4.40, 1.20 to 3.60 and 4.22 to 5.40 me L⁻¹, respectively. In Madhupur Tract, the concentration of CO₃ in water varied from trace to 2.00 mg L⁻¹ and HCO₃ content ranged from 0.50 to 8.00 me L⁻¹ (Nizam, 2000). Ground waters of Madhupur under Tangail district contained CO₃ and HCO₃ within the limit from 0.04 to 0.40 and 0.80 to 2.52 me L⁻¹, respectively (Zaman and Majid, 1995). Razzaque

(1995) examined 66 water samples to evaluate the ionic toxicity of waters and reported that the water samples contained CO_3 and HCO_3 within the limit from 0.50 to 0.85 and 0.60 to 2.85 me L^{-1} respectively. The contents of CO_3 and HCO_3 in surface and ground waters in some villages of Meherpur sadar under Meherpur district was found to vary from 0.20 to 0.40 and 0.60 to 3.10 me L^{-1} , respectively (Quddus and Zaman, 1996). Alamgir *et al.* (1999) conducted a study at Madhupur Tract and revealed that the amount of HCO_3 ranged from 13.50 to 60.10 mg L^{-1} in groundwater and the amount of CO_3 in each groundwater sample was undetectable. Ali (1997) found that the content of HCO_3 in groundwater samples collected from Northern and Eastern Piedmont plains varied from 0.61 to 6.55 me L^{-1} and all the waters were not problematic for irrigating agricultural crops. Helaluddin (1996) described that the concentration of HCO_3 in surface and groundwater samples of Khagrachari aquifers ranged from 0.10 to 1.25 me L^{-1} .

2.8 Water quality on the basis of Arsenic

Zaman *et al.* (2001) analyzed 18 groundwater samples collected from shallow and deep tubewell of different villages of Bhaluka upazila under Mymensingh district and found that only two samples responded to As test, where the concentration of As in each sample was 0.05 mg L^{-1} and also were safe for irrigating agricultural crops. Out of the 103 surface 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 area and he observed that in 30 samples collected from Bagmara upazila, As content of only three water samples were 0.05, 0.19 and 0.35 mg L^{-1} , respectively. Alam and Sattar (1999) analyzed tube-well water samples collected from five selected sites of four districts of Bangladesh and found that As content in tubewell waters of Chapainawabganj sadar, Kushtia sadar, Bera, Ishurdi and Sharishabari thana ranged from 0.010 to 0.056, 0.01 to 0.071, 0.010 to 0.056, 0.010 to 0.056 and 0.025 to 0.071 mg L^{-1} , respectively and out of the 25 water samples, 17 samples contained variable amount of As but only six sampling sites contained As above 0.05 mg L^{-1} . A DPHE / DFID regional survey showed that in 59 districts of Bangladesh, groundwater was contaminated with As (Shahidullah, 2000).

Based on information from the DPHE-UNICEF national testing programme, 29% of 51000 random tube-wells across the country contained As above the 'maximum permissible' level. The As contamination zone extended up to depth of 150 meters and tube-well waters at depth of 200 meters or below were mostly safe (Quadiruzzaman, 1999). In Northern and Eastern Piedmont Plains, As content of surface and ground water samples were detected in trace amount ($<0.05 \text{ mg L}^{-1}$) and these waters were not toxic to soils and crops (Ali, 1999). Mondal *et al.* (1998) stated that in all the tube-well waters collected from Fakirpara in Parganas district of West Bengal, 89% tube-well waters contained above 0.50 mg L^{-1} As, 4.3% having $<0.01 \text{ mg L}^{-1}$, 6.5 % having 0.01 to 0.05 and 0.051 to 0.099 mg L^{-1} , 26.1% having 0.01 to 0.299 mg L^{-1} , 21.74% having 0.30 to 0.499 mg L^{-1} , 17.5% having 0.50 to 0.699 mg L^{-1} and 10.9% having 0.70 to 1.00 mg L^{-1} As. Sen *et al.* (1997) reported that As pollution was not detected in all the water samples collected from Tongi aquifers because the content of As was below 0.05 mg L^{-1} .

2.9 Water quality on the basis of Hardness

Ca^{+2} and Mg^{+2} cause by far the greatest portion of the hardness occurring in natural waters.

Acharya *et al.* (2008) found that The $\text{Ca}^{+2} + \text{Mg}^{+2}$ hardness values of the ground water samples of Bhiloda taluka of Sabarkantha district (North Gujarat), India ranged from 3.1 to 12.3 me L^{-1} . The lowest value of 3.1 me L^{-1} from Sunokh where the highest value of 12.3 me L^{-1} was recorded in water samples from Kebava.

The H_T values of ground water in sadar upazila under Pabna district varied from 183.08 to 376.72 mg L^{-1} (Arefin, 2002). Rahman (2001) reported that the H_T values ranged from 84.9 to 265.9 mg L^{-1} in groundwater in selected aquifers of Bogra. Siddique (2000) stated that the hardness values of waters ranged from 64.90 to 299.49 mg L^{-1} in Lower Atrai Basin. In surface and groundwater samples collected from 11 unions of Bhaluka upazila under Madhupur Tract, the hardness of waters ranged from 29.94 to 304.39 mg L^{-1} indicating 'soft' to 'very hard' waters in category (Nizam,2000). Hoque (2000) revealed that the hardness (H_T) values of ground waters collected from Sherpur sadar under the district of Sherpur ranged from 36.96 to 159.91 mg L^{-1} . Jesmin (2000) found that in 55 groundwater samples collected from Gaibandha aquifers, the hardness (H_T) of all the ground waters were within the limit of 109.64 to 459.24 mg L^{-1} showing 'moderately hard' to 'very hard' in quality. Ali (1997) revealed that the hardness values of 50 ground

waters collected from Nachoul upazila at High Barind Tract varied from 49.98 to 227.02 mg L⁻¹ and only 25 samples were classified as 'hard'. Zaman (2000) stated that the hardness (H_T) values of ground waters samples 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. Sarker (1997) analyzed 112 groundwater samples collected from different locations of Naryanganj aquifers and reported that the hardness (H_T) value was within the limit of 49.00 to 569.60 mg L⁻¹. He reported that out of 112 samples were soft, 39 samples were 'moderately hard' 45 samples were 'hard' and the rest 12 samples were 'very hard' classes.

2.10 Water quality on the basis of Sodium Adsorption Ratio and Soluble Sodium Percentage

Acharya *et al.* (2008) stated that the sodium adsorption ratio (SAR) values varied from 0.37 to 26.40 in the ground water of Bhiloda taluka of Sabarkantha district (North Gujarat), India. They also found that about 54% of the water samples of the taluka under study have low values (<10.0). Sarfraz and *et al.* (2007) carried out a research study to determine the sodium adsorption ratio (SAR) in metal-polluted irrigation water from a Nullah Dek at Thatta Wasiran in Sheikhpura District (Pakistan) over a period of time. Water samples were collected during rice crop (cv. Super Basmati and Basmati 385) growth at 15-day intervals from 3 August to 1 November 2002. The results showed that Nullah Dek water had an SAR which was within the safe limit. Mostafa *et al.* (2006) stated that sodium adsorption ratio (SAR) in drainage water (DW) and sewage water (SW) used for irrigation was 6.90 and 5.06, respectively in El-Sharkia Governorate, Egypt.

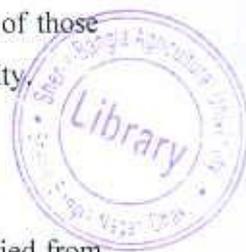
Islam *et al.* (2003) stated that Sodium Adsorption Ratio (SAR) values were between 0.36 and 3.40 in the ground water sample of Matiranga Upazilla under Khagrachari Hill District of Bangladesh. Arefin (2002) stated that the SAR values of groundwater samples in sadar upazila under Pabna district varied from 0.38 to 1.05. The SAR values of groundwaters of Sherpur upazila in Bogra district ranged from 0.22 to 0.90 (Rahman, 2001). Nizam (2000) found that the SAR values of Bhaluka upazila under the district of Mymensingh ranged from 0.06 to 0.30. Hoque (2000) analyzed groundwaters of Sherpur sadar under the district of Sherpur and found that the SAR values ranged from 0.07 to 2.69 reflecting 'low' alkalinity hazard (SI). Jesmin (2000) found that the SAR values of

groundwaters collected from Gaibandha aquifers varied from 0.29 to 3.28. The values of SAR varied from 0.12 to 0.89 in groundwaters of Lower Atrai Basin in Naogaon district (Siddique, 2000). An experiment was conducted by Zaman (2000) and found that the SAR values of groundwaters collected from Mahadebpur upazila of Naogaon district, Bagmara and Nachoul upazilas of Rajshahi district varied from 0.52 to 3.30, 0.74 to 5.06 and 0.36 to 1.83, respectively indicating 'low' sodium hazard (SI). Mitra and Gupta (1999) revealed that the SAR values of tubewell waters of Calcutta in India during monsoon and winter seasons were 0.55 and 0.65, respectively and remarked that on the basis of SAR, all the waters are excellent in quality. Hussain and Ahmed (1999) analyzed groundwaters of Muktagacha under the district of Mymensingh and indicated that water samples were graded as 'excellent' to poor in quality. Ali (1997) reported that the SAR values of groundwater of Nachoul under Nawabgang district at High Barind Tract varied from 0.36 to 2.70 and all the waters were excellent for irrigation.

Acharya *et al.* (2008) found that the soluble sodium percentage (SSP) values of the ground water samples of Bhiloda taluka of Sabarkantha district (North Gujarat), India ranged from 12.2 to 91.4. The lowest value of 12.2 per cent was observed in Jinava whereas the highest value of 94.4 per cent was recorded in a water sample from Sunokh. They further found that about 61.53 per cent of the water samples have high values (>60) of SSP.

Zaman (2000) observed that the SSP values of groundwaters collected from Bagmara, Mahadebpur and Nachoul upazilas in Barind area ranged from 25.53 to 75.61, 21.20 to 79.42 and 17.00 to 51.56 percent, respectively. Nizam (2000) found that the SSP values of 103 surface and groundwater samples collected from 11 unions of Bhaluka upazila under Mymensingh district ranged from 2.38 to 17.41 percent. In Gaibandha aquifers, the SSP values of groundwater samples varied from 9.20 to 45.75% and all waters under test were 'excellent', 'good' and 'permissible' classes (Jesmin, 2000). In 25 groundwater samples used for irrigation, the computed SSP values varied from 15.99 to 69.67% and all the waters were 'excellent' in quality (Hussain and Ahmed, 1999). Sarker (1997) reported that the SSP value of groundwaters in Naryanganj aquifers varied from 6.31 to 91.20% and also stated that all the water samples were categorized into 'excellent', 'good', 'permissible' and 'doubtful' in quality. In 50 groundwater samples of Nachoul at High Barind Tract, the SSP values of those waters ranged from 17.00 to 51.56 % (Ali, 1997). Quddus and Zaman (1996) conducted an experiment to assess the quality of groundwaters

of Meherpur sadar under Meherpur district and the revealed that the SSP value of those waters varied within the limit of 8.14 to 14.7% reflecting 'excellent' in water quality.



2.11 Water quality on the basis of Residual Sodium Carbonate

Acharya *et al.* (2008) found that the Residual sodium carbonate (RSC) values varied from -6.60 to 12.20 in the ground water of Bhiloda taluka of Sabarkantha district (North Gujarat), India. Sarfraz and *et al.* (2007) carried out a research study to determine the residual sodium carbonate (RSC) in metal-polluted irrigation water from a Nullah Dek at Thatta Wasiran in Sheikhpura District (Pakistan) over a period of time. Water samples were collected during rice crop (cv. Super Basmati and Basmati 385) growth at 15-day intervals from 3 August to 1 November 2002. The results showed that Nullah Dek water had a RSC of 2.78-4.11 meL^{-1} , which was hazardous for crops.

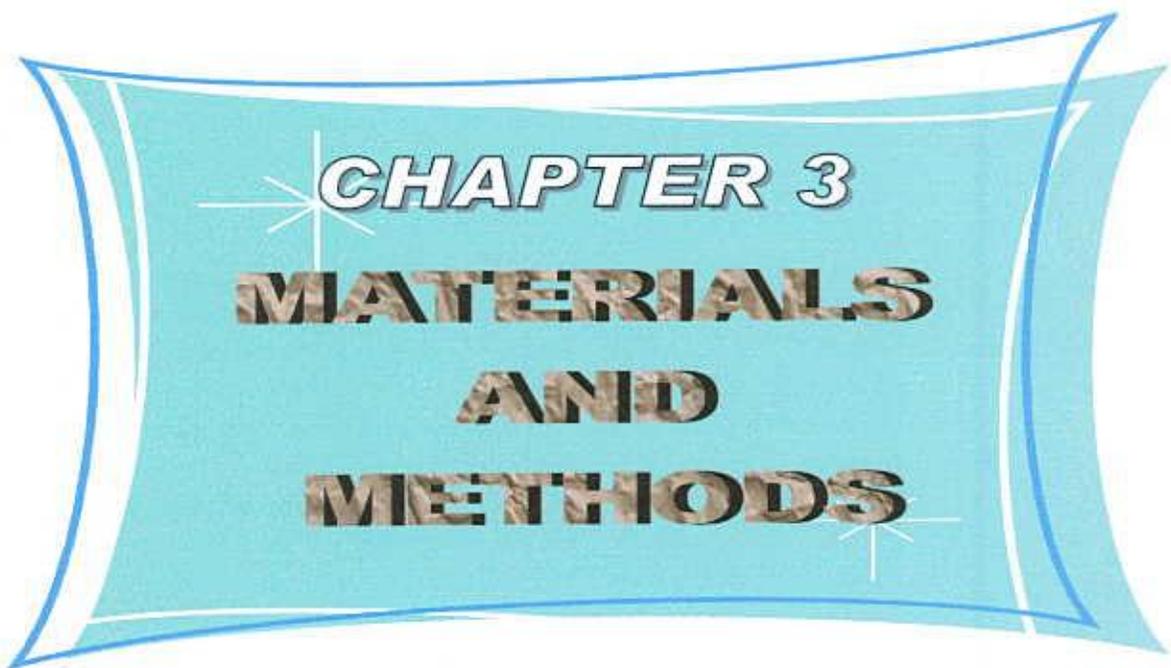
Arefin (2002) reported the RSC values of groundwater samples in sadar upazila under Pabna district varied to -0.10 to 0.10 me L^{-1} . Rahman (2001) stated that the RSC values of groundwater samples of Sherpur upazila in Bogra district were found between -0.1 to 2.40 me L^{-1} . Hoque (2000) analyzed groundwater samples of Sherpur sadar under Sherpur district and reported that the RSC values ranged from -1.10 to -0.10 and 0.00 to 1.90 me L^{-1} showing 'suitable' and 'marginal' water cases. Siddique (2000) reported that in all the groundwater samples collected Lower Atrai Basin RSC values varied from -1.80 to 0.15 meL^{-1} and these waters were rated as 'suitable' and 'marginal' classes. Jesmin (2000) found that in 55 groundwater samples collected from Gaibandha aquifers, RSC value was within the range of 0.10 to 0.61 me L^{-1} . Zaman (2000) conducted a research work by collecting 90 groundwater samples from Bagmara, Mahadebpur, and Nachoul upazilas and observed that the RSC value fluctuated within the range of -8.1 to 0.8, -6.0 to 2.2 and -0.75 to 8.8 me L^{-1} , respectively. Nizam (2000) stated that in surface and groundwater samples collected from Madhupur Tract, RSC values fluctuated between -0.30 to 5.8 me L^{-1} and these water samples were 'suitable' and 'unsuitable' classes. Lal *et al.* (1998) carried out an experiment with 173 water samples collecting from different locations of Bikaner district of Rajasthan Pradesh in India to evaluate the 'suitability' of groundwaters for irrigation and reported that 75.70, 21.20 and 3.00 percent samples contained <2.50, 2.50 to 5.00 and >5.00 mmol L^{-1} RSC, respectively. Sarker (1997) observed that the value of RSC of groundwaters in Naryanganj aquifers fluctuated between -0.643 to 2.93 me L^{-1} with the mean value of -1.84 me L^{-1} . He also reported that out of 112 water

samples, 109 samples were in 'suitable' and the rest 3 samples were in 'marginal' categories. The RSC of groundwater samples of Nachoul thana under Nawabganj district was computed by Ali (1997) and found RSC within the limit of -0.03 to -0.75 and 0.05 to 1.22 me L⁻¹. The RSC value of 19 surface and groundwater samples collected from Shahzadpur thana under the district of Sirajganj were negative which indicated that all the samples were free from RSC and 'suitable' for irrigation (Rahman and Zaman, 1995).

Water quality in general

Diel *et al.* (2007) conducted a study which was aimed at quantifying nutrients concentration in the irrigation waters used in the southern region of the State of Rio Grande do Sul, Brazil, and to estimate its possible contribution to rice nutrition. Sixty water samples (twenty each) were collected from dams, lagoons and rivers. Results revealed the N-ammonium, N-nitrate, phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), zinc (Zn), iron (Fe), manganese (Mn) and silicon (Si) content, pH and electrical conductivity values. The elements concentration in the irrigation waters decreased in the order Na > Ca > Si > Fe > Mg > K > Mn > N > Zn > P. The average elements contents were different between irrigation sources: N and Si in rivers were higher than those in lagoons; Ca and Mg were more concentrated in lagoons than in dams; and Fe was more concentrated in dams and rivers compared to the lagoons.

From the above research findings related to the present study, it is found that a considerable number of scattered investigations have been carried out in Bangladesh and different parts of the globe on water quality for various usages. At present, water pollution is a great threat all over the world. Ground water environment was deteriorating rapidly by the discharge of municipal wastes, industrial effluents, agricultural wastes and indiscriminate use of agrochemical. It is necessary to assess the ground water quality for irrigation, drinking and livestock consumption for the judicious management of water efficiently.



CHAPTER 3
MATERIALS
AND
METHODS

CHAPTER 3

MATERIALS AND METHODS

Water quality is important for its suitability for specific use. An attempt has been taken to analyze ground water samples collected from Kushtia district and the chemical analysis include the estimation of pH, electrical conductivity (EC), total dissolved solids (TDS) and major ionic constituents like Ca, Mg, K, Na, Fe, Mn, B, As, Cu, PO₄, CO₃, HCO₃, SO₄ and Cl.

3.1 Collection and Preparation of Groundwater Samples:

The ground water sampling sites were selected in Kushtia district. Forty one (41) ground water samples were randomly collected to cover most of the investigated area during January, 2008 to February, 2008 following the sampling techniques as outlined by Hunt and Wilson (1986) and APHA (1995). The sites of water sampling for ground water sources were shown in Fig.1. The information regarding groundwater sampling has been presented in Table I. All the ground water samples were collected in 2.0 litre fresh plastic container. These containers were cleaned with dilute hydrochloric acid (1:1) and then washed with tap water followed by distilled water. Before sampling containers were again rinsed 3 to 4 times with water to be sampled. All the ground water samples were collected at running conditions of deep, shallow and hand tube-wells after pumping sufficient quantity of water. The collected samples were tightly sealed immediately to avoid exposure to air. During water sampling, all waters were colorless, odorless and also free from turbidity. The chemical analysis of groundwater was performed as quickly as possible on arrival at laboratory Bangladesh Agricultural Research Institute (BARI) Laboratory, Gazipur.



Fig 1: Water sampling sites of Kushtia district along with map of Bangladesh

Parameters:

Table 1. Information of Groundwater Sources of Kushtia Districts

Sample No.	Sampling location			Source	Depth (m)	Date of Installation	Duration (years)
	Village	Union	Upazila				
1	Barkhada	Barkhada	Kushtia Sadar Upazila	STW	48.78	19-01-1988	21
2	Chachua	Mazampur	Kushtia Sadar Upazila	STW	37.55	05-03-2004	5
3	Sastipur	Jagati	Kushtia Sadar Upazila	HTW	43.54	14-03-2003	6
4	Fakirabad	Patikabari	Kushtia Sadar Upazila	STW	46.45	12-11-1997	11
5	Sonaidanga	Alampur	Kushtia Sadar Upazila	STW	39.26	11-06-2005	4
6	Boddanathpur	Jhaudia	Kushtia Sadar Upazila	HTW	47.25	11-10-1995	13
7	Bittipara	Ujangram	Kushtia Sadar Upazila	STW	35.27	05-04-1997	12
8	Abdalpur	Laxmipur	Kushtia Sadar Upazila	STW	29.27	08-06-1993	16
9	i Fakirpara	Monohard	Kushtia Sadar Upazila	STW	32.56	12-05-1999	10
10	Ahsannagar	Gosaindurgaur	Kushtia Sadar Upazila	STW	33.54	11-06-1996	13
11	Aylchara	Aylchara	Kushtia Sadar Upazila	STW	28.65	12-04-2000	9
12	Harishankarpur	Harisankarpur	Kushtia Sadar Upazila	DTW	88.25	07-05-1998	11
13	Kalishankarpur	Kalisankarpur	Kushtia Sadar Upazila	DTW	94.28	05-06-1997	12
14	Aruapara	Aruapara	Kushtia Sadar Upazila	HTW	42.12	14-06-2002	7
15	Amlapara	Amlapara	Kushtia Sadar Upazila	HTW	44.18	13-04-2001	8
16	Nishinda	Piarpur	Kushtia Sadar Upazila	STW	31.52	12-06-2007	2
17	Sastipur	Santidanga	Kushtia Sadar Upazila	STW	36.63	17-03-2006	3
18	Sinda	Kamlapur	Kushtia Sadar Upazila	STW	34.64	19-07-1999	10
19	Raidanga	Kaya	Kumarkhali Upazila	STW	47.55	07-05-1990	19
20	Jahedpur	Shelaidah	Kumarkhali Upazila	STW	48.77	16-05-2001	8
21	Bakhai	Nandalalpur	Kumarkhali Upazila	HTW	38.58	22-02-1989	20

Table 1 (Continued)

Sample No.	Sampling location			Source	Depth (m)	Date of Installation	Duration (years)
	Village	Union	Upazila				
22	Shymnagar	Chapra	Kumarkhali Upazila	STW	47.65	14-03-1990	19
23	Bhaluka	Jodboira	Kumarkhali Upazila	STW	45.25	05-03-1999	10
24	Mohendrapur	Mohendrapur	Kumarkhali Upazila	STW	49.25	09-06-2003	6
25	Amlabari	Hashimpur	Kumarkhali Upazila	STW	45.23	22-12-1993	16
26	Boira	Jotpara	Kumarkhali Upazila	STW	39.26	11-06-2005	4
27	Ambaria	Ambaria	Khoksa Upazila	STW	38.74	12-06-2001	8
28	Gosaidangi	Dhokrakhhol	Khoksa Upazila	STW	41.26	11-06-2003	6
29	Utholi	Mohisbathan	Khoksa Upazila	HTW	42.84	10-05-2005	4
30	Fulbaria	Fulbaria	Khoksa Upazila	STW	37.29	12-07-2000	9
31	Baraichara	Samashpur	Khoksa Upazila	DTW	54.28	10-05-1991	18
32	Joyantihazra	Joyantihazra	Khoksa Upazila	HTW	41.38	21-04-2002	7
33	Mohishakula	Nischintobaria	Khoksa Upazila	STW	39.17	24-06-1997	12
34	Mirzapur	Mirzapur	Khoksa Upazila	STW	42.19	19-04-1996	13
35	Osmanpur	Janipur	Khoksa Upazila	DTW	87.42	24-05-1993	16
36	Taherpur	Taherpur	Khoksa Upazila	HTW	45.26	27-05-2006	3
37	Ranakharia	Talbaria	Mirpur Upazila	STW	38.78	19-01-1998	11
38	Katlamari	Sadarpur	Mirpur Upazila	STW	37.25	05-03-2007	2
39	Ahmedpur	Poradah	Mirpur Upazila	HTW	47.54	14-03-2003	6
40	Chhatian	Chhatian	Mirpur Upazila	STW	36.45	12-11-1999	10
41	Pagla	Malihad	Mirpur Upazila	STW	34.52	11-06-2008	1

Legend: DTW= Deep Tube-well Water
STW= Shallow Tube-well Water
HTW= Hand Tube-well Water



3.2 Analytical Methods of Water Analysis

3.2.1 pH

The pH of water samples were determined electrometrically following the procedure mentioned by Ghosh *et al.* (1983) using pH meters (HI 8424 Model) in the laboratory of Biotechnology Department, Sher-e-Bangla Agricultural University, Dhaka.

3.2.2 Electrical Conductivity

The electrical conductivity (EC) of a system actually represents the concentration of total dissolved solids (TDS) or total salinity in water excluding the amount of silica. The EC of collected water samples was determined electrometrically using conductivity meter (Model HI 8423) according to the method of mentioned by Tandon (1995) in the laboratory of the Department of Biotechnology, Sher-e-Bangla Agricultural University, Dhaka.

3.2.3 Total Dissolved Solids

Total dissolved solids (TDS) were determined by weighing the solid residue obtained by evaporating a measured aliquot of filtered water samples according to the procedure described by Chopra and Kanwar (1980).

3.2.4 Sodium and Potassium

Sodium and potassium were determined with the help of a flame emission spectrometer (Model Jenway PEP 7) at 768 nm for K and 589 nm for Na. The desired spectral line was isolated using interference filters. The percent emission was recorded following the procedure mentioned by Golterman (1971) and Ghosh *et al.*, (1983).

3.2.5 Calcium, Magnesium, Iron, Copper, and Manganese

Calcium, magnesium, iron, copper, and manganese were analyzed by atomic absorption spectrophotometer (Model UNICAM 969) at the wavelengths of 324.8 nm, 248.3nm, and 279.5 nm, respectively in the Soil Science Laboratory, Bangladesh Agricultural Research Institute, Gazipur.

3.2.6 Arsenic

Total arsenic content in water was determined from the sample flow injection hydride generation atomic absorption spectrophotometer with UNICAM Model, No. 969 with hydride generator assembly using matrix matched standards (Welsch *et al.*, 1990).

3.2.7 Phosphate and Sulphate Sulphur

Phosphate was analyzed colorimetrically by Stannous Chloride method according to the procedure outlined by APHA (1995). Stannous Chloride ($\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$) reagent was added as a reducing agent which developed blue colour complex with the reduction of heteropolycomplex formed by co-ordination of molybdate and phosphate ions. Exactly 50 mL water was taken in a 100 mL volumetric flask followed by the addition of 4 mL of sulphomolybdic acid and 5 drops of Stannous Chloride reagent. The intensity of blue colour was measured at λ max. 660 nm of the help of a Spectrophotometer (Model Spectronic Genesys TM₅) within 15 minutes after the addition of Stannous Chloride (Jackson, 1958). Sulphate was estimated turbidimetrically with the help of spectrophotometer Turbidimetric reagent ($\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$) was added in a definite volume of sample. Sulphate ion reacted with barium chloride to form barium sulphate. Readings were taken in spectrophotometer ((Model Spectronic Genesys TM₅) after 30 minutes of BaCl_2 addition at 425 nm wavelength following the methods of (Wolf, 1982 and Tandon, 1995).

3.2.8 Carbonate and Bicarbonate

Carbonates and bicarbonates of water samples were determined by acidimetric method of titration using phenolphthalein indicator ($\text{C}_{20}\text{H}_{14}\text{O}_4$) for carbonate. With dilute sulphuric acid, carbonate forms colourless and bicarbonate forms rose red colour complex at the end of titration. The carbonate and bicarbonate were estimated titrimetrically by taking 10 mL water samples following the method described by Tandon (1995) and Singh *et al.*, (1999). The reactions are mentioned below:



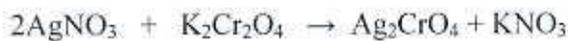
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2.3.15

3.2.9 Boron

Boron was determined by Azomethine-H method. Exactly 2 mL of water sample was taken in a polypropylene tube following by the addition of 2 mL of $\text{NH}_4\text{OAC-Na}_2\text{EDTA}$ -Glacial acetic acid buffer and 2 mL of Azomethine-H reagent. Absorbance was read at λ_{max} at 420 nm following the instructions of Page *et al.*, (1982).

3.2.10 Chloride

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



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

3.3 Evaluation of water quality or toxicity

The rating of water quality for a specific use depends on some defined quality factors. Some quality factors preferred to evaluate water quality or toxicity or pollution indicate their potential to foster soil conditions detrimental to crop growth. Some parameters to evaluate the water quality are as follows:

Sodium adsorption ratio (SAR):

It is the ratio of the concentration of sodium to the concentration of calcium plus magnesium and all these concentrations are expressed in meL^{-1} . High concentrations of sodium are undesirable in water because sodium adsorbs onto the cation exchange sites, causing soil aggregates to break down (deflocculation), sealing the pores of the soil, and making it impermeable to water flow. The tendency for sodium to increase its proportion on the cation exchange sites at the expense of other types of cations is estimated by the ratio of sodium content of calcium plus magnesium in the irrigation water.

$$\text{SAR} = \frac{\text{Na}^+}{\frac{\sqrt{\text{Ca}^{++} + \text{Mg}^{++}}}{2}} \quad (\text{Das, 1983})$$

Potassium adsorption ratio (PAR):

It is the ratio of the concentration of potassium to the concentration of calcium plus magnesium and all these concentrations are expressed in meL^{-1} .

$$\text{PAR} = \frac{\text{K}^+}{\frac{\sqrt{\text{Ca}^{++} + \text{Mg}^{++}}}{2}} \quad (\text{Das, 1983})$$

Soluble sodium percentage (SSP):

Where all soluble cations are expressed in me L^{-1} . Irrigation waters having SSP value of 60 and above are considered as harmful.

$$\text{SSP} = \frac{\text{Na}^+ + \text{K}^+}{\text{Ca}^{++} + \text{Mg}^{++} + \text{Na}^+ + \text{K}^+} \times 100 \quad (\text{Das, 1983})$$

Residual sodium carbonate (RSC):

$$\text{RSC} = (\text{CO}_3^{--} + \text{HCO}_3^-) - (\text{Ca}^{++} + \text{Mg}^{++}) \quad (\text{Das, 1983})$$

Hardness (H_T)

Hardness in water is caused primarily by calcium and magnesium, although iron and manganese also contribute to the actual hardness. Hardness may be divided into two types: carbonate and noncarbonate. Carbonate hardness is that portion of calcium and magnesium that can combine with bicarbonate to form calcium and magnesium carbonate. If the hardness exceeds the alkalinity (expressed as mg/L CaCO_3), the excess is termed noncarbonate hardness. The carbonate hardness is an indicator of the potential for

calcium carbonate precipitation and scale formation. Total hardness (carbonate and noncarbonate) is customarily expressed as equivalents of calcium carbonate (CaCO₃). Since the formula weight of CaCO₃ is near 100, hardness expressed in terms of mg/L of CaCO₃ can be converted to meq/L by dividing by 50.

$$H_T = 2.5X Ca^{++} + 4.1 X Mg^{++} \quad (\text{Das, 1983})$$

Where, concentrations of ionic constituents for calculating all parameters except hardness in me L⁻¹ and incase of hardness as 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 scientific calculator (Casio Super fx-991 MS). Correlation studies were also performed following the standard method of computer programme (SPSS).

3.5 Checking the Correctness of Analysis

The accuracy of chemical analysis of water samples were checked by means of the following procedure. Electrical conductivity (EC), pH, total dissolved solids (TDS) and major anion-cation constituents were the indications of irrigation water quality. The difference between the sum of cations and sum of anions and the measured or calculated TDS to EC ratio were required for detecting discrepancies. The correctness of analysis of water samples were checked following the methods described by APHA (1995).

3.5.1 Anion-cation balance

The sum of anions and cations expressed as meL⁻¹ must be balanced because all potable waters are electrically neutral. The difference between the anion and cation sums fall between acceptable limits (5-10%) and percentages of differences is calculated on the basis of the following equation:

$$\% \text{ difference} = \frac{\sum \text{Cations} - \sum \text{Anions}}{\sum \text{Cations} + \sum \text{Anions}} \times 100$$

3.5.2 Ratio of measured or calculated TDS to EC

The values of measured TDS and EC are necessary to compare with the calculated TDS and EC values for checking of analysis. The TDS values were calculated from the \sum of major cationic and anionic constituents (in mgL^{-1}) which are as follows:

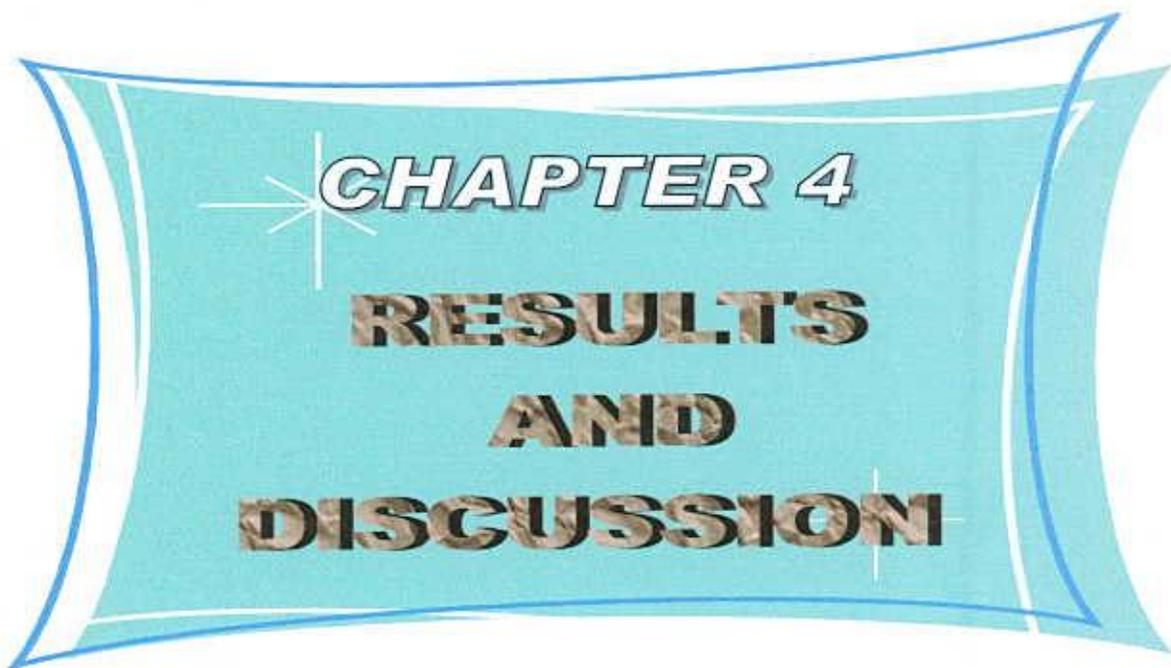
$$\text{TDS} = \text{CO}_3^- + \text{HCO}_3^- + \text{Na}^{++} + \text{K}^+ + \text{Ca}^{++} + \text{Mg}^{++} + \text{SO}_4^{--} + \text{Cl}^-$$

The electrical conductivity (EC) was also calculated from the \sum of cation or anion (in me L^{-1}) as follows:

If calculated TDS or EC is higher or lower beyond the acceptable range than the measured value, the reanalysis is necessary to check the accuracy of chemical analysis. The acceptable criteria for the ratio of calculated or measured TDS to EC is from 0.55 to 0.70. The criteria for acceptable ratio are as follows:

$$1.0 < \frac{\text{Measured TDS}}{\text{Calculated TDS}} < 1.2$$

$$0.90 < \frac{\text{Calculated EC}}{\text{Measured EC}} < 1.1$$



CHAPTER 4
RESULTS
AND
DISCUSSION

CHAPTER 4

RESULT AND DISCUSSION

The ionic concentrations of Ca, Mg, Na, K, Fe, Cu, Mn, As, B, PO₄, SO₄, HCO₃ and Cl were present in variable quantities 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 analysis is usually done after USEPA (United States Environment Protection Agency) standards. Different leading organizations also follow USEPA criteria such as FAO, UNICEF, USDA etc. The experimental findings described in the foregoing chapter are described and are discussed here in the light of relevant research reports wherever applicable. The concentrations of major ions (Ca, Mg, Na, K, Cl, CO₃²⁻ and HCO₃⁻) were presented in Fig.2 where the vertical bar diagrams presented major ionic concentrations.

The obtained results are described and discussed under following headings:

4.1 Groundwater Rating for Irrigation

4.1.1 pH

The pH of waters varied from 6.53 to 7.63 (Table.2) and indicated that waters were acidic to alkaline. Out of 41 samples, 5 samples were below 7.0 (i.e. 6.53 to 6.99) and were acidic to slightly acidic in nature. These 5 samples would be suitable for acid loving crops. The remaining 36 samples under the study showed higher pH values above 7.0 ranging from 7.03 to 7.63 and were slightly alkaline in nature. Ayers and Westcott (1985) mentioned that the normal pH range of irrigation usually varied from 6.0 to 8.5. It indicated that the pH of all water samples under test were within the normal range and these waters might not be harmful for soils and crops.

Table 2: Concentrations of pH, EC, TDS, Ca, Mg, Na, K, Fe, Mn, Cu, B, As, SO₄, PO₄, CO₃, HCO₃ and Cl in groundwater

SL. No	pH	EC (μS cm ⁻¹)	TDS (mg L ⁻¹)	Ca (mg L ⁻¹)	Mg (mg L ⁻¹)	Na (mg L ⁻¹)	K (mg L ⁻¹)	Fe (mg L ⁻¹)	Mn (mg L ⁻¹)	Cu (mg L ⁻¹)	B (mg L ⁻¹)	As (mg L ⁻¹)	SO ₄ (mg L ⁻¹)	PO ₄ (mg L ⁻¹)	CO ₃ (mg L ⁻¹)	HCO ₃ (mg L ⁻¹)	Cl (mg L ⁻¹)
1	7.12	845	827.54	61.0	33.0	43.76	0.61	0.43	Trace	0.05	0.16	0.11	0.5	4.36	Trace	466.87	56.3
2	7.16	675	667.93	44.0	35.1	36.61	1.82	0.38	Trace	0.02	0.14	0.11	0.7	1.78	Trace	375.24	63.8
3	7.03	560	623.93	34.8	28.2	51.69	2.12	0.46	Trace	0.05	0.14	0.03	0.7	6.39	Trace	257.69	33.7
4	7.03	652	756.84	48.3	43.2	39.0	3.94	0.30	Trace	Trace	0.12	0.06	0.6	1.78	Trace	327.35	37.2
5	7.11	503	675.38	56.2	37.2	30.15	2.12	0.28	Trace	Trace	0.12	0.03	0.7	0.98	4.7	245.24	51.7
6	7.14	670	338.07	30.1	25.3	36.15	1.56	0.29	Trace	Trace	0.11	0.07	1.1	2.83	1.97	326.54	9.2
7	7.14	775	751.59	35.5	26.0	30.61	1.21	0.31	0.03	Trace	0.12	0.04	0.6	3.77	18	339.25	31.6
8	7.20	798	866.37	43.6	27.1	31.30	0.61	0.25	Trace	Trace	0.13	0.06	0.8	7.25	Trace	325.14	23.8
9	7.21	1025	293.75	37.2	30.2	34.43	0.91	0.30	Trace	Trace	0.13	0.03	0.5	10.43	6.4	312.65	61.0
10	7.16	1127	675.07	41.8	40.0	29.46	1.82	0.16	Trace	0.01	0.10	0.67	1.2	1.57	5.5	463.87	42.9
11	6.98	1057	522.44	38.8	29.3	33.46	1.56	0.22	Trace	Trace	0.11	0.03	1.2	1.59	4.8	385.72	74.2
12	7.13	480	495.64	28.7	18.8	37.53	3.0	0.30	Trace	Trace	0.12	0.02	1.7	7.56	Trace	413.66	80.6
13	6.53	1060	634.35	70.0	29.0	21.67	1.21	0.20	Trace	Trace	0.15	0.01	1.0	0.95	Trace	321.25	47.9
14	7.21	1310	629.89	61.2	42.0	28.69	3.64	0.14	Trace	Trace	0.08	0.04	0.8	3.77	8.3	257.36	38.6
15	7.29	503	535.25	40.6	31.0	31.07	1.52	0.34	0.01	Trace	0.10	0.06	3.7	1.78	5.9	277.24	9.9
16	7.09	990	639.38	44.8	36.5	32.82	1.52	0.21	Trace	0.02	0.09	0.08	2.7	1.69	9.4	257.86	27.7
17	7.20	801	384.52	35.2	30.0	42.69	0.30	0.40	Trace	0.04	0.10	0.09	1.7	4.36	5.1	194.52	17.5
18	7.11	785	436.52	61.5	36.3	37.15	3.30	0.35	Trace	0.01	0.10	0.34	3.5	0.95	5.4	300.25	9.8
19	7.14	954	257.58	43.6	38.0	31.61	3.64	0.23	0.05	Trace	0.11	0.05	3.4	0.98	9.3	303.54	76.9
20	6.99	835	268.76	37.8	36.2	39.46	3.65	0.32	Trace	Trace	0.08	0.07	2.6	6.39	8.3	366.74	67.4
21	6.99	702	579.87	38.8	40.3	37.69	3.42	0.19	Trace	Trace	0.07	0.04	1.4	1.69	Trace	320.25	51.8
22	6.93	980	476.39	70.3	52.3	46.46	2.12	0.41	Trace	Trace	0.08	0.03	2.1	3.77	25.3	254.87	41.5
23	7.07	676	387.36	45.5	44.0	36.23	2.42	0.26	Trace	Trace	0.40	0.09	1.3	2.83	Trace	253.40	76.2
24	7.06	730	649.23	40.8	37.1	32.61	1.83	0.20	0.02	Trace	0.08	0.06	2.6	1.57	Trace	317.81	40.1
25	7.05	476	356.49	38.2	35.2	29.84	4.85	0.15	0.04	Trace	0.12	0.04	1.8	5.54	8.6	191.23	62.7
26	7.21	411	477.78	40.4	31.0	47.30	1.81	0.45	Trace	Trace	0.11	0.08	1.6	2.83	6.8	195.35	72.8

Table 2: (Continued)

SL. No.	pH	EC ($\mu\text{S cm}^{-1}$)	TDS (mg L^{-1})	Ca (mg L^{-1})	Mg (mg L^{-1})	Na (mg L^{-1})	K (mg L^{-1})	Fe, (mg L^{-1})	Mn (mg L^{-1})	Cu (mg L^{-1})	B (mg L^{-1})	As (mg L^{-1})	SO ₄ (mg L^{-1})	PO ₄ (mg L^{-1})	CO ₃ (mg L^{-1})	HCO ₃ (mg L^{-1})	Cl (mg L^{-1})
27	7.09	843	503.67	59.6	28.5	34.92	1.51	0.35	Trace	Trace	0.15	0.05	2.0	1.78	15.8	180.27	65.4
28	7.11	635	457.52	23.8	20.3	52.30	3.24	0.46	Trace	Trace	0.12	0.07	2.3	3.77	17.5	226.58	63.8
29	7.16	579	602.69	29.5	30.5	38.92	1.52	0.29	Trace	Trace	0.14	0.04	2.0	0.95	9.4	192.87	43.5
30	7.18	925	623.23	100	57.0	49.61	5.76	0.48	Trace	Trace	0.08	0.09	1.5	3.77	Trace	170.35	65.6
31	7.09	545	644.03	90.3	39.3	35.53	1.53	0.32	0.06	Trace	0.06	0.02	0.5	1.69	5.8	210.36	74.6
32	7.37	767	539.10	96.8	41.0	20.23	1.52	0.18	Trace	0.01	0.06	0.08	2.5	1.57	11.4	347.30	36.9
33	7.23	636	823.03	35.9	20.8	23.0	2.12	0.14	Trace	0.03	0.01	0.04	3.0	7.51	13.2	210.52	63.5
34	7.25	658	757.35	100.2	27.0	31.23	2.13	0.34	Trace	Trace	0.10	0.07	5.6	1.87	5.8	143.40	38.9
35	7.24	776	593.08	29.8	23.2	17.38	2.11	0.12	Trace	Trace	0.04	0.02	2.7	1.69	6.8	258.36	41.5
36	7.32	667	471.09	42.6	21.5	16.49	0.36	0.14	0.03	Trace	0.01	0.08	1.8	3.77	9.2	132.51	52.3
37	7.32	703	377.09	44.4	22.0	21.61	1.82	0.20	0.01	Trace	0.02	0.57	4.4	7.51	5.4	183.77	51.8
38	7.25	847	613.97	27.8	27.3	18.33	1.52	0.15	Trace	Trace	0.02	0.08	1.4	0.98	7.6	265.11	48.2
39	7.33	553	552.63	49.6	23.9	26.0	1.49	0.24	Trace	Trace	0.02	0.06	4.5	4.36	6.4	234.65	76.6
40	7.16	581	451.33	49.0	35.8	21.0	1.21	0.17	Trace	Trace	0.04	0.03	3.9	1.69	5.8	216.68	39.7
41	7.63	700	755.28	43.4	34.1	34.92	2.41	0.22	Trace	Trace	0.03	0.05	2.0	3.77	11.2	236.09	42.7
Range	6.53 to 7.63	411.0 to 1310.0	257.58 to 866.37	23.8 to 100.2	18.8 to 57.0	16.49 to 52.30	0.30 to 4.85	0.12 to 0.48	Trace To 0.06	Trace To 0.05	0.01 to 0.16	0.01 to 0.67	0.5 to 5.6	0.95 to 10.43	Trace To 25.3	132.51 to 466.87	9.2 to 80.6
S(x ⁻)	6.98	751.09	560.32	48.57	32.79	33.43	2.116	0.276	178.6	178.6	0.099	0.09	1.966	3.318	8.055	284.38	49.07
SD	0.16	198.88	153.99	19.21	8.31	8.99	1.16	0.102	0.018	0.017	0.063	0.134	2.31	2.30	2.62	80.18	19.28
CV %	2.24	26.48	27.48	39.54	25.33	26.88	54.97	36.07	58.06	62.18	63.63	66.79	69.51	69.27	32.54	29.49	39.29

4.1.2 Electrical Conductivity

The electrical conductivity (EC) of all water samples was within the limit of 411 to 1310 $\mu\text{S cm}^{-1}$ with the mean value of 751.09 $\mu\text{S cm}^{-1}$ (Table 2). The EC values of 23 samples (56.09%) were less than the mean value and the rest 18 samples (43.91%) were higher than the average value. The highest value (1310 $\mu\text{S cm}^{-1}$) was recorded from the sample no.14 and lowest amount (411 $\mu\text{S cm}^{-1}$) was obtained from the sample no.26. According to Richards (1968) as illustrated in Fig.3, all the ground waters under test were rated as 'medium salinity' (C2) and 'high salinity' (C3) waters. Out of 41 samples, 18 samples were of 'medium salinity' and 23 samples were of 'high salinity' water. According to Wilcox, L.V.(1995) as reported in Appendix I, ground water of such quality (i.e. <250 to 2000 $\mu\text{S cm}^{-1}$) 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

The amount of total dissolved solids (TDS) of ground water samples in the investigated area varied from 257.58 to 866.37 mg L^{-1} with mean value of 560.32 mg L^{-1} and CV value 27.48% (Table 2). Out of 41 samples, about 48.78% TDS values (20 samples) were found below the mean value and remaining 51.22% samples (21 samples) were found above the average value. The highest TDS value (866.37 mg L^{-1}) was detected in shallow tube well (sample no.8). Sufficient quantities of bicarbonate, sulphates and chloride of Ca, Mg and Na caused to high TDS value. Similar opinion stated by Karanth, (1994). According to Freeze and Cherry (1997) as reported in Appendix III, all the ground waters under investigation contained less than 1,000 mg L^{-1} TDS and were classified 'freshwater' 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.

4.1.4 Ionic constituents

In the study, major ions like Ca, Mg, K, Na, CO_3 , HCO_3 and Cl 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:

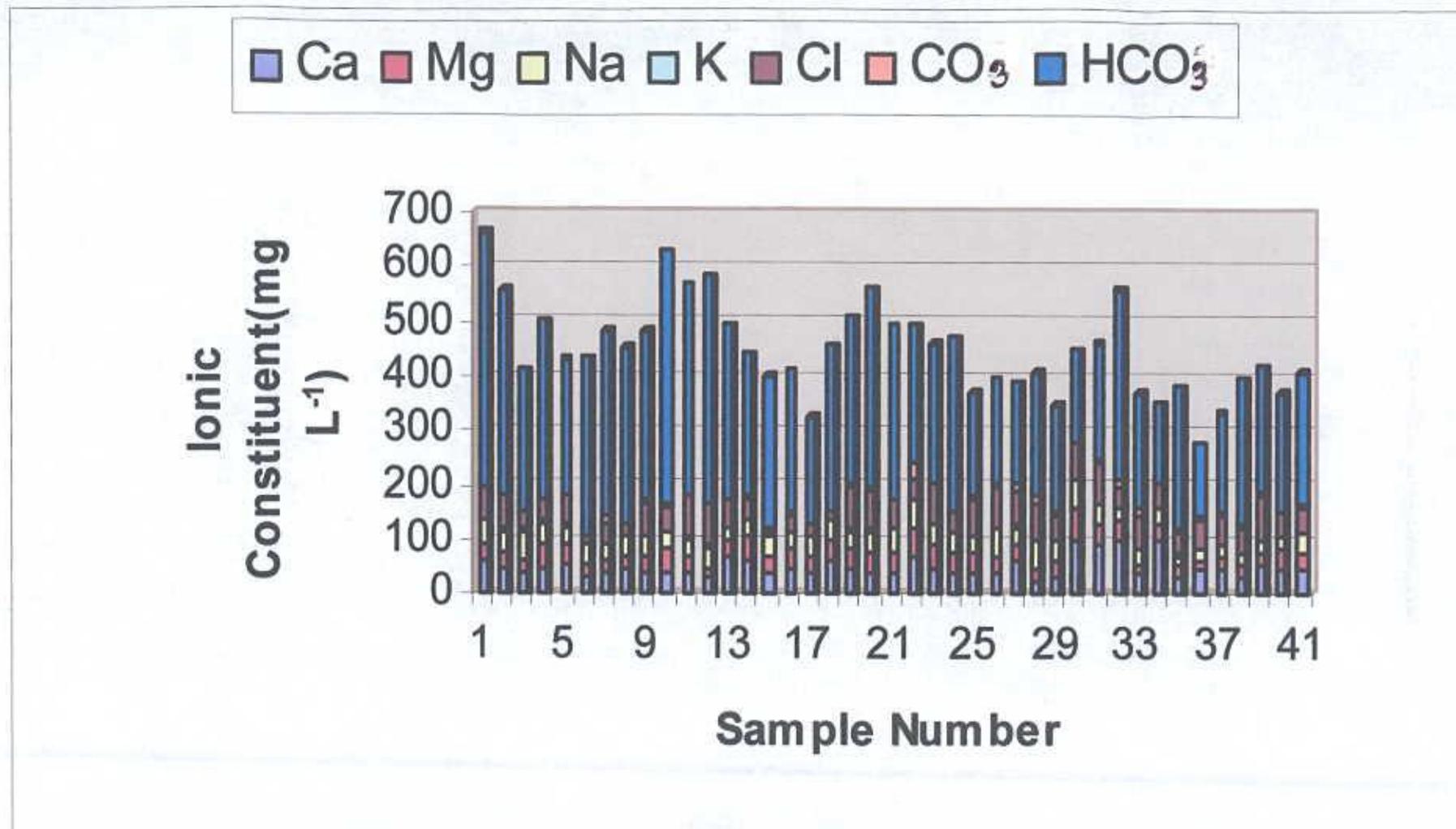


Fig. Bar diagrams for representing major ionic constituents of ground waters

4.1.4.1 Calcium

The concentration of calcium (Ca) was found within the range 23.80 to 100.20 mg L⁻¹ with the mean value of 48.57 mg L⁻¹ and CV value 39.54% (Table 2). Out of the 41 samples, 28 samples were found below the mean and the rest 13 samples were above the mean value. The standard deviation (SD) and co-efficient of variation (CV) were 19.20 and 39.54% respectively (Table 2). The highest concentration (100.20 mg L⁻¹) was found at Mirzapur village in Khoksha upazila (sample no. 34). The lowest value (23.8 mg L⁻¹) was observed at Goshaidangi village in Khoksha upazila (sample no. 28). The concentration of Ca content in ground water was largely dependent on solubility of CaCO₃ and CaSO₄. Irrigation water containing less than 20 me L⁻¹/400 mg L⁻¹ Ca was 'suitable' for crop plants (Ayers and Westcot, 1985). On the basis of Ca content, all the water samples can safely be used for irrigation and would not affect the soils.

4.1.4.2 Magnesium

Groundwater samples collected from Kushtia district, magnesium (Mg) content was found within the range of 18.80 to 57.00 mg L⁻¹ with the mean value of 32.79 mg L⁻¹ (Table 2). Out of 41 samples, 21 samples (51.22%) were found below the average value and the rest 20 samples (48.78%) recorded above the mean value. The calculated standard deviation (SD) and co-efficient of variation (CV) were 8.307 and 25.33% respectively. According to Ayers and Westcot (1985), all the irrigation waters contain below 60.75 mg L⁻¹ of Mg. In the study area, all of samples were below this limit. So, all the groundwater samples were 'suitable' for irrigation with respect to Mg content.

4.1.4.3 Sodium

The concentration of sodium (Na) in different water samples were within the range of 16.49 to 52.30 mg L⁻¹ and the mean value was 33.44 mg L⁻¹. About 20 (48.78%) samples were below the mean value and rest 21 (51.22%) samples were above the mean mean. The standard deviation (SD) and co-efficient of variation (CV %) were 8.99 and 26.88%, respectively (Table 2). Ground waters generally contain less than 40 me L⁻¹ Na (Ayers and Westcot, 1985). The recorded Na content in all the ground waters under test was far below this specified limit. In respect of Na content, all the waters of the study area can safely be applied for long-term irrigation without the harmful effects on soils and crops.

4.1.4.4 Potassium

The concentration of potassium (K) in collected water samples ranged from 0.30 to 4.85 mg L⁻¹ with 2.12 mg L⁻¹ as mean value. 56.09% values (23 samples) were below the mean, 29.68 % (12 samples) were above the mean and 14.34% (6 samples) were equal to the mean value. The standard deviation (SD) and coefficient of variation (CV %) were 1.16 and 54.97%, respectively (Table 2). The higher quantity of K in some groundwater samples might be due to the presence of some potash bearing minerals like sylvite (KCl) and niter (KNO₃) in the aquifers (Karanath,1994). The detected quantity of K in all the collected groundwater samples had no significant influence on water quality for irrigation.

4.1.4.5 Iron

All water sample contained small amount of iron (Fe) and varied from 0.12 to 0.48 mg L⁻¹. The obtained mean value was 0.28 mg L⁻¹ (Table 2). About 48.78% (20 samples) were below the mean, 1 sample was equal to mean value and rest 20 (48.78%) samples were above the mean value. The standard deviation (SD) and co-efficient of variation were 0.101 and 36.07%, respectively (Table 2). The recorded Fe concentration of groundwater samples was far below the acceptable limit (Fe = 5.00 mg L⁻¹).

4.1.4.6 Copper

All water samples contained very little amount of copper (Cu) and varied from trace to 0.05 mg L⁻¹. Mean value of this element is 0.0267. Out of 41 samples, 13 samples (31.70%) contained 0.01 to 0.05 mg L⁻¹ Copper. Cu content in rest of 28 samples were not detected by Atomic Absorption Spectrophotometer (AAS). Standard deviation (SD) and co-efficient of variation (CV %) were 0.017 and 62.18%, respectively. According to Ayers and Westcot (1985), the acceptable limit of Cu in irrigation water is less than 0.20 mg L⁻¹. On the basis of this limit, all the waters under investigation were not problematic for irrigation.

4.1.4.7 Manganese

Trace amount of manganese (Mn) was present in all water samples. According to Ayers and Westcot (1985) as shown in appendix VII, the maximum recommended content of Mn for water used for irrigation is 0.20 mg L⁻¹. On the basis of Mn content, all the waters under test were not toxic for long-term irrigation.

4.1.4.8 Arsenic

The concentration of arsenic (As) in ground water samples was within the range of 0.01 to 0.67 mg L⁻¹ with the mean value of 0.09 mg L⁻¹ (Table 2). Out of 41 samples, about 33 samples (80.48%) were below the mean value (0.09 mg L⁻¹), 3 (7.31%) samples were equal to the mean value and rest of 5 samples (12.20%) was above the mean content of As. The calculated standard deviation (SD) and co-efficient (CV %) were 0.134 and 66.79%, respectively. The status of As in 37 ground water samples was found within the recommended limit (As = 0.1 mg L⁻¹) as per Ayers and Westcot (1985) but only 4 samples collected from Barkhada, Mazumpur, Gosaindurgapur and Kamlapur villages in Kushtia sadar upazilla (nos. 1, 2, 10 and 18) were problematic for long-term irrigation.

4.1.4.9 Boron

Detected amount of boron (B) varied from 0.01 to 0.16 mg L⁻¹ having mean value of 0.099 mg L⁻¹. About 17 samples (41.46%) were below the mean value and the rest 24 samples (58.54%) values were found above the mean value. The obtained standard deviation (SD) and co-efficient of variation (CV) were 0.063 and 63.63%, respectively (Table 2). The recommended maximum concentration of B for irrigation water used continuously on soil less than 0.75 mg L⁻¹ (Ayers and Westcot, 1985). In the study area, all the ground water samples were 'suitable' for irrigation based on B content as per appendix VIII.

4.1.4.10 Phosphate

The phosphate (PO₄) content of all collected ground waters varied from 0.95 to 10.43 mg L⁻¹ with the mean value of 3.32 mg L⁻¹ (Table 2). Out of the 41 samples, 23 samples (56.09%) were below the mean value and rests of 18 samples (43.91%) were above the mean value. The obtained standard deviation (SD) and co-efficient of variation (CV) were 2.30 and 69.27%, respectively (Table 2). The status of PO₄ in 18 groundwater samples was found within the recommended limit as per Ayers and Westcot (1985) but 23 samples (nos. 1, 3, 6, 7, 8, 9, 12, 14, 17, 18, 20, 22, 24, 25, 26, 28, 29, 31, 33, 36, 37, 39 and 41) were "doubtful" for long-term irrigation and exceeded the acceptable limit (2.00 mg L⁻¹).

4.1.4.11 Sulphate

In all the ground waters, sulphate (SO_4) content varied from 0.5 to 5.6 mg L^{-1} with the mean value of 3.32 mg L^{-1} (Table 2). Out of 41 samples, 82.92 percent (34 samples) were below the mean value (3.32 mg L^{-1}) and the rest 17.08 percent (7 samples) were greater than that of mean. The standard deviation and co-efficient of variation were 2.308 and 69.51%, respectively. According to Ayers and Westcot (1985), the acceptable limit of SO_4 in irrigation water is less than 20 mg L^{-1} . On the basis of this limit; all the waters under investigation were not problematic for irrigation without any toxic effect on soils and crops grown in the study area.

4.1.4.12 Carbonate

Groundwater samples collected from the study area contained carbonate (CO_3) ranging from trace to 25.3 mg L^{-1} . Among the collected amount of CO_3 was not detectable in 11 samples. The mean value was 8.05 mg L^{-1} . About 39.02% samples were below the mean and rest 60.98% samples were above the mean (Table 2). The computed standard deviation was 2.62 and coefficient of variation was 32.54%, respectively. In respect of CO_3 content, 30 ground water samples were toxic for irrigation because CO_3 content exceeded the recommended limit as mentioned in Appendix VII.

4.1.4.13 Bicarbonate

The concentration of bicarbonate (HCO_3) in water samples were within the range of 132.51 to 466.87 mg L^{-1} and the mean value was 284.38 mg L^{-1} . Out of 41 samples, 51.22% samples (21 samples) were below the mean value and rest 48.78% (20 samples) were above the mean value. The standard deviation and co-efficient of variation were 80.18 and 29.49%, respectively. Bicarbonate content was recorded comparatively higher among the ionic constituents. In respect of HCO_3 content, all the groundwater samples were toxic for irrigation because HCO_3 content exceeded the recommended limit as mention in Appendix VII.

4.1.14 Chloride

Chloride (Cl) content varied from 9.2 to 80.6 mg L^{-1} . The mean value was 49.07 mg L^{-1} . About 51.22% (21 samples) values were below the mean value and rest 48.78 % (20 samples) were above the mean value (49.07 mg L^{-1}). The standard deviation and co-efficient of variation were 19.28 and 39.29%, respectively. Chloride content of all the

ground waters collected from the study area was not problematic for irrigation because the concentration was below recommended limit (Appendix VII). Most of the chloride in groundwater was present sodium chloride (NaCl) but chloride content may exceed sodium due to the Base Exchange phenomena (Karanth, 1994).

4.1.5 Groundwater Quality Determining Indices

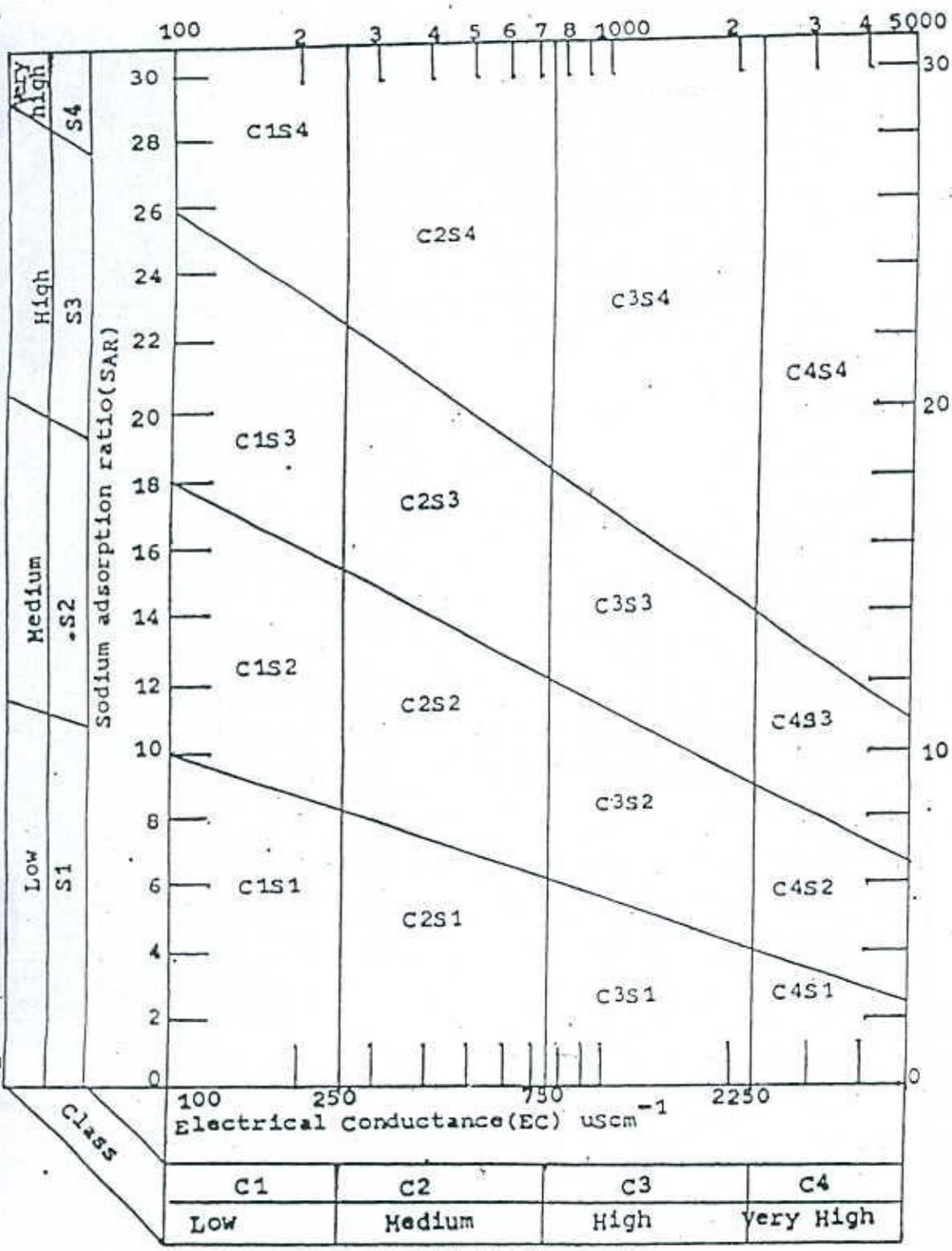
4.1.5.1 Sodium adsorption ratio

The computed sodium adsorption ratio (SAR) of groundwater samples was within the range of 2.91 to 11.13 with average value of 5.41 (Table 3). About 31.71% samples (13 samples) were found below the average value and the rest 68.29% samples (28 samples) were more than the average value (5.41). The standard deviation (SD) and co-efficient variation were 1.71 and 31.61%, respectively.

On the basis of SAR, Todd (1980) categorized irrigation waters into 4 groups as shown in Appendix IV. Considering this classification, 40 groundwater samples were 'excellent' and rest one is good for irrigation. The present investigation expressed that a good proportion of Ca and Mg existed in waters which was 'suitable' for good structure and tilth condition of soil also would improve the soil permeability. The irrigation water with SAR less than 10 might not be harmful for agricultural crops (Todd, 1980). All the groundwater samples used for irrigation were also classified on the basis of alkalinity hazard as cited diagrammatically in Fig. 3 (Richards, 1968). According to this classification, almost all samples were rated as 'low' alkalinity hazard (SI) class for irrigation as per SAR value (Table 3).

4.1.5.2 Soluble sodium percentage

The soluble sodium percentage (SSP) of all 41 water samples varied from 13.63 to 55.74. The obtained mean value was 31.52 (Table 3). About 56.09% (23 samples) values were below the mean. The standard deviation and co-efficient of variation were 8.63 and 27.38%, respectively. According to the water classification proposed by Wilcox (1955), 3 samples were classified as 'excellent' (SSP<20%), 33 samples were rated as 'good' (SSP = 20 to 40%) and the rest 5 samples were rated as 'permissible' (SSP = 40 to 60%) as reported in Appendix I. In the study area, the ground waters might safely be applied for irrigating agricultural crops.



Salinity hazard

Fig. 2. Diagram for the classification of irrigation waters (Richards, 1968).

Table 3. Classification of ground waters based on B, EC, TDS, SAR, SSP, RSC and H_T

Sample Sl. No.	B (mg L ⁻¹)		EC (μS m ⁻¹)		TDS (mg L ⁻¹)		SAR		SSP (%)		RSC (me L ⁻¹)		Hardness (mg L ⁻¹)		Alkalinity & Salinity hazard class
	Value	Class	Value	Class	Value	Class	Value	Class	Value	Class	Value	Class	Value	Class	
1	0.16	Ex	845	Per	827.54	FW	6.38	Ex	32.07	Good	1.85	Mar	287.80	H	C2S1
2	0.14	Ex	675	Good	667.93	FW	5.82	Ex	32.70	Good	1.02	Suit	253.91	H	C2S1
3	0.14	Ex	560	Good	623.93	FW	9.21	Ex	46.07	Per	0.13	Suit	202.62	H	C2S1
4	0.12	Ex	652	Good	756.84	FW	5.77	Ex	31.94	Good	-0.65	Suit	297.87	H	C2S1
5	0.12	Ex	503	Good	675.38	FW	4.40	Ex	25.68	Good	-1.89	Suit	293.02	H	C2S1
6	0.11	Ex	670	Good	338.07	FW	6.87	Ex	40.50	Per	1.74	Mar	178.98	H	C2S1
7	0.12	Ex	775	Per	751.59	FW	5.52	Ex	34.09	Good	1.62	Mar	195.35	H	C2S1
8	0.13	Ex	798	Per	866.37	FW	5.26	Ex	31.09	Good	0.89	Suit	220.11	H	C2S1
9	0.13	Ex	1025	Per	293.75	FW	5.93	Ex	34.40	Good	0.76	Suit	216.82	H	C2S1
10	0.10	Ex	1127	Per	675.07	FW	4.60	Ex	27.66	Good	2.36	Mar	268.50	H	C2S1
11	0.11	Ex	1057	Per	522.44	FW	5.73	Ex	33.96	Good	2.09	Mar	217.13	H	C2S1
12	0.12	Ex	480	Good	495.64	FW	7.71	Ex	46.04	Per	3.78	UnSuit	148.83	MH	C2S1
13	0.15	Ex	1060	Per	634.35	FW	3.08	Ex	18.77	Ex	-0.66	Suit	293.9	H	C2S1
14	0.08	Ex	1310	Per	629.89	FW	4.0	Ex	23.85	Good	-2.06	Suit	325.20	VH	C3S1
15	0.10	Ex	503	Good	535.25	FW	5.20	Ex	31.28	Good	0.13	Suit	228.60	H	C2S1
16	0.09	Ex	990	Per	639.38	FW	5.14	Ex	29.70	Good	-0.75	Suit	261.65	H	C2S1
17	0.10	Ex	801	Per	384.52	FW	7.49	Ex	39.74	Good	-0.90	Suit	211.00	H	C2S1
18	0.10	Ex	785	Per	436.52	FW	5.31	Ex	29.26	Good	-1.02	Suit	302.58	VH	C3S1
19	0.11	Ex	954	Per	257.58	FW	4.95	Ex	30.17	Good	-0.06	Suit	264.80	H	C2S1
20	0.08	Ex	835	Per	268.76	FW	6.49	Ex	36.81	Good	1.38	Mar	242.92	H	C2S1
21	0.07	Ex	702	Good	579.87	FW	8.47	Ex	34.20	Good	-0.05	Suit	262.23	H	C2S1
22	0.08	Ex	980	Per	476.39	FW	5.93	Ex	28.38	Good	-2.86	Suit	390.18	VH	C3S1

Table 3 (Continued.)

Sample Sl. No	B (mg L ⁻¹)		EC (μS m ⁻¹)		TDS (mg L ⁻¹)		SAR		SSP (%)		RSC (me L ⁻¹)		Hardness (mg L ⁻¹)		Alkalinity & Salinity hazard class
	Value	Class	Value	Class	Value	Class	Value	Class	Value	Class	Value	Class	Value	Class	
23	0.40	Good	676	Good	387.36	FW	5.42	Ex	30.16	Good	-1.79	Suit	294.15	H	C2S1
24	0.08	Ex	730	Good	649.23	FW	5.23	Ex	30.65	Good	0.08	Suit	254.11	H	C2S1
25	0.12	Ex	476	Good	356.49	FW	5.93	Ex	32.09	Good	-1.42	Suit	239.82	H	C2S1
26	0.11	Ex	411	Good	477.78	FW	4.92	Ex	40.76	Good	-1.17	Suit	228.10	H	C2S1
27	0.15	Ex	843	Per	503.67	FW	5.26	Ex	29.26	Good	-1.87	Suit	265.85	H	C2S1
28	0.12	Ex	635	Good	457.52	FW	11.13	Good	55.74	Good	1.41	Mar	142.73	MH	C2S1
29	0.14	Ex	579	Good	602.69	FW	7.10	Ex	40.26	Per	-0.55	Suit	198.80	H	C2S1
30	0.08	Ex	925	Per	623.23	FW	5.6	Ex	26.07	Good	-6.95	Suit	483.70	VH	C3S1
31	0.06	Ex	545	Good	644.03	FW	4.42	Ex	18.19	Ex	-4.75	Suit	386.88	VH	C3S1
32	0.06	Ex	767	Per	539.10	FW	2.44	Ex	13.63	Ex	-2.19	Suit	410.10	VH	C3S1
33	0.01	Ex	636	Good	823.03	FW	4.32	Ex	30.70	Good	0.36	Suit	175.03	H	C2S1
34	0.10	Ex	658	Good	757.35	FW	3.92	Ex	20.02	Good	-4.72	Suit	361.20	VH	C3S1
35	0.04	Ex	776	Per	593.08	FW	3.37	Ex	26.90	Good	1.04	Suit	169.62	H	C2S1
36	0.01	Ex	667	Good	471.09	FW	2.91	Ex	20.82	Good	-1.44	Suit	194.65	H	C2S1
37	0.02	Ex	703	Good	377.09	FW	3.75	Ex	26.08	Good	-0.86	Suit	201.20	H	C2S1
38	0.02	Ex	847	Per	613.97	FW	3.5	Ex	51.99	Per	2.58	UnSuit	181.43	H	C2S1
39	0.02	Ex	553	Good	552.63	FW	4.29	Ex	27.44	Good	-0.41	Suit	221.99	H	C2S1
40	0.04	Ex	581	Good	451.33	FW	3.23	Ex	20.76	Good	-0.53	Suit	269.28	H	C2S1
41	0.03	Ex	700	Good	755.28	FW	5.61	Ex	32.50	Good	2.50	Mar	248.31	H	C2S1

Legend: Ex= Excellent; FW= Fresh Water; Per = Permissible; Suit = Suitable; UnSuit= Unsuitable Mar = Marginal; H = Hard; VH= Very Hard; C2= Medium Salinity; C3= High Salinity and S1= Low alkalinity.

EC, B, TDS, SAR, SSP, RSC and H₇ classification based on Appendix I,II, III,IV,V and VI.

Alkalinity and salinity hazard classification based on Figure 3.

4.1.5.3 Residual sodium carbonate

The computed residual sodium carbonate (RSC) of ground water samples ranged from -6.95 to 3.78 me L⁻¹ with mean value of -0.337 me L⁻¹ (Table 3). Out of the 41 samples, about 53.66 samples (22 samples) were below the mean value and the rest 46.34 (19 samples) were above the mean value. The standard deviation and co-efficient of variation (CV) were 2.09 and -16.10%, respectively. 23 groundwater samples under test, contained negative value and rest of 18 groundwater samples contained positive value.

According to Eaton (1950) and Ghosh *et al.* (1983), all the groundwater samples were found to be 'suitable' class (RSC <1.25 me L⁻¹), 'marginal' class (RSC 1.25-2.50 me L⁻¹) and 'unsuitable' class (RSC >2.50 me L⁻¹) as mentioned in Appendix V. For this reason, almost 2 ground water samples (sample No. 12 and 38) might be problematic for irrigation purposes but rest all the ground waters might not be problematic for irrigation purposes.

4.1.5.4 Total hardness

The total hardness (H_T) of water samples was within the range of 142.73 to 483.70 mg L⁻¹ with a mean value of 255.88 mg L⁻¹ (Table 3). About 58.54% values (24 samples) were found below the mean and 41.46% (17 samples) were above the mean. The computed standard deviation and co-efficient of variation were 71.96 and 28.12%, respectively. Sawyer and McCarty (1967) classified irrigation water into 4 classes based on hardness as mentioned in Appendix VI. According to this classification, 7 samples were 'very hard' 2 samples were moderately hard and the rest 32 samples were 'hard'. Hardness resulted due to presence of appreciable amount of divalent cations like Ca and Mg (Todd, 1980).

4.2 Water Quality Rating for Drinking Usage

The relative suitability of drinking water standards on the basis of TDS, As, Cl, B, Fe, Mn and SO₄ as per USEPA (United States Environmental Protection Agency) 1975 were presented in Appendix VIII. Among the 41 water samples, 19 samples were 'suitable' and the rest 22 samples (Sl. No. 1,2, 4, 6, 8, 10,15,16,17, 18,20,23,24,26, 28, 30, 32, 34,36, 37, 38, & 39) were found 'unsuitable' for drinking due to the exceeded the tolerance limit of As (0.05 mg L⁻¹) and this ion was considered as pollutant in the study area (USEPA, 1975). Considering Mn ion, 40 samples were 'suitable' but the rest 1 sample (nos. 31) was 'unsuitable' for drinking due to higher quantities of Mn (> 0.05 mg L⁻¹).

Out of the 41 samples, 15 samples (Sl. No. 1, 2, 3, 7, 15, 17, 18, 20, 22, 26, 27, 28, 30, 31 and 34) were unfit for drinking based on Fe content, while the recommended limit of Fe for drinking water is 0.30 mg L^{-1} (USEPA, 1975). So these ground water samples were problematic for drinking because Fe content of those waters exceeded the acceptable limit ($\text{Fe} = 0.30 \text{ mg L}^{-1}$). The rest ground water samples were fit for drinking based on Fe content. Among 41 samples, 3 were 'suitable' and the rest 38 samples were found 'unsuitable' for drinking due to the exceeded the recommended limit of TDS (500 mg L^{-1}) as per USEPA (1975). As regards to B, SO_4 and Cl ions, all waters were suitable for drinking because the concentrations of these ions were less than the recommended limits (Appendix VIII).

4.3 Groundwater Quality Rating for Livestock Use

The concentrations of ions like As, B, Fe, Mn, Cl and TDS value were considered for classifying ground water samples on the basis of ESB (1972) as presented in Appendix IX. Out of 41 samples, 39 were fit but only 2 samples (Sl.No. 18 & 37) were toxic to livestock consumption because As content exceeded the recommended limit ($\text{As} = 0.20 \text{ mg L}^{-1}$). B and TDS status of all the ground waters were below the specified limits. Considering Mn ion, 40 were 'suitable' but the rest 1 sample (Sl.No.1) was 'unsuitable' for livestock usage due to higher quantities of Mn ($> 0.05 \text{ mg L}^{-1}$). Out of the 41 samples, only 15 samples (Sl. No. 1, 2, 3, 7, 15, 17, 18, 20, 22, 26, 27, 28, 30, 31 & 34) were hazardous for livestock consumptions because of higher amount of Fe ($> 0.30 \text{ mg L}^{-1}$) showing this ion as pollutant but the rest 26 samples were fit for livestock consumptions because of acceptable amount of Fe (appendix IX). In respect of Cl ion, 35 samples were toxic to livestock consumption because Cl content exceeded the recommended limit ($> 30 \text{ mg L}^{-1}$) as per ESB (1972).

4.4 Groundwater Quality Rating for Aquaculture, Poultry and Different Industrial Usage

Based on pH, TDS, H_T , Fe, Mn, Cl and SO_4 water qualities for aquaculture, poultry and different industrial purposes were classified. Quality assessment for aquaculture was judged after Meade (1989), water quality for poultry was evaluated as per Carter and Sneed (1987) water quality for industrial usage was rated as per AWWA (1971). The water class rating for aquaculture, poultry and different industrial usage have been cited in Table 4 and 5. The pH of groundwater ranged from 6.53 to 7.63. All the waters would

be suitable for tanning, rayon manufacture, aquaculture, poultry and all samples were found unsuitable for laundering but except one sample are suitable for laundering. Among the 41 samples, 36 samples were found suitable for confectionery and 5 were found suitable for brewing while the recommended limit of confectionery and brewing is from $\text{pH} > 7.0$ and 6.5 to 7.0, respectively (Appendix XI).

TDS of all waters were suitable for ice manufacture and carbonated beverage except 1 sample (Sl.No. 8). Out of 41 samples 26 and 15 were suitable for brewing and aquaculture respectively. All the waters were unsuitable for confectionery and paper & pulp industries based on TDS values (Appendix XI).

Considering hardness, out of 41 samples, all samples were suitable for tanning industries and 39 samples are suitable for aquaculture. Only 22 samples (Sl.No. 3, 4, 6, 7, 8, 9, 11, 12, 15, 17, 20, 25, 26, 28, 29, 33, 35, 36, 37, 38, 39 and 41) were suitable for carbonated beverage. Not a single water sample was suitable for poultry use, confectionery, laundering, paper & pulp industries, rayon manufacture and textile. The SO_4 ions content in ground water sources ranged from 0.5 to 5.6 mg L^{-1} . Hence, SO_4 content in all waters would not create problem for aquaculture, poultry and industrial uses. Mn content in ground waters ranged from trace to 0.06 mg L^{-1} . All waters were found suitable for air conditioning, carbonated beverage, confectionery, ice manufacture and laundering because the Mn content of all waters were less than the recommended limit (Appendix XI). Among the 41 samples, all samples were suitable based on TDS, hardness, Fe and Mn content (Appendix XI) for brewing, paper & pulp, textile and tanning except one sample (Sl. No.31)which was unsuitable for paper & pulp. Out of 41 samples, 33 samples were suitable for aquaculture.

Fe content in ground waters ranged from 0.12 to 0.48 mg L^{-1} . Out of all water samples, only 10 samples (Sl. No.10,14, 21, 25, 32, 33, 35, 36, 38, and 40) were found unsuitable for laundering because the Fe content of these samples were lower than the recommended limit (Appendix XI). On the basis of Fe content, all the water samples were suitable for brewing, paper & pulp, sugar industries and unsuitable for aquaculture and air conditioning. 26 water samples were suitable for poultry use, 13 water samples were suitable for ice manufacture and 28 water samples were unsuitable for carbonated beverage, confectionery, and tanning industries because the Fe content of all samples were higher than the recommended limit (Appendices X and XI).

Table 4. Suitability classification of groundwater for irrigation, drinking, livestock, poultry, aquaculture and industrial usage based on Cl, Mn and Fe.

S/N	Cl (mg L ⁻¹)		Mn (mg L ⁻¹)		Fe (mg L ⁻¹)	
	Suit	Unsuit	Suit	Unsuit	Suit	Unsuit
1	IR,DR,PL,CB, TX	LS,AQ,BW, SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN, TX	IR	DR,LS,PL,AQ,AC,BW,CB, CF,IM,LD, PP,SG,TN, TX
2	IR,DR,PL,BW, CB, TX	LS,AQ,SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN, TX	IR	DR,LS,PL,AQ,AC,BW,CB, CF,IM,LD,PP,SG,TN, TX
3	IR,DR,PL,CB, TX	LS,AQ,BW,SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN, TX	IR	DR,LS,PL,AQ,AC,BW,CB, CF,IM,LD,PP,SG,TN, TX
4	IR,DR,PL,CB, TX	LS,AQ,BW, SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN, TX	IR,LS,LD,DR, TX	LS,PL,AQ,AC,BW,CB,CF, IM,PP,SG, TN,
5	IR,DR,PL,CB, TX	LS,AQ,BW, SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN, TX	IR,LS,LD,DR ,TX	PL,AQ,AC,BW,CB,CF,IM PP,SG,TN
6	IR,DR,PL,CB, TX	LS,AQ,BW,SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN, TX	IR,LS,LD,DR, TX	PL,AQ,AC,BW,CB,CF,IM, PP,SG, TN
7	IR,DR,PL,CB, TX	LS,AQ,BW,SG	IR,DR,LS,AQ,AC, CB,CF,IM,LD,BW, PP	TN, TX	IR,LD, TX	DR,LS,PL,AQ,AC,BW,CB, CF,IM,PP,SG,TN
8	IR,DR,PL,CB, TX	LS,AQ,BW, SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN, TX	IR,LS,LD,DR, TX	PL,AQ,AC,BW,CB,CF,IM, PP,SG, TN

Table 4 : (Continued)

S/N	Cl (mg L ⁻¹)		Mn (mg L ⁻¹)		Fe (mg L ⁻¹)	
	Suit	Unsuit	Suit	Unsuit	Suit	Unsuit
9	IR,DR,PL,CB, BW,TX	LS,AQ,SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN,TX	IR,LS,LD,DR TX	PL,AQ,AC,BW,CB,CF,IM PP,SG,TN
10	IR,DR,PL,CB, TX	LS,AQ, BW,SG	IR,DR,LS,AQ,AC,CB, CF,IM, LD,BW,PP	TN,TX	IR,LS,LD,DR,TX	PL,AQ,AC,BW,CB,CF,IM PP,SG,TN
11	IR,DR,PL,CB, BW,TX	LS,AQ, SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN,TX	IR,LS,LD,DR ,TX	PL,AQ,AC,BW,CB,CF,IM PP,SG,TN
12	IR,DR,PL,CB, BW,TX	LS,AQ, SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN,TX	IR,LS,LD,DR ,TX	PL,AQ,AC,BW,CB,CF,IM PP,SG,TN
13	IR,DR,PL, CB, TX	LS,AQ, BW,SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN,TX	IR,LS,LD,DR, TX	PL,AQ,AC,BW,CB,CF,IM PP,SG,TN
14	IR,DR,PL, CB, TX	LS,AQ, BW, SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN,TX	IR,LS,LD,DR,TX	PL,AQ,AC,BW,CB,CF,IM PP,SG,TN
15	IR,DR,PL, CB,TX	LS,AQ, BW,SG	IR,DR,AQ,AC,CB,CF,I M,LD,BW	TN,TX, PP ,LS,	IR,LD,TX	LS,PL,AQ,AC,DR,BW,CB, CF, IM,PP,SG,TN
16	IR,DR,PL, CB, TX	LS,AQ, BW,SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN,TX	IR,LS,LD,DR, TX	PL,AQ,AC,BW,CB,CF,IM PP,SG,TN

Table 4 : (Continued)

S/N	Cl (mg L ⁻¹)		Mn (mg L ⁻¹)		Fe (mg L ⁻¹)	
	Suit	Unsuit	Suit	Unsuit	Suit	Unsuit
17	IR,DR,PL, CB, TX	LS,AQ, BW, SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN, TX	IR,LD, TX	LS,PL,AQ,AC,DR,BW,CB, CF,IM,PP,SG,TN
18	IR,DR,PL, CB, TX	LS,AQ, BW,SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN, TX	IR,LD, TX	LS,PL,AQ,AC,DR,BW,CB, CF,IM,PP,SG,TN
19	IR,DR,PL,CB, BW, TX	LS,AQ, SG	IR,DR,AQ,AC,CB,CF,I M,LD,BW,PP	TN,LS, DR, TX	IR,LS,LD,DR, TX	PL,AQ,AC,BW,CB,CF,IM PP,SG,TN
20	IR,DR,PL,CB, BW, TX	LS,AQ,SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN, TX	IR,LD, TX	LS,PL,AQ,AC,DR,BW,CB, CF,IM,PP,SG,TN
21	IR,DR,PL, CB, TX	LS,AQ, BW,SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN, TX	IR,LS,LD,DR, TX	PL,AQ,AC,BW,CB,CF,IM PP,SG,TN
22	IR,DR,PL,CB, TX	LS,AQ,BW, SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN, TX	IR,LD, TX	LS,PL,AQ,AC,DR,BW,CB, CF,IM,PP,SG,TN
23	IR,DR,PL, CB,BW, TX	LS,AQ, SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN, TX	IR,LS,LD,DR, TX	PL,AQ,AC,BW,CB,CF,IM PP,SG,TN
24	IR,DR,PL, CB, TX	LS,AQ, BW, SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN, TX	IR,LS,LD,DR, TX	PL,AQ,AC,BW,CB,CF,IM PP,SG,TN

Table 4: (Continued)

S/N	Cl (mg L ⁻¹)		Mn (mg L ⁻¹)		Fe (mg L ⁻¹)	
	Suit	Unsuit	Suit	Unsuit	Suit	Unsuit
25	IR,DR,PL, CB,BW, TX	LS,AQ, SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN, TX	IR,LS,LD,DR, TX	PL,AQ,AC,BW,CB,CF,IM PP,SG,TN
26	IR,DR,PL, CB,BW, TX	LS,AQ, SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN, TX	IR,LD, TX	LS,PL,AQ,AC,DR,BW,CB, CF,IM,PP,SG,TN
27	IR,DR,PL,CB, BW, TX	LS,AQ,SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN, TX	IR,LS,LD,DR, TX	PL,AQ,AC, BW,CB,CF,IM PP,SG,TN
28	IR,DR,PL, CB,BW, TX	LS,AQ, SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN, TX	IR,LD, TX	PL,LS,DR,AQ,AC,BW,CB, CF,IM,PP,SG,T
29	IR,DR,PL, CB, TX	LS,AQ, BW,SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN, TX	IR,LS,LD,DR, TX	PL,AQ,AC,BW,CB,CF,IM PP,SG,TN
30	IR,DR,PL,CB, BW, TX	LS,AQ,SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN, TX	IR,LD, TX	PL,LS,DR,AQ,AC,BW,CB, CF,IMPP,SG,TN
31	IR,DR,PL,CB, BW, TX	LS,AQ, SG	IR,LS,AQ,AC,CBCF,I M,LD,BW, TX	TN,PP,DR	IR,LD, TX	PL,LS,DR,AQ,AC,BW,CB, CF,IM,PP,SG,TN
32	IR,DR,PL, CB, TX	LS,AQ,BW,SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN, TX	IR,LS,LD,DR, TX	PL,AQ,AC,BW,CB,CF,IM PP,SG,TN

Table 4: (Continued)

S/N	Cl (mg L ⁻¹)		Mn (mg L ⁻¹)		Fe (mg L ⁻¹)	
	Suit	Unsuit	Suit	Unsuit	Suit	Unsuit
33	IR,DR,PL,CB, BW,TX	LS,AQ, SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN,TX	IR,LS,LD,DR,TX	PL,AQ,AC,BW,CB,CF,IM PP,SG,TN
34	IR,DR,PL, CB,TX	LS,AQ, BW,SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN,TX	IR,LD,TX	PL,LS,DR,AQ,AC,BW,CB, CF,IM,PP,SG,TN
35	IR,DR,PL, CB,TX	LS,AQ, BW,SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN,TX	IR,LS,LD,DR,TX	PL,AQ,AC,BW,CB,CF,IM PP,SG,TN
36	IR,DR,PL, CB,BW,TX	LS,AQ, SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN,TX	IR,LS,LD,DR,TX	PL,AQ,AC,BW,CB,CF,IM PP,SG,TN
37	IR,DR,PL, CB,TX	LS,AQ, BW,SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN,TX	IR,LS,LD,DR,TX	PL,AQ,AC,BW,CB,CF,IM PP,SG,TN
38	IR,DR,PL, CB,TX	LS,AQ, BW,SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN,TX	IR,LS,LD,DR,TX	PL,AQ,AC,BW,CB,CF,IM PP,SG,TN
39	IR,DR,PL, CB,TX	LS,AQ, BW,SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN,TX	IR,LS,LD,DR,TX	PL,AQ,AC,BW,CB,CF,IM PP,SG,TN
40	IR,DR,PL,CB, TX	LS,AQ,BW,SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN,TX	IR,LS,LD,DR,TX	PL,AQ,AC,BW,CB,CF,IM PP,SG,TN

Table 4: (Continued)

S/N	Cl (mg L ⁻¹)		Mn (mg L ⁻¹)		Fe (mg L ⁻¹)	
	Suit	Unsuit	Suit	Unsuit	Suit	Unsuit
41	IR,DR,PL,CB, TX	LS,AQ,BW,SG	IR,DR,LS,AQ,AC,CB, CF,IM,LD,BW,PP	TN,TX	IR,LS,LD,DR,TX	PL,AQ,AC,BW,CB,CF,IM PP,SG,TN

Legend:

IR= Irrigation
 DR= Drinking
 LS= Livestock
 PL= Poultry
 AQ= Aquaculture
 Suit= Suitable

BW= Brewing
 CB= Carbonated beverage
 CF= Confectioner
 IM= Ice manufacture
 LD= Laundering
 Unsuit= Unsuitable

PP= Paper and Pulp
 RM= Rayon manufacture
 SG= Sugar industries
 TN= Tanning
 TX= Textile

4.5 Correctness of Groundwater Analyses

In the present study anion-cation balance, ratios of measured or calculated TDS to EC, ratio of measured TDS to calculate TDS and calculated EC to measure EC were checked to find out the accuracy of chemical analyses of ground water samples. The percentage difference between the sums of anion and cation was observed ranging from 3.26 to 10.00 (Table 5). Considering these obtained ratios, these results were within the acceptable criteria as described by APHA (1995). The obtained ratios of measured TDS to calculated TDS and ratios of calculated EC to measured EC were found to vary from 1.00 to 1.10 and 1.00 to 1.11, respectively but the ratio of calculated TDS to EC also ranged from 0.27 to 0.99 (Table 5). All the ratios were found within the specified range (APHA, 1995). The obtained chemical analyses of ground waters were found to be correct fulfilling all the criteria required for this experiment

4.6 Relationship between Quality Factors and Major Ionic Constituents of Ground waters

The relationship between water quality factors viz. pH, EC, TDS, SAR, SSP, RSC and H_T were studied. The calculated 'r' values for all the combinations of seven factors such as pH vs. EC, pH vs. TDS, pH vs. SAR, pH vs. SSP, pH vs. RSC, pH vs. H_T , EC vs. TDS, EC vs. SAR, EC vs. SSP, EC vs. RSC, EC vs. H_T , TDS vs. SAR, TDS vs. SSP, TDS vs. RSC, H_T vs. TDS, SAR vs. SSP, SAR vs. RSC, SAR vs. H_T , SSP vs. RSC, SSP vs. H_T and RSC vs. H_T were shown in Table 6 and 7.

Among the combinations, the following combinations of EC vs TDS, EC vs H_T , EC vs. RSC, TDS vs H_T , TDS vs. RSC, SAR vs SSP and SSP vs RSC were indicated significant as positive correlations while pH vs EC, pH vs H_T , EC vs RSC, SSP vs H_T and RSC vs H_T revealed negative significant correlations at 1% and 5% level of significance (Table 6 and 7). To the contrary, the rest combinations showed insignificant correlations because their respective calculated 'r' values were below the tabulated 'r' values both the 1% and 5% levels of significance (table 7). The significant relationships between major quality factors have been illustrated in Fig.4 to 12.

On the basis of major ionic constituents, 16 ionic combinations were significant at both the 5 % and 1% levels. These results indicated that an increase of one element may

increase or decrease the other elements due to synergistic or antagonistic behavior amongst the dissolved ions water sources. The results in Table 8 showed that significant major ionic combinations were Ca vs. Mg($r=0.523$); Ca vs Mn ($r = 0.617$), Ca vs Cu ($r = -0.414$), Mg vs. K($r = 0.466$), Mg vs.Mn ($r = 0.596$). Mg vs Cu, ($r = -0.637$), Na vs Fe ($r = 0.862$), Na vs Mn ($r = 0.412$), Na vs Cu ($r = 0.717$), K vs Cu ($r = -0.500$), Na vs B ($r = 0.391$), Fe vs Cu ($r = 0.660$), Cl vs Mn ($r = 0.796$) Mn vs. SO_4 ($r = -0.611$), Cu vs. B ($r = 0.413$) and Cu vs. SO_4 ($r = 0.550$) revealing synergistic relationships but rest combinations indicated antagonistic behavior as illustrated in Fig. 13 & 14.

Table 5. Checking correctness of groundwater analysis

Sl. No.	Anion-cation-balance			Total dissolved solids (mg L ⁻¹)		Ratio of measured TDS to calculated TDS	Electrical Conductivity (EC)		Ratio of calculated EC to measured EC	Ratio of measured or calculated TDS to calculated EC
	∑Cation (me L ⁻¹)	∑ Anion (me L ⁻¹)	Difference (%)	Measured	Calculated		Measured	Calculated		
1	8.79	7.59	7.33	827.54	820.57	1.01	845	827.15	1.02	0.98
2	7.81	6.58	8.54	667.93	660.58	1.01	675	635.24	1.06	0.99
3	6.78	5.86	7.27	623.93	621.65	1.00	660	656.29	1.03	0.94
4	7.94	6.56	9.51	756.84	754.54	1.00	758	757.27	1.00	0.99
5	7.46	6.28	8.58	675.38	643.26	1.00	703	657.24	1.06	0.96
6	5.38	4.69	6.85	338.07	336.21	1.05	670	612.41	1.09	0.50
7	5.36	4.42	9.61	751.59	746.25	1.01	775	747.28	1.03	0.96
8	6.01	5.13	7.89	866.37	864.21	1.00	798	778.68	1.02	0.92
9	6.19	5.07	9.94	293.75	281.24	1.04	1025	987.85	1.04	0.29
10	6.79	5.78	8.03	675.07	671.52	1.01	1127	1101.35	1.02	0.60
11	6.02	5.57	3.88	522.44	521.01	1.00	1057	985.45	1.07	0.49
12	4.78	3.99	9.00	495.64	473.12	1.05	480	477.95	1.00	0.96
13	7.31	5.96	10.00	634.35	628.14	1.01	1060	963.86	1.10	0.60
14	7.96	6.68	8.74	629.89	577.84	1.09	1310	1213.68	1.08	0.48
15	6.23	5.24	8.41	535.25	522.27	1.02	543	456.38	1.10	0.98
16	6.77	5.76	7.46	639.38	627.32	1.02	990	989.35	1.00	0.65
17	6.29	5.26	8.91	384.52	382.08	1.00	801	775.54	1.03	0.48
18	7.82	6.79	7.04	436.52	374.87	1.16	785	685.21	1.15	0.56
19	7.13	6.68	3.26	257.58	254.13	1.01	954	889.35	1.07	0.27
20	6.57	5.87	5.62	268.76	266.42	1.00	835	759.85	1.10	0.32
21	7.61	6.31	9.33	579.87	575.26	1.01	702	689.27	1.02	0.83

Table 5 (Continued)

Sl. No.	Anion-cation-balance			Total dissolved solids (mg L ⁻¹)		Ratio of measured TDS to calculated TDS	Electrical Conductivity (EC)		Ratio of calculated EC to measured EC	Ratio of measured or calculated TDS to calculated EC
	∑Cation (me L ⁻¹)	∑ Anion (me L ⁻¹)	Difference (%)	Measured	Calculated		Measured	Calculated		
22	6.63	5.79	6.76	476.39	471.85	1.01	980	909.49	1.08	0.49
23	6.31	5.21	9.54	387.36	377.25	1.03	676	627.52	1.08	0.57
24	6.72	5.61	9.01	649.23	647.52	1.01	730	698.75	1.04	0.89
25	6.92	5.75	9.23	356.49	324.21	1.10	476	453.29	1.05	0.75
26	5.27	4.38	9.22	477.78	475.45	1.00	481	479.05	1.00	0.99
27	5.77	4.79	9.28	503.67	488.48	1.03	843	786.31	1.07	0.60
28	12.11	9.89	10.00	457.52	455.21	1.00	635	631.54	1.00	0.72
29	9.38	7.79	9.26	602.69	587.98	1.03	632	624.18	1.01	0.95
30	9.27	8.57	3.92	623.23	612.42	1.02	925	885.28	1.04	0.67
31	4.78	3.97	9.25	644.03	624.85	1.03	545	486.39	1.12	0.84
32	8.69	7.28	8.82	539.10	537.05	1.00	767	698.28	1.09	0.70
33	4.33	3.96	4.46	823.03	816.45	1.01	636	631.56	1.01	0.77
34	4.77	3.98	9.02	757.35	752.64	1.01	658	652.39	1.01	0.87
35	5.11	4.51	6.23	593.08	561.05	1.05	776	725.54	1.06	0.76
36	4.56	3.98	6.79	471.09	458.41	1.03	667	614.46	1.08	0.71
37	5.67	5.01	6.17	377.09	374.98	1.01	703	663.35	1.05	0.54
38	6.41	5.95	3.72	613.97	605.46	1.01	847	758.69	1.11	0.72
39	5.64	4.97	6.31	552.63	546.38	1.01	553	499.39	1.10	0.99
40	6.37	5.86	4.17	451.33	449.24	1.00	581	556.28	1.04	0.78
41	6.61	5.52	8.98	655.28	651.87	1.01	700	689.23	1.02	0.94

Table 6. Regression and correlation analysis of quality criteria

Quality criteria	Correlation co-efficient (r)	Regression equation
pH vs. SAR	-0.1987 ^{NS}	Y= -0868x + 8.092
pH vs. H _T	-0.1254 ^{NS}	Y= -0.0003x + 7.217
EC vs. TDS	0.00759 ^{NS}	Y= 0.0097x + 745.4
EC vs. H _T	0.2695 ^{NS}	Y= 0.7357x + 562.84
H _T vs. TDS	0.1497 ^{NS}	Y= 0.07x + 216.66
SAR vs. SSP	0.7475**	Y= 0.1484x + 0.7283
RSC vs. SSP	0.5674**	Y= 0.1377x - 4.679
EC vs. SSP	-0.2060 ^{NS}	Y= -0.254x + 927.23
EC vs. RSC	0.0208 ^{NS}	Y=0.0002x - 0.5046
SSP vs. H _T	-0.6376**	Y= -5.3164x +423.46
RSC vs. H _T	-0.7718**	Y=-0.0225x + 5.413
Ca vs. HCO ₃	-0.1776 ^{NS}	Y=-0.0427x + 60.305
Mg vs. HCO ₃	0.0775 ^{NS}	Y= 0.0081x + 30.578

Legend: NS= Not Significant

* Significant at 5% level and

** Significant at 1% level

Tabulated value of r with 39 df = 0.299 at 5% level and 0.388 at 1% level.

Table 7. Relationship between water quality factors

Parameters	EC	TDS	SAR	SSP	RSC	H _T
pH	-0.2387 ^{NS}	0.0923 ^{NS}	-0.1987 ^{NS}	-0.0158 ^{NS}	0.0698 ^{NS}	-0.1254 ^{NS}
EC	-	0.0075 ^{NS}	-0.1859 ^{NS}	-0.2060 ^{NS}	0.0208 ^{NS}	0.2695 ^{NS}
TDS	-	-	-0.1458 ^{NS}	-0.1623 ^{NS}	0.0087 ^{NS}	0.1498 ^{NS}
SAR	-	-	-	0.7475**	0.2807 ^{NS}	-0.3145*
SSP	-	-	-	-	0.5674**	-0.6376**
RSC	-	-	-	-	-	-0.7718**

Legend: NS= Not Significant

* Significant at 5% level and

** Significant at 1% level

Tabulated value of r with 39 df = 0.299 at 5% level and 0.388 at 1% level.

Table 8. Correlation co-efficient (r) among ions

	Mg	Na	K	Fe	Mn	Cu	B	Cl	CO ₃	HCO ₃	SO ₄
Ca	0.523**	-0.0002 ^{NS}	0.146 ^{NS}	0.179 ^{NS}	0.617**	-0.414**	-0.035 ^{NS}	0.025 ^{NS}	0.058 ^{NS}	-0.177 ^{NS}	0.140 ^{NS}
Mg	-	0.306*	0.466**	0.155 ^{NS}	0.596**	-0.637**	0.210 ^{NS}	-0.003 ^{NS}	0.183 ^{NS}	0.078 ^{NS}	-0.208 ^{NS}
Na	-	-	0.315*	0.862**	0.412**	0.717**	0.391**	0.080 ^{NS}	0.289 ^{NS}	0.069 ^{NS}	-0.295 ^{NS}
K	-	-	-	0.091 ^{NS}	0.335*	-0.500**	0.041 ^{NS}	0.254 ^{NS}	0.113 ^{NS}	-0.072 ^{NS}	0.054 ^{NS}
Fe	-	-	-	-	0.054 ^{NS}	0.660**	0.327*	0.022 ^{NS}	0.258 ^{NS}	-0.031 ^{NS}	-0.157 ^{NS}
Mn	-	-	-	-	-	-	0.221 ^{NS}	0.796**	0.085 ^{NS}	-0.058 ^{NS}	-0.611**
Cu	-	-	-	-	-	-	0.413**	0.172 ^{NS}	0.049	-0.189 ^{NS}	-0.550**
B	-	-	-	-	-	-	-	0.135 ^{NS}	0.073	0.214 ^{NS}	-0.359*
Cl	-	-	-	-	-	-	-	-	0.125	-0.022 ^{NS}	-0.075 ^{NS}
CO ₃	-	-	-	-	-	-	-	-	-	-0.087 ^{NS}	-0.086 ^{NS}
HCO ₃	-	-	-	-	-	-	-	-	-	-	-0.385*

Legend: NS= Not Significant

* Significant at 5% level and

** Significant at 1% level

Tabulated value of r with 39 df = 0.299 at 5% level and 0.388 at 1% level.

Table 9. Water suitability rating against different criteria

	No of water sample(s) suitable												
	pH	TDS	H _T	SO ₄	Cl	Mn	Fe	Cu	As	B	CO ₃	HCO ₃	PO ₄
1. Irrigation	41	-	-	41	41	41	41	41	37	41	11	Nil	18
2. Drinking	-	-	-	41	41	41	23	41	1	41	-	-	-
3. Livestock	-	41	-	-	41	40	26	41	39	41	-	-	-
4. Aquaculture	41	8	39	41	Nil	33	-	-	-	-	-	-	-
5. Poultry	39	-	Nil	41	41	-	26	41	-	-	-	-	-
6. Ind. Usage													
7. Air Conditioning	-	-	-	-	-	41	Nil	-	-	-	-	-	-
8. Brewing	5	26	-	-	15	41	Nil	-	-	-	-	-	-
9. Carbonated beverage	-	41	11	41	41	41	13	-	-	-	-	-	-
10. Confectioner	36	Nil	Nil	-	-	41	13	-	-	-	-	-	-
11. Ice manufacture	-	41	-	-	-	41	13	-	-	-	-	-	-
12. Laundering	1	-	Nil	-	-	41	31	-	-	-	-	-	-
13. Rayon manufacture	41	-	Nil	-	-	-	-	-	-	-	-	-	-
14. Sugar industries	-	-	-	41	4	-	Nil	-	-	-	-	-	-
15. Tanning	41	-	41	-	-	41	13	-	-	-	-	-	-
16. Textile	-	-	Nil	41	41	41	41	-	-	-	-	-	-
17. Paper and Pulp	-	Nil	Nil	-	-	40	Nil	-	-	-	-	-	-

4.7 Salient Features of the Investigation

It is evident from above discussion that out of the 41 ground water samples analyzed all the waters were not found 'suitable' for irrigation. Considering all the criteria of water quality evaluation 19 samples were suitable for drinking and livestock consumption. Only 13 samples were suitable for ice manufacture. It may be mentioned here that none of the water sources alone were found suitable for aquaculture, poultry, air-conditioning, brewing, carbonated beverage, confectionery, laundering, rayon manufacture, sugar industries, tanning, textile and paper & pulp industries. Considering all the criteria suitability evaluation, some water samples of the study areas contained higher amounts of some pollutants like As, Fe, Mn, Cl, CO_3 and HCO_3 and were not 'suitable' for specific usage. Before the specific use of polluted or contaminated groundwater samples, appropriate sustainable measures should be adopted for the remediation of these waters.

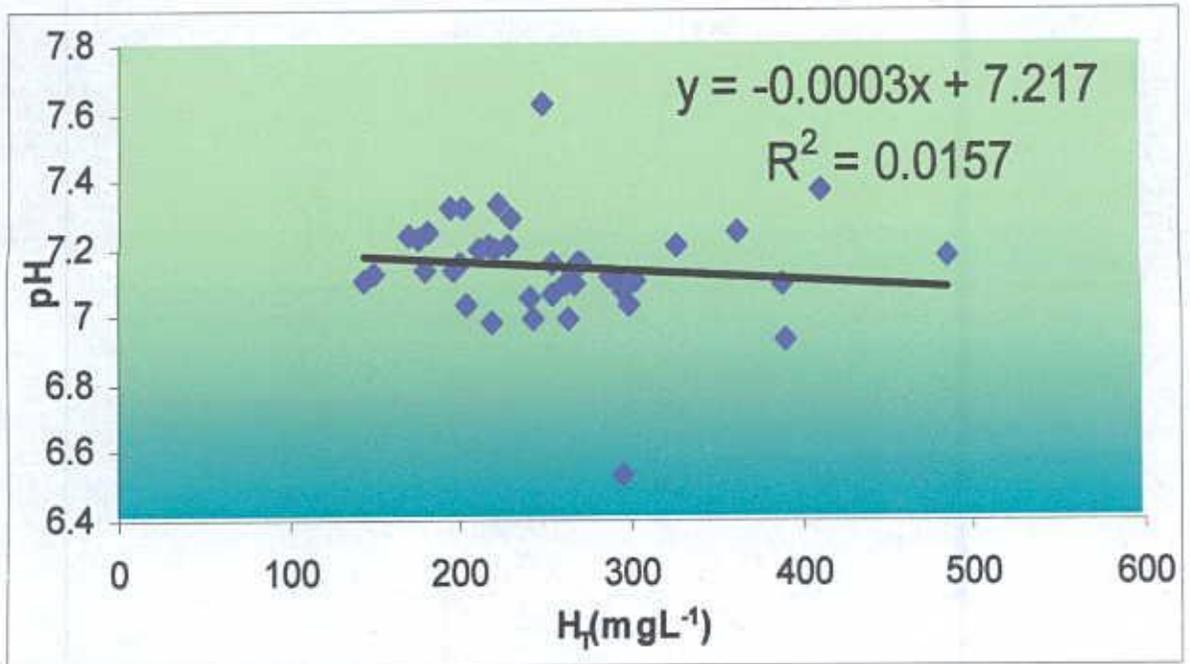


Fig.4. Relationship between pH and H_T

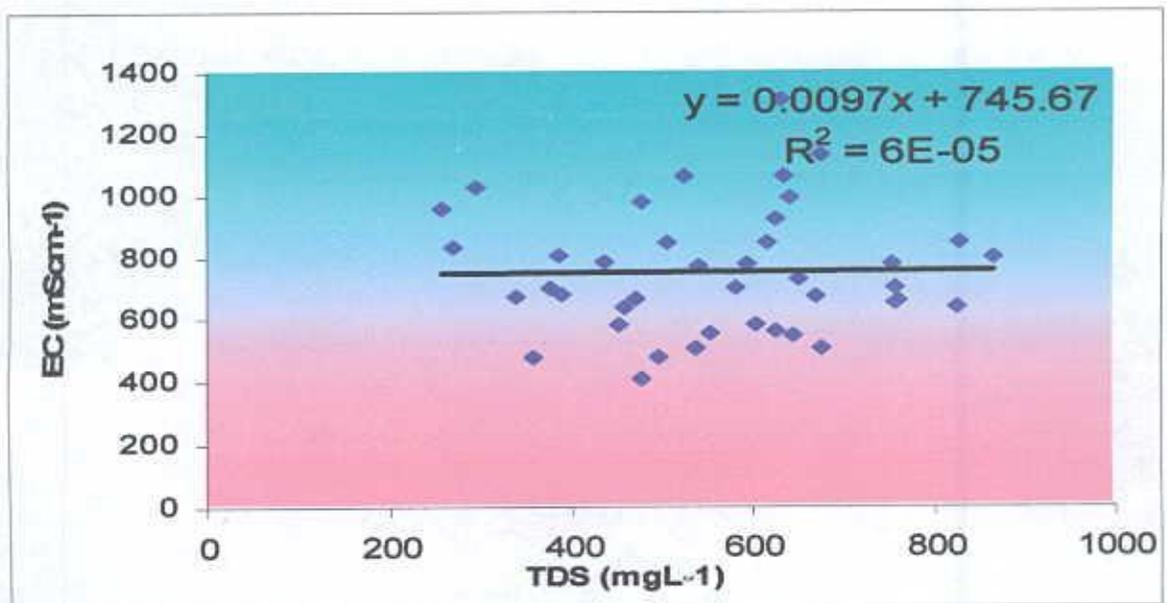


Fig.5. Relationship between EC and TDS

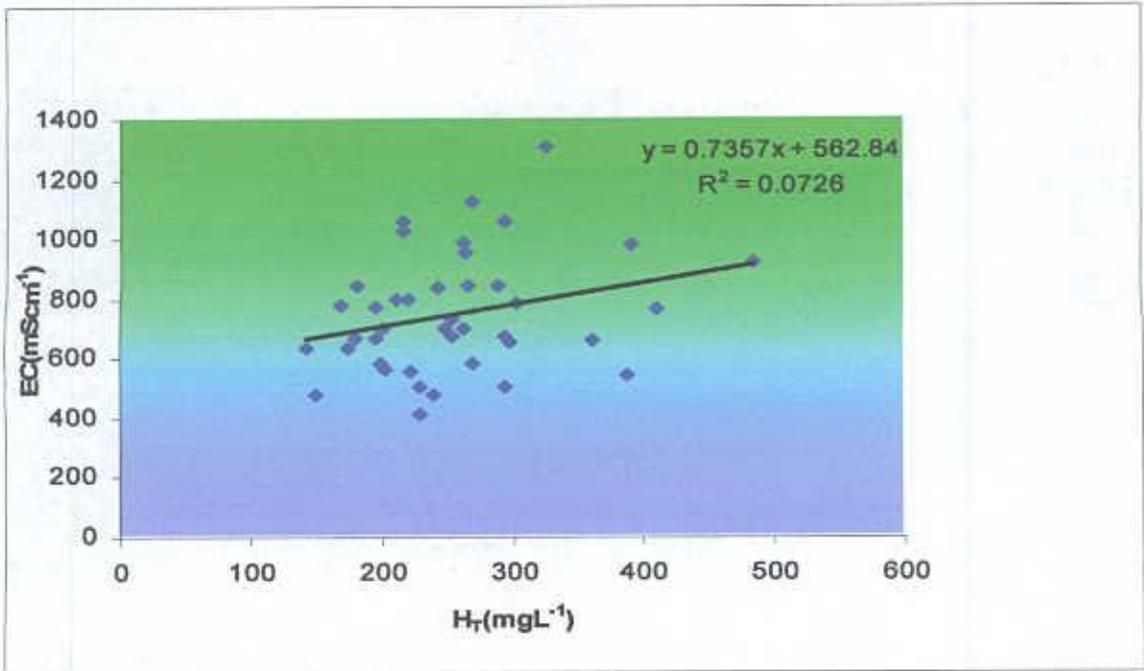


Fig.6. Relationship between EC and H_T

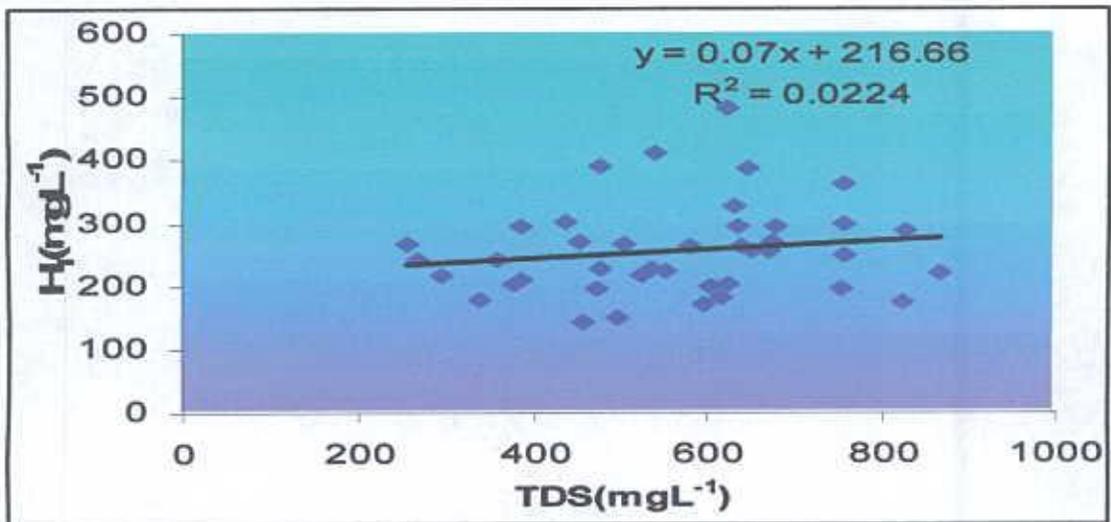


Fig.7. Relationship between H_T and TDS.

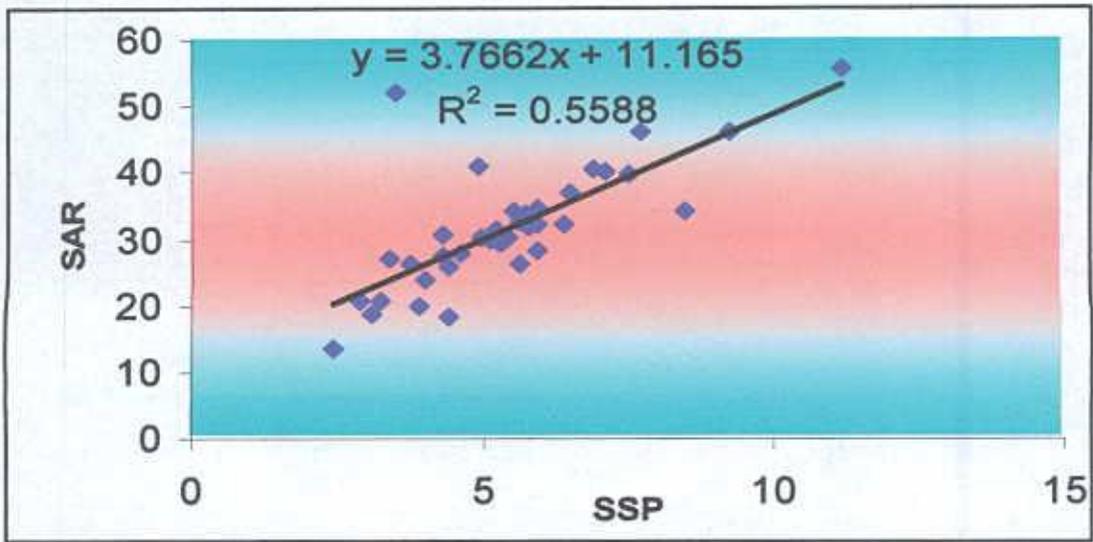


Fig.8. Relationship between SAR and SSP

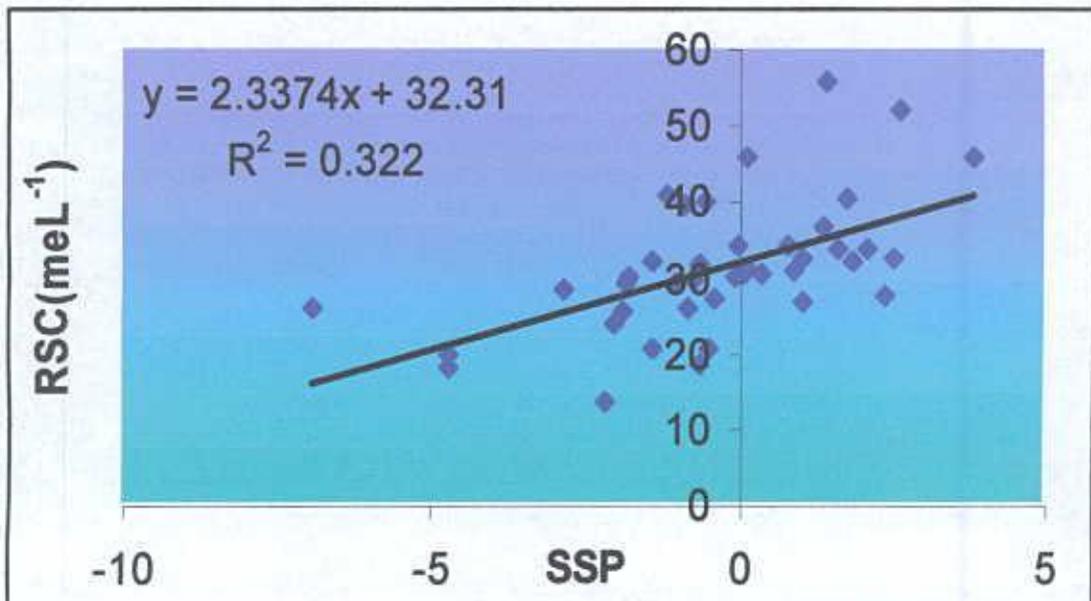


Fig.9. Relationship between SSP and RSC

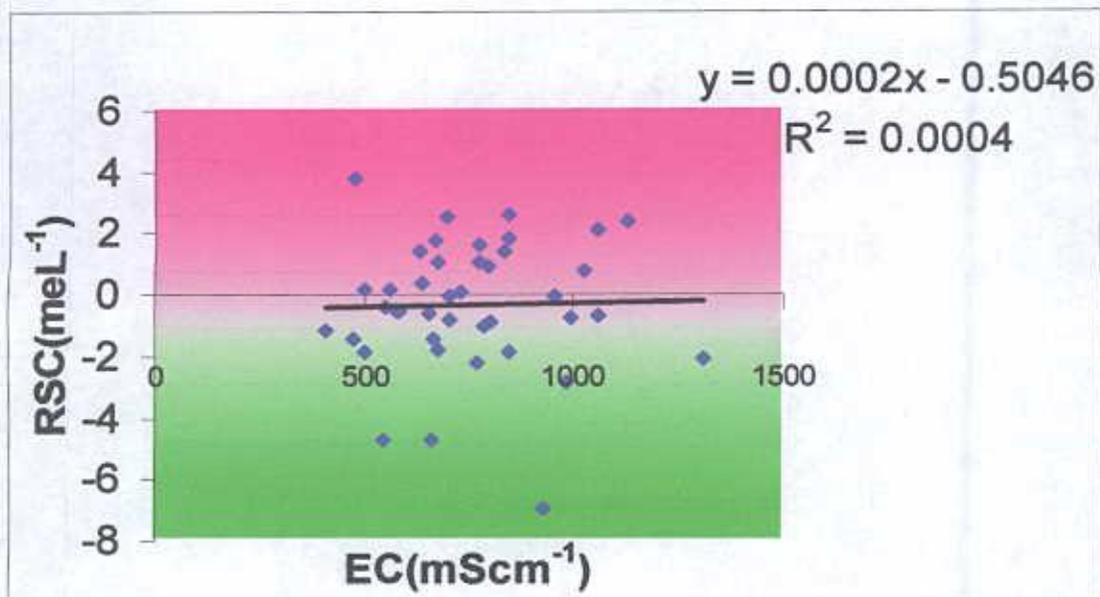


Fig.10 Relationship between EC and RSC

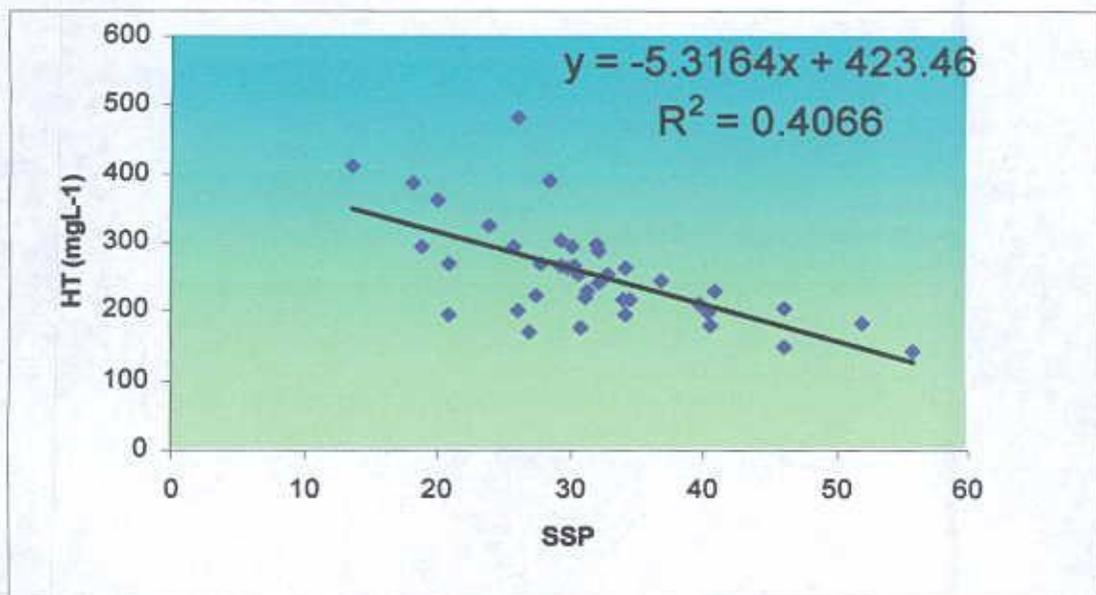


Fig.11 Relationship between SSP and H_T

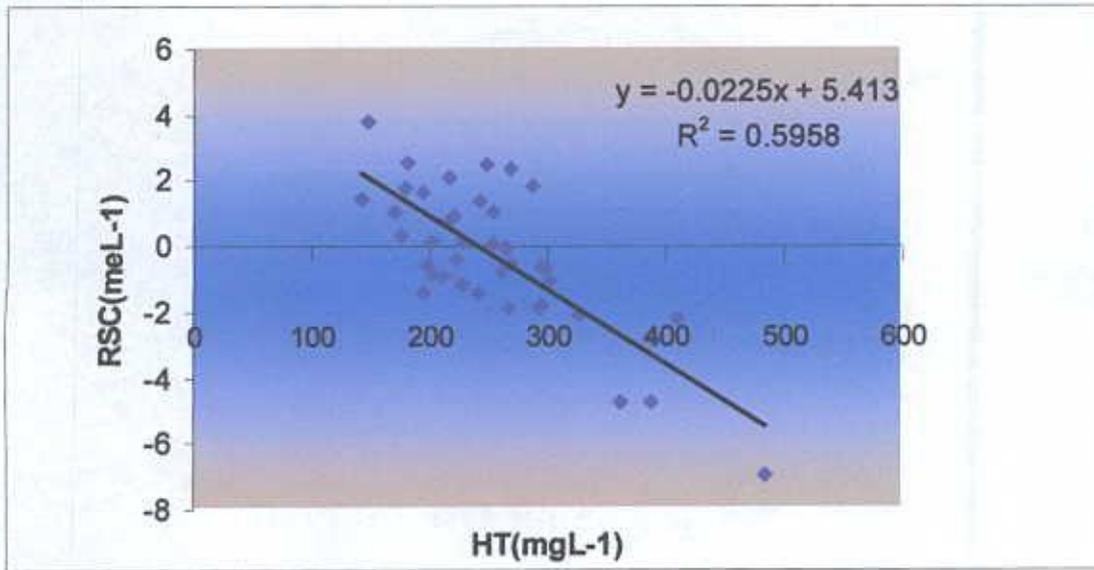


Fig.12 Relationship between H_T and RSC

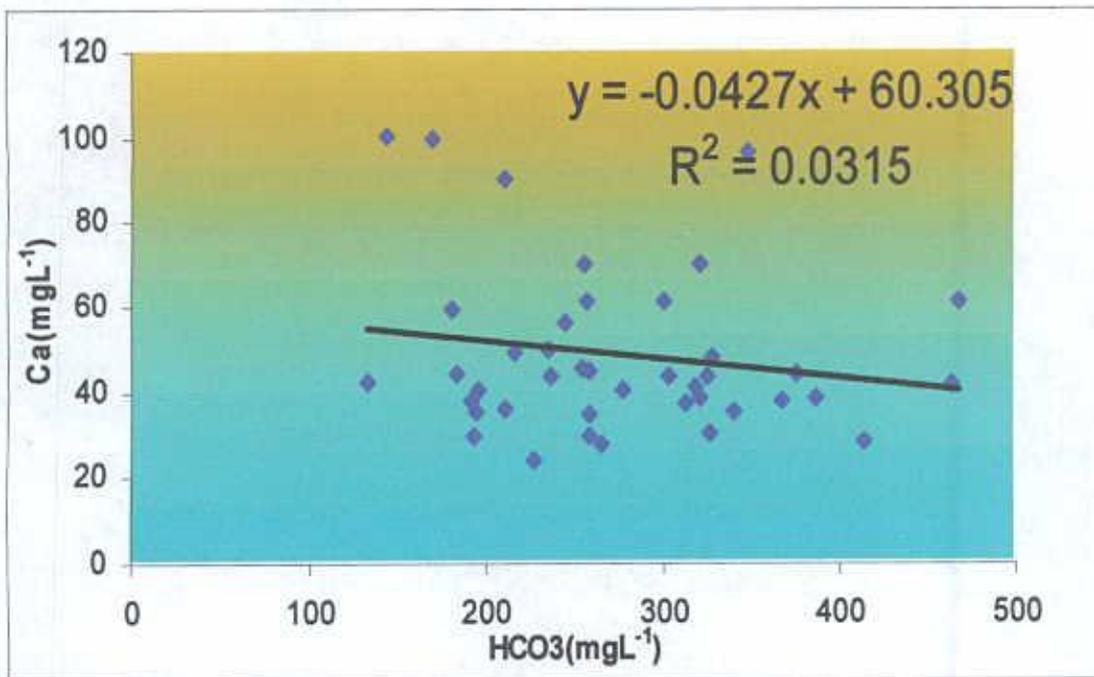


Fig.13 Relationship between Ca and HCO₃

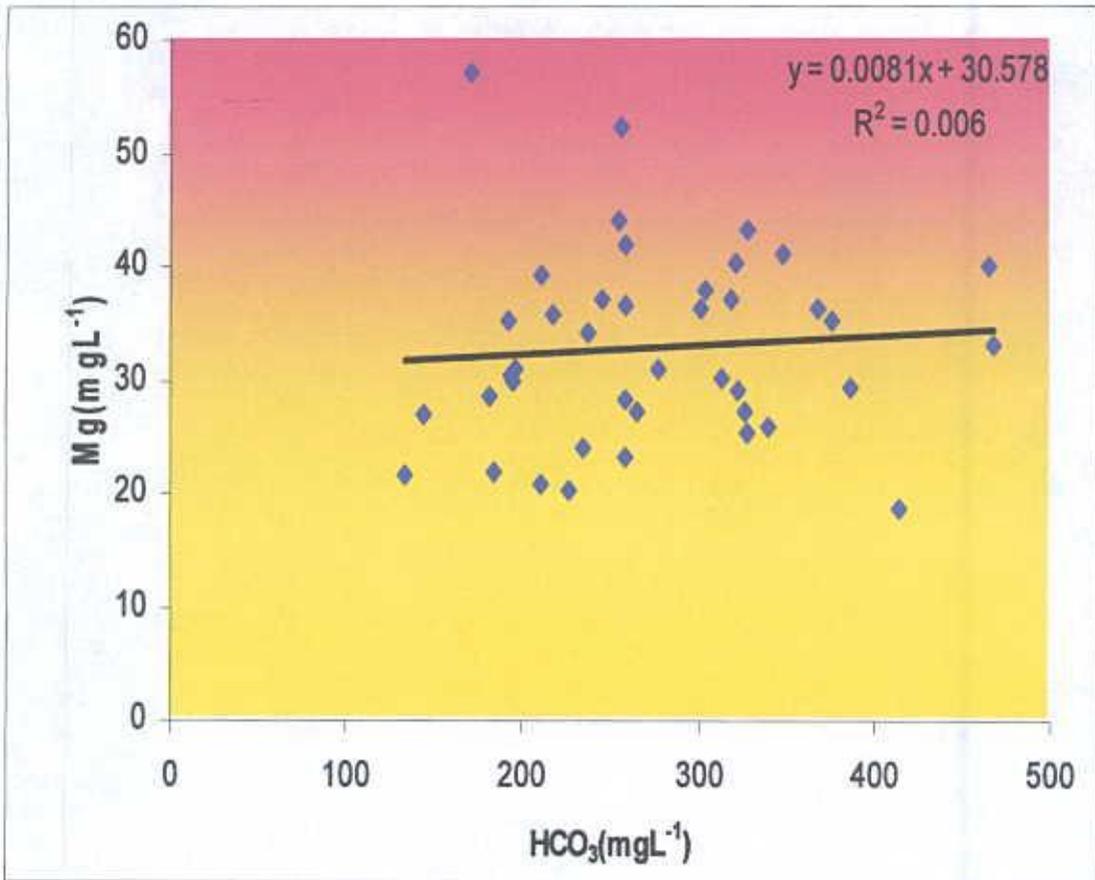


Fig. 14 Relationship between Mg and HCO_3

CHAPTER 5
SUMMARY
AND
CONCLUSION



CHAPTER 5

SUMMARY AND CONCLUSION

The study was conducted to assess the degree of ionic toxicity of ground water sources in Kushtia district. Forty one water samples were collected from different locations in order to study the chemical constituents of water and classify the waters on the basis of their suitability for irrigation, livestock, poultry, aquaculture and industrial usage.

The classification of all ground waters was accomplished on the basis of pH, electrical conductivity (EC), total dissolved solids (TDS), sodium adsorption ratio (SAR), soluble sodium percentage (SSP), residual sodium carbonate (RSC) and hardness (H_T). The pH values were within the range of 6.53 to 7.63 indicating the slightly acidic to slightly alkaline and were not problematic for successful crop production. EC of the samples were within the range of 411.0 to 1310.0 $\mu\text{S cm}^{-1}$ and were rated as 'good' and 'permissible' categories. Out of 41 samples, 22 samples were 'good' and the rest 19 samples were in 'permissible' categories.

All the samples were graded as 'fresh water' in respect to TDS because all waters contained TDS less than 1000 mg L^{-1} . The concentrations of total cations (4.56 to 12.11 mg L^{-1}) and total anions (3.96 to 9.89 mg L^{-1}) under study were within the safe limit for soils and crops. The concentration of B in different water sources ranged from 0.01 to 0.40 mg L^{-1} , which were within 'safe' limit ($<1.0 \text{ mg L}^{-1}$) for all crops. Regarding Fe content, all the ground water samples contained Fe below the specific limit (5.0 mg L^{-1}). On the basis of As content, all the water samples except four samples were not problematic for irrigation. Considering Mn, B and Cl ions, all the samples were not problematic for irrigation and those ions would not be created harmful effect on soils and crops but HCO_3 ions was treated as pollutant for irrigation usage because all the samples contained HCO_3 above the recommended limit (1.5 me L^{-1}). Regarding SO_4 content all the water samples below the recommended limit (20 mg L^{-1}). Because of PO_4 concentrations, 23 samples were found unsuitable and the rest 18 samples were suitable for irrigation.

Water samples were of 'excellent' class regarding SAR values, as the SAR values ranged from 2.91 to 11.13. On the combination basis of SAR and EC, all samples were graded as 'medium' and 'high' salinity (C2 and C3) and 'low' alkali hazards (S1) class, combinedly expressed as C2S1 for 34 samples and C3S1 for the rest 7 samples. Out of 41 samples, 3 samples were 'excellent', 33 samples were 'good' and rest 5 samples were 'permissible' categories based on SSP. According to RSC, 31 water samples were classified as 'suitable', 8 samples were classified as 'marginal' and rest 2 samples were unsuitable in quality for irrigation. As regards to hardness 7 samples were 'very hard' 2 samples were 'moderately hard' and rest 32 samples were 'hard'. The ionic concentrations of water samples analyzed were in the descending order of magnitude as:



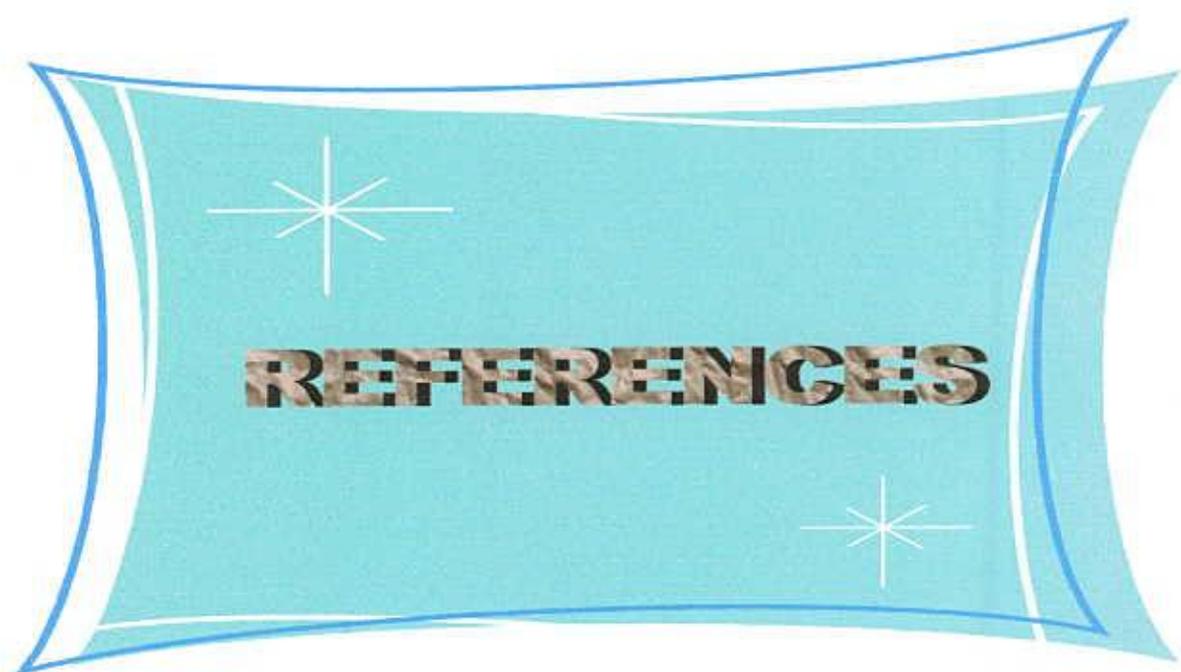
According to water quality standard for drinking, only 19 samples were 'suitable' for drinking purpose due to lower concentration of Fe ($< 0.30 \text{ mg L}^{-1}$) and the rest of 22 samples were 'unsuitable' for drinking of human and livestock because these ground water samples contained higher amount of Fe ($> 0.30 \text{ mg L}^{-1}$) indicating Fe as pollutant. Out of the 41 ground water samples, 40 samples were 'suitable' for drinking of human and livestock uses because these ground water samples contained lower amount of Mn ($< 0.05 \text{ mg L}^{-1}$) but the rest 1 sample was 'unsuitable' for drinking of human and livestock because Mn content of those samples exceeded the recommended limit (0.05 mg L^{-1}). Among the 41 samples, 37 samples were suitable for drinking and 39 samples were fit for livestock consumption on the basis of As. Based on B, SO_4 , and Cl ions were all waters were suitable for drinking because the concentration of these ions were less than the recommended limits and respect to Cl ion 35 samples were toxic to livestock consumption because Cl content exceeded the recommended limit.

Regarding aquaculture purpose, based on Cl and Fe content all water were found unsuitable. Fe content of 33 samples was suitable for aquaculture. The pH and SO_4 contents of all the values were suitable for aquaculture. Considering H_T , 39 samples were for aquaculture. TDS values of only 15 samples were suitable and rest 26 samples were unsuitable for aquaculture. All the waters samples were suitable for poultry on the basis of pH, SO_4 and H_T . Fe content of only 13 samples was found suitable for laundering, textile and ice-manufacture. But all water samples were suitable for brewing, paper & pulp and sugar industries. Fe content of all water samples were found unsuitable for air-

conditioning, aquaculture, 28 samples were unsuitable for carbonated beverage, confectionery and tanning industries. Mn content of all waters were suitable for air-conditioning, ice manufacture carbonated beverage, confectionery and laundering. For brewing, 40 samples were suitable for paper & pulp; all samples were suitable for textile and tanning. For SO₄ status, all water samples were suitable for all purpose.

The relationship of SAR vs SSP and SSP vs RSC indicated significant positive correlation while SSP vs H_T and RSC vs H_T combinations revealed negative significant correlation. To the contrary, the relationship between pH vs. SAR, pH vs. H_T, EC vs. TDS, EC Vs SSP, EC vs. H_T, H_T vs. TDS, EC vs. SSP and EC vs. RSC, were found insignificant. Among the major ionic constituents remarkable significant correlation existed between Ca vs. Mg; Ca vs. Mn , Ca vs. Cu, Mg vs. K, Mg vs. Mn , Mg vs Cu , , Na vs Fe, Na vs. Mn , Na vs Cu , K vs. Cu , Na vs. B , Fe vs. Cu , Cl vs. Mn , Mn vs. SO₄, Cu vs. B and Cu vs. SO₄.

From the present study, it can be concluded that the groundwater samples had no B, Mn and Cl toxicities for irrigation but CO₃ , HCO₃, Fe, As and PO₄ toxicities were detected in some water sources. Considering drinking, livestock and poultry usage both Fe and Mn were treated as pollutants in most of the samples. It may be suggested that ground water samples should be treated to remove the pollutants before the use of water for specific purpose. The chemical assessment of irrigation water should be taken into consideration for fertilizer recommendation as it contains reasonable quantity of PO₄, SO₄, K and some micronutrients. In addition to the chemical quality of water, bio-logical and radiological qualities should also be assessed in future for the efficient management of water use.



CHAPTER 6

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APPENDICES

APPENDICES

Appendix I. Water classification on the basis of EC to SSP

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

Source: Wilcox, L.V. 1995. Classification and use of irrigation water. USDA. Circular no. 969. Washington D.c.p.19.

Appendix II. Water classification based on B concentration

Water class	Boron (mg L^{-1})		
	Sensitive	Semi-tolerant crops	Tolerant crops
Excellent	<0.33	<0.67	<1.00
Good	0.33-0.67	0.67-1.33	1.00-2.00
Permissible	0.67-1.00	1.33-2.00	2.00-3.00
Doubtful	1.00-1.25	2.00-2.50	3.00-3.75
Unsuitable	>1.25	>2.50	>3.75

Source: Wilcox, L.V. 1995. Classification and use of irrigation water. USDA. Circular no. 969. Washington D.C.p.19.



APPENDIX III. Water Classification as per TDS

Water class	Total Dissolved Solids (mg L ⁻¹)
Fresh water	0-1,000
Brackish water	1,000-10,000
Saline water	10,000-100,000
Brine water	>100,000

Source: Freeze, A.R. and Cherry, J. A. 1979. Groundwater. Prentice Hall Inc. Englewood Cliffs. New Jersey 07632. p.84.

Appendix IV. Water class rating based on SAR

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

Source: Todd, D.K. 1980. Groundwater Hydrology, 2nd edn. John Wiley and Sons Inc. New York 10016. p.304.

Appendix V. Water classification according to RSC

Suitability of the water	Residual sodium carbonate (RSC) (me L ⁻¹)
Suitable	<1.25
Marginal	1.25-2.50
Unsuitable	>2.50

Source: Eaton, F.M.1950. Significance of carbonate in irrigation waters. Soil Sci.67: 12-133.



Appendix VI. Classification of water on the basis of hardness (mg L⁻¹)

Water class	Hardness (mg L ⁻¹)
Soft	0-75
Moderately hard	75-150
Hard	150-300
Very hard	>300

Source: Sawyer, C.N. and Mc. Carty, P.L. 1967. Chemistry for sanitary Engineers. 2nd edn. Mcgraw Hill, New York. P.518.

Appendix VII. Recommended maximum concentration of quality factor and different ions in irrigation water

Elements	For waters used continuously on all soils (mg L ⁻¹)
pH	6.5-8.40
Arsenic (As)	0.10
Boron (B)	0.75
Bicarbonate (HCO ₃)	92.00
Carbonate (CO ₃)	0.10
Chloride (Cl)	142.00
Iron (Fe)	5.00
Manganese (Mn)	0.20
Copper (Cu)	0.20
Phosphate (PO ₄)	2.00
Sulfate (SO ₄)	20.00

Source: Ayers, R.S. and Wescot, D.W.1985. Water Quality for Agriculture.FAO Irrigation and Drainage paper 29(Rev.1): 40-96.

Appendix VIII. Recommended concentration of different ions for drinking water

Constituents	Recommended limits (mg L ⁻¹)
Arsenic (As)	0.01
Chloride (Cl)	250.00
Iron (Fe)	0.30
Manganese (Mn)	0.05
Copper (Cu)	1.00
Nitrate (NO ₃)	45.00
Sulfate (SO ₄)	250.00
Boron (B)	1.00
Total dissolved solids (TDS)	500.00

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

Appendix IX. Recommended for the level of toxic substance in drinking water for livestock use

Constituents	Recommended limit (mg L⁻¹)
Arsenic (As)	0.20
Boron (B)	5.00
Iron (Fe)	0.30
Manganese (Mn)	0.05
Copper (Cu)	0.50
Nitrate + Nitrite+ (NO ₃ -N+ NO ₂ -N)	100.00
Chloride (Cl)	30.00
Total dissolved solids (TDS)	10,000.00

Source: ESB(Environmental Studies Board) 1972. National Academy of Sciences, National Academy of Engineering, U.S.A.

Appendix X. Water quality standards for aquaculture

Parameter	Concentration (mgL⁻¹)
Chloride (Cl)	<0.003
Hardness (H _T)	10-400
Iron (Fe)	<0.01
Manganese (Mn)	<0.01
pH	6.50-8.00
Sulfate(SO ₄)	<50
Total dissolved solids (TDS)	<400

Source: Meade, J.W. 1989. Aquaculture Management. New York. Van Nostr and Reinhold.

Note: Concentrations are in mg L⁻¹ except for pH.

Appendix XI. Recommended concentrations of different ions for industrial water supply.

Use	pH	TDS	H _T	Cl	SO ₄	Fe	Mn
		(mg L ⁻¹)					
Air-conditioning	-	-	-	-	-	0.05	0.5
Brewing	6.5-7.0	500-1500	-	60-100	-	0.1	0.1
Carbonated beverage	-	850	200-250	250	250	0.1-0.2	0.2
Confectionery	>7.0	50-100	70	-	-	0.1-2	0.2
Ice Manufacture	-	170-1300	-	-	-	0.2	0.2
Laundering	6.0-6.8	-	0-50	-	-	0.2-1.0	0.2
Paper and Pulp	-	100-200	100	-	-	0.1	0.05
Rayon manufacture	7.8	-	55	-	-	-	-
Sugar	-	-	-	20	20	0.1	-
Tanning	6.0-8.0	-	50-500	-	-	0.1-0.2	0.1-0.2
Textile	-	-	0-50	100	100	0.1-1.0	0.05-1.0

Source: U.S. Environmental Protection Agency (Federal Register, V. 40, No. 248,

pp. 59555-59588, December 24, 1795)

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