ASSESSMENT OF IONIC TOXICITY OF WATER SOURCES IN RAJBARI DISTRICT IN BANGLADESH

By

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CERTIFICATE

This is to certify that the thesis entitled "Assessment of Ionic Toxicity of Water Sources in Rajbari District in Bangladesh" **submitted to the Faculty of Agriculture Sher-e-Bangla Agricultural University, Dhaka in partial fulfillment of the requirements for the degree of** ***MASTER OF SCIENCE IN AGRICULTURAL CHEMISTRY*** **embodies the result of a piece of** ***bona fide*** **research work carried out by Mohammad Nurul Islam , Registration No.04-01407 under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma in any other institutes.**

I further certify that such help or sources of information, as have been availed during the course of this investigation have duly been acknowledged.

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Dedicated to
My Beloved
Parents

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ABSTRACT

The study was conducted to assess the degree of ionic toxicity and to classify the water on the basis of standard criteria for irrigation, drinking, livestock, poultry, aquaculture and industrial purposes of 20 ground water sources in Rajbari district. The chemical analysis included pH, electrical conductivity (EC), total dissolved solids (TDS), sodium adsorption ratio (SAR), soluble sodium percentage (SSP), residual sodium carbonate (RSC) and hardness (H_T) and major ionic constituents like Ca^{2+}, Mg^{2+}, K^+, Na^+, Fe^{2+}, Mn^{2+}, B^+, Cu^{2+}, PO_4^{3-}, CO_3^{2-}, HCO_3^-, SO_4^{2-} and Cl^- were also calculated. The pH (6.85 to 7.33) showed slightly acidic to slightly alkaline. The TDS values rated all samples as 'fresh water'. EC and SAR were 'medium' and 'high salinity' (C2 and C3) classes and 'low alkali hazard' (S1) class, combined 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 Mn and Cu were not found in the study area for irrigation, drinking and livestock but Fe, Cl, SO_4 and B toxicities were found in some sources. Iron content of all samples was suitable for irrigation but 12 samples of Fe were unsuitable for drinking and livestock. Cl concentrations of all samples were below toxic level and thus suitable for irrigation and drinking and all but one sample was suitable for livestock. All samples of NO_3 were not toxic for drinking and livestock but all samples of HCO_3^- were toxic for irrigation. The following combinations of pH vs SAR, SAR vs SSP , Ca vs HCO_3^- and Mg vs HCO_3^- were indicated significant as positive correlations while SSP vs H_T and RSC vs H_T revealed negative significant correlations at 1% and 5% level of significance. To the contrary, the rest combinations showed insignificant correlations. On the basis of major ionic constituents, it was observed that water from pond and deep tube-wells were comparatively better than well waters for irrigation, drinking, livestock and industrial purposes.

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LIST OF ABBREVIATIONS AND ACRONYMS

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 Absorption Ratio
SSP = Soluble Sodium Percentage
RSC = Residual Sodium Carbonate
AAS = Atomic Absorption Spectrophotometer
PAR = Potassium Absorption 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)
dS cm^{-1} = Deci Siemens per centimeter
% =Percentage
^{0}C = Degree Celsius
cm = Centimeter
g = Gram
Mg L^{-1} = Milligram per Litre
Me L^{-1} = Milli Equivalent per Litre
R^2 = Co-efficient of Determination
m = Meter
r = Correlation of Coefficient
μS m^{-1} = Micro Siemens per metre

Chapter I

Introduction

CHAPTER I

INTRODUCTION

Water quality for irrigation is an important criterion for successful crop production as it contains different toxic ions in varying concentrations. Irrigated agriculture is dependent on water of useable quality. If low quality of water is utilized for irrigation, toxic elements may accumulate in the soil thus deteriorating soil properties. In Bangladesh, major part of arable land is under rain fed ecosystem. This is why; farmers face acute shortage of irrigation water during dry season and use irrigation water from both surface and ground sources. Besides agricultural point of view, water of desirable quality is absolutely essential for drinking, domestic and industrial purposes. Thus, water quality assessment is the most significant aspect of water management irrespective of its utility. Water is one of the most valuable natural resources on earth but its quality is of prime importance. As because, the chemical constituents of water determine its quality as well as its utilization for irrigation, industrial and domestic usages. All water bodies contain varying amount of different species of cations and anions. Among them, the main soluble constituents are Ca, Mg, Na and K as cations and Cl^-, SO_4^{-2}, CO_3^{-2} and HCO_3^- as anions. Out of the soluble constituents, Ca, Mg, Na, Cl^-, SO_4^{-2}, K, HCO_3^- and B are of prime importance in judging the water quality for irrigation (Michael, 1978). Some of these ions are more or less beneficial to plant growth but certain soluble ions at relatively high concentrations have a direct toxic effect on insensitive crops. Waters contain certain potentially toxic ions such as B, Na, Cl^- and Li etc. 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 (Bohn *et al.,* 1985). Moreover, specific water may be suitable for irrigation purpose but may be unsuitable for drinking and industrial usages due to the presence of some other ions at toxic- level. Toxic ions are As, Cd, Cr, Fe, Pb and Mn for drinking water and are also As, Cd, Cu, Pb, Mn, Hg, and Se for livestock consumption. Some ions like Cl^-, SO_4^{-2}, Fe and Mn are troublesome for industrial process waters irrigation water quality is generally judged by its total salt concentrations, relative proportions of ions or sodium adsorption ratio and the contents of HCO_3^- and B. For this reason, some important chemical constituents of water are indispensable to assess its suitability for irrigation, drinking, livestock and industrial usages. Water quality is important for long term irrigation system because it influences on soil properties in this tact, land areas applying water to irrigate their crops are always doubting whether irrigation water is improving or deteriorating soil conditions in this context, it becomes a crying need to conduct field level investigations or the existing water management practices in rural areas of Bangladesh. Again, water pollution is severe problem in domestic and industrial purposes. So, it is necessary to assess the degree of ionic toxicity in both surface and ground waters for specific purposes. Some systematic investigations on the water quality in some selected sites of Bangladesh viz., Goalando, Meherpur, Kalihati, Khagrachari, Phulpur, Madhupur, Muktagacha, Trishal and Pangsha Thana has been conducted. Most of the chemical analyses of these investigations confined within pH, EC, Ca, Mg, K, CO_3^{-2}, HCO_3^-, Cl^-, SO_4^{-2}, NO_3^{-2}, Fe, B and Na. But little attention has been paid to trace elements, e.g. A Cu, Mn, Zn and as yet no attention has given to the concentration of toxic elements e.g. As, Cr, Pb, Hg, Cd etc. Now days, toxic elements are very important for irrigation, drinking, livestock and industrial purposes. In fact, there is no laboratory for systematic assessment of water quality in Bangladesh. The total land area of Rajbari municipality is 17.5 sq. mile of which 13.0 sq. mile is arable lands and 4.5 sq. mile are under industrial and commercial areas. About 50% of arable lands are irrigated by ground and surface waters. In the study area, there are water sources in which waters of deep tubewell and rivers are mainly utilized for irrigation and industrial purposes and waters of pond, well and hand tubewell are also mainly used for drinking, domestic and livestock lieu consumption. The study area is considered as one of densely industrialized area in Rajbari, Bangladesh. Presently, water is probably polluted due to the industrial expansion and industrial wastages are incorporated into the water bodies. Water of undesirable quality may create problem for various uses. A systematic investigation on water quality was not conducted before this area. Keeping above points in mind, this area was selected for the present study. The investigation was conducted at the Department of Agricultural Chemistry, Sher-e-Bangla Agricultural University, Dhaka with the following main objectives;

i) To assess the degree of ionic toxicity for different water sources.

ii) To classify waters on the basis of standard criteria as regards to suitability for irrigation, drinking, livestock and industrial usages.

iii) To identify the polluted water sources for future recommendations.

Chapter II

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

Water quality for long-term irrigation has a tremendous impact on soil properties and furthermore its quality for drinking, domestic, livestock and industrial usages are of prime importance. A few research works relevant to the present studies has been conducted in home and abroad. However, an attempt has been taken to review some of the findings in relation to water quality under the following sequences.

2.1 Water quality based on pH

The pH values of the ground and surface waters of Matiranga Thana in Khagrachari district ranged from 4.02 to 7.54 (Helaluddin, 1996). Razzaque (1995) stated that the pH of different sources of irrigation water of Kalihati and Ghatail Thana's under Tangail district varied from 6.88 to 8.29. In ground water samples of Gazipur, the pH value ranged from 7.25 to 8.62 (Quayum, 1995). Mosharaf (1992) stated that the pH values of ground water samples of Muktagacha of Mymensingh district varied from 7.5 to 8.5. The pH of ground water of Madhupur under Tangail district was within the range from 8.0 to 8.5 (Zaman and Majid, 1995). Another investigation was conducted of Meherpur, where pH value varied within the limit of 7.8 to 8.1 (Zaman and Quddus, 1996). Zaman and Mohiuddin (1995) conducted a study at Pangsha Thana in Rajbari district and found that the pH was from 8.1 to 8.3. The pH of ground and surface waters of Shahzadpur under Sirajgonj district from 8.2 to 8.7 (Rahman and Zaman, 1995).

In Pakistan, the pH of irrigation water of Faisalabad city effluent varied from 7.0 to 8.2 (Ibrahim and Salmon, 1992). The pH values of some canal waters of North India were confined within the range of 7.4 to 8.5 (Paliwal, 1972) while, Baddesha *et al* (1988) reported that the raw sewage waters of Haryana had the pH of 7.0 to 7.5. Water containing high concentrations of Ca, Mg, Na and HCO_3; resulted high pH value (Michael, 1978).

2.2 Water quality based on EC and salinity

The salinity of water is usually expressed in electrical conductance (EC) reflecting salt concentration (Agarwal *et al.*, 1982). Richards (1968) suggested four salinity water classes according to electrical conductivity. These classes were 'low salinity water' (C1) having EC < 250 µS cm^{-1}; 'medium salinity water' (C2) containing EC in the range of 250 to 750 µS cm^{-1}; 'high salinity water' (C3) containing EC from 750 to 2,250 µS cm^{-1} and 'very high salinity water' having EC 250-5,000 µS cm^{-1} C1 class of water was considered safe with no likelihood of any salinity problem; C2 was used with moderate leaching; C3 and C4 were not suitable for irrigation purposes. Wilcox (1955) also classified the irrigation water on the basis of EC values '·excellent' containing EC < 250 µS cm^{-1}; 'good' containing EC from 250-750 µS cm^{-1}; permissible' having EC from 750-2000 µS cm^{-1}; 'doubtful' containing EC from 2000-3000 µS cm^{-1} and 'unsuitable' with EC > 3000 µS cm^{-1}. Gupta (1984) revealed that groundwater quality deteriorated with the increasing depth and also found that EC varied from 4 to 74 dS cm^{-1} at 13-38 m depth and also from 31.1 to 44.8 dS cm^{-1} at 38-210 (1:1) depth. Whereas EC of groundwater of Shalizadpur under Sirajgonj district ranged from 340 to 445 µS cm^{-1} (Zaman and Rahman, 1997). Majority of water samples collected from Dinajpur district were characterized in the 'lower salinity' group and were suitable for crop production. The ground water of that district was 'excellent' to 'good' for irrigation purpose (Biswas and Khan, 1976). Helaluddin (1996) also found the water samples of Matiranga Thana of Khagrachari district to be in the 'low salinity' group and were 'excellent' to 'good' for irrigation. Gupta (1986) reported the ground water quality of Rajasthan in 'low' to 'medium' salinity category. Zaman and Majid (1995) stated the EC value of samples in some selected villages of Madhupur was within the limit of 220-570 μS cm^{-1}. The EC values of groundwater for irrigation at Meherpur Sadar were found between 400 to 540 μS cm^{-1} (Zaman and Quddus, 1996). Razaaque (1995) reported the EC values of ground and surface waters of Kalihati and Ghatail Thana varied 130 to 420 μS cm^{-1}. Another investigation conducted by Rahman and Zaman (1995) at Shahzadpur Thana under Sirajgonj district revealed that the EC of some selected river and ground water for irrigation was within the range of 500 to 834 μS cm^{-1}. The EC of 15 groundwater samples varied from 240 to 670 μS cm^{-1} at Pangsha thana of Rajbari district (Zaman and Mohiuddin, 1995).

Soderstrom and Soderstrom (1989) described that high saline groundwater was responsible for increasing salt content of irrigated soil, particularly where drainage was poor. Michael (1978) reported that a highly saline water may be suitable in a well drained, light textured, fertile soil, while a much less saline water may be more harmful (for the same crop grown on a heavy textured soil. Rao *et al.* (1982) analyzed 605 underground irrigation water samples collected from five taluka of Bijapur, Karnataka and reported that all the waters were of Na Mg-Ca type and considerable numbers of samples were found with very high salinity. Singh and Narain (1984) observed the seasonal fluctuations of water quality for irrigation small at 26 sites of Agra district of Northern India affected by brackish water. Salinity were maximized in June, minimized in December and intermediate in February. Costa *et al.* (1985) classified 160 water samples with respect to salinity. 74.38 belong to class C1S1 and C2S1 considered with 'good' quality waters; 22.78 belonged to classes C4S1. C4S2, C3S1, C3S2 may be suitable for irrigation depending upon soil type and crop. Only 38 belonged to class C3S4, C4S3 and C4S4 considered "appropriate" for irrigation on soils with restricted drainage. Khan and Basak (1986) examined 35 deep tube well water samples from Sadar and Trishal Thana under Mymensingh and obtained few tube wells in Sadar were in "moderate salinity" and other selected locations were in 'low salinity' group and were suitable for growing all agricultural crops.

2.3 Water quality based on dissolved solid (TDS)

Carroll (1962) and Freeze and Cherry (1979) expressed that the solid residues almost invariably consists of inorganic constituents and very small amount of organic substances. They classified groundwater into four categories based on total dissolved solids (TDS).Waters containing TDS values 0-1,000; 1,000-10,000; 10,000-100,000 and >100,000 mg L^{-1} are categories as 'fresh water' ; 'brackish water'; 'saline water' and 'brine' respectively.

In Iraq, the water of Tigris River was excellent for irrigation purposes on the basis of TDS along its whole length with some deterioration especially in the middle southern reaches of the river course (Fathallah, 1983). Zaman and Majid (1994) reported that the ground water of Madhupur Thana, Tangail had the TDS which varied from 100 to 600 mg L^{-1}. Richards (1968) stated that the total dissolved solids of some river waters in United States ranged from108 to 2,380 mg $L^{-1.}$ The TDS values of river and ground waters at Shahzadpur were within the range of 500 to 834 mg L^{-1} (Rahman and Zaman, 1995). Helaluddin (1996) found that the TDS value ranged from 20 to 200 mg L^{-1} in ground and surface waters in different aquifers of Khagrachari. The TDS values of both ground and surface waters at Kalahari and Ghatail Thana of Tangail district varied from 90 to 212 mg L^{-1} (Razzaque, 1995). Quddus and Zaman (1996) stated that the TDS values were within the range of 282g to 462 mg L^{-1} in irrigation water of both surface and groundwater sources of Meherpur Sadar Thana. The TDS values of irrigation water reported by Quayum (1995) at Sadar thana of Gazipur and Shahidullah (1995) at Phulpur Thana of Mymensingh ranged from 70 to 260 mg L^{-1} and 112 to 268 mg L^{-1} respectively.

2.4 Water quality based on calcium, magnesium and potassium

Na was the dominant cation over the entire; range of electrical conductivity followed by Ca, Mg and K in water sample collected from 150 wells in cultivated farms throughout Qatar (Ismail, 1984). Davis and De Weist (1966) studied that Ca, Mg and Na were considered as major constituent in groundwater while Fe as minor constituent. Abu-Sharar (1987) conducted a study on Arabian Gulf water and reported that Mg was the predominant divalent cation with concentration 5.2 times greater than that of Ca. Rao *et al.* (1982) examined 605 ground irrigation water samples collected from Taluka of Bijapur, Karnataka state and found that most of the water were of Na-Mg, Ca cationic type.

Rahman and Zaman (1995) reported that the contents of Ca, Mg, K and Na present in irrigation waters collected from surface and ground sources of 1 Shahzadpur thana ranged from 2.00 to 4.40, 1.09 to 2.19, 0.10 to 0.42 and 0.91 to 1.39 meL^{-1}; respectively. Ca, Mg, K and Na concentrations in groundwater of Pangsha Thana under Rajbari district were obtained within the range of 1.20 to 2.90, 1.00 to 1.30, 0.43 to 3.05 and 0.05 to 0.18 me L^{-1} respectively (Zaman and Mohiuddin, 1995). Shahidullah (1995) stated that the concentrations of Ca, Mg, Na and K in groundwater collected from Phulpur Thana under Mymensingh district varied from 1.40 to 2.65, 0.65 to 1.08, 0.23 to 1.40 and 0.04 to 0.26 me L^{-1} respectively. Another study revealed that all the groundwater's collected from Gazipur Sadar Thana contained Ca, Na and K within the range of 0.55 to 1.65, ;

0.04 to 1.54, 0.43 to 1.00 and 0.02 to 0.05 meL^{-1}; respectively (Quayum, 1995) and Majid (1989) mentioned that the concentrations of Ca, Mg, Na and K of groundwater collected from some villages of Madhupur Thana under Mymensingh district varied from 0.72 to 3.12, 0.78 to 3.12, 0.10 to 0.80 and 0.14 to 0.58 me L^{-1} respectively. K content ranged from 1-193 mg L^{-1} in irrigation water collected from 201 wells in Northern FRG (Koster *et al*., 1990). James *et al.* (1982) also revealed that some irrigation waters contained enough dissolved K to obviate the need for K fertilization. Costa *et al.* (1985) stated that Ca, Mg, K and Na contents in some river water ranged from 0.23 to 7.18, 0.08 to 5.51, 0.02 to 0.31 and 0.19 to 10.66 me L^{-1} respectively. The concentrations of Ca, Mg, Na and K of ground and surface waters in different aquifers of Khagrachari district ranged from 0.1 to 11.4, 0.175 to 7.25, 3.0 to 44 and 2 to 21 mg L^{-1} respectively (Helaluddin, 1996).

2.5 Water quality based on iron and manganese

Fe and Mn contents of collected irrigation water from surface and ground sources ranged from 0.10 to 0.42 and 0.03 to 0.064 mg L^{-1} respectively and Fe was found to be dominant in groundwater as compared to surface water (Rahman, 1993). Khan and Basak (1986) analyzed 35 deep tube well water from Sadar and Trishal thana of Mymensingh district and found most of water samples to lie within the 'safe' limit, but water samples in Trishal thana contained a maximum concentration of Fe (4.5 mg L^{-1}) that was harmful to the soil as well as crops. Zaman and Majid (1995) stated that the concentration of Fe in ground water of some villages of Madhupur Thana varied from traces to 0.02 mg L^{-1}. Helaluddin (1996) reported that the concentrations f of Fe and Mn of ground and surface waters in different aquifers of Khamrangirchar varied from trace to 2.00 and trace to 0.70 respectively. Iron concentration varied from 1 to 2 mg L^{-1} in ground water from different aquifers in the Brahmaputra valley in Assam (Karanth,1987). Recommended maximum concentrations of Fe and Mn in irrigation water were 5.00 and 0.20 mg L^{-1} respectively (Ayers and Westcot, 1985). Zaman and Quddus (1996) reported that the concentrations of Fe and Min in surface and groundwater's of Meherpur Sadar Thana ranged from traces to 0.05 and K traces to 0.20 mg L^{-1} respectively. Fe and Mn contents in groundwater of Pangsha Thana under Rajbari district were found to vary from 0.20 to 1.70 and 0.01 to 0.70 mg L^{-1} respectively Mohiuddin, 1995). Razzaque (1995) found that the concentrations of Fe and Mn in ground and surface waters of Kalihati and Ghatail Thana ranged from 0.045 to 2.045 and 0.01 to 0.072 mg L^{-1} respectively. Ground water of Dinajpur district contained Fe within the limit of 0.02 to 1.00 mg L^{-1} (Biswas and Khan, 1976).

2.6 Water quality based on zinc and copper

Maximum recommended concentrations of Zn and Cu in irrigation water were 2.0 and 0.20 mg L^{-1} respectively (Ayers and Westcot, 1985). Quddus and Zaman (1996) reported that the concentrations of Zn and Cu in surface and ground waters of some villages in Meherpur Sadar varied from traces to 0.05 and traces to 0.1 mg L^{-1} respectively. Zn and Cu contents in irrigated groundwater of Gazipur Thana varied from traces to 0.08 and traces to 0.05 mg L^{-1} respectively (Quayum.1995). Zaman and Mohiuddin (1995) mentioned that the collected irrigation water samples of Pangsha thana under Rajbari district contained Zn and Cu within the limit of 0.02 to 0.05 and 0.01 to 0.06 mg L^{-1} respectively. Helaluddin (1996) analyzed 88 ground and surface water samples of Khagrachari district and found the concentrations of Zn and Cu ranged from trace to 0.46 and trace to 0.05 mg L^{-1}

respectively. Zn and Cu concentrations in ground waters of Phulpur thana under Mymensingh district were within the ranges of g 0.01 to 0.03 and 0.10 to 0.03 mg L^{-1} respectively (Shahidullah, 1995). Rahman (1993) reported that the concentrations of Zn and Cu in surface and ground waters of some villages in Shahjadpur Thana varied from 0.01 to 0.03 and 0.10 to 0.03 mg L^{-1} respectively.

2.7 Water quality based on boron

Higher concentration of B in water affected plant growth and also caused soil toxification (Gupta, 1983). Biggar and Nielson (1972) categorized irrigation water on the basis of B content related to irrigation water quality and found less than 0.5 mg L^{-1} B within safe limits for sensitive crops; from 0.5 to 1.0 mg L^{-1} B for sensitive crops showing slight to moderate injury; from 1.00 to 2.00 mg L^{-1} B for semi tolerant crops showing slight to moderate injury; from 2.00 to 4.00 mg L^{-1} B for tolerant crops slight to moderate injury and more than 4.0 mg L^{-1} B hazardous for nearly all crops. Sarir *et al.* (1981) examined 30 tube well water samples and found that B concentration of all the samples were within 'safe' limits (<1.00 mg L^{-1}). Out of 160 water samples, it was reported that only 18% of the samples obtained B concentration over 1.5 mg L^{-1} (Costa *et al.,* 1985). Wilcox (1955) classified irrigation water based on B concentration into five groups viz., "excellent'. 'good', 'permissible', 'doubtful' and 'unsuitable' and plants into three groups viz., `insensitive`, semi tolerant' and 'tolerant' for B tolerance. For sensitive crops like lemon, 0.3 mg L^{-1} of boron in water was adequate and 1.0 mgL^{-1} was toxic (Richards, 1968). Khan and Basak (1986) investigated the suitability of groundwater for irrigation use in Sadar and Trisal thana under Mimensingh district and found B content in most of the samples were within 'safe' limit (<1 mg L^{-1}) for irrigation even for sensitive crops. Raghunath (1987) described that traces of B (> 0.5 mg L^{-1}) are injurious to citrus, nuts and deciduous fruits but cereals and cottons are moderately tolerant to B while alfalfa, beets and dates are quite tolerant (1-2 mg L^{-1} B).

Rahman and Zaman (1995) stated that B concentration in surface and groundwater of Shahzadpur Thana under Sirajgonj district ranged from 0.10 to 0.40 mg L^{-1}. Boron content was found to vary from traces to 0.92 mg L^{-1} in ground water of some villages of Modhupur Thana (Zaman and Majid, 1995). Quddus and Zaman (1996) reported that B concentration in surface and ground water of some villages of Meherpur Sadar thana ranged from 0.10 t0 to 0.63 mg L^{-1}. Zaman and Mohiuddin (1995) found that B concentration in ground water of Pangsha Thana under Raibari district varied from 0.08 to 0.45 mg L^{-1}. Another study showed that content of B in ground waters of Gazipur Sadar was within 0.15 to 0.54 mg L^{-1} (Quayum,1995). Kanwar and Mehta (1970) stated that B content of irrigation waters collected from surface dug wells ranged from trace to 2.47 mg L^{-1}.

2.8 Water quality based on nitrate

Nitrates polluted ground water when applied N-fertilizer excessively for crop production (Follet and Walker, 1989). The findings revealed that intensive agricultural activities were the cause of nitrate increase in ground water (Keeney, 1989). As a mobile and highly soluble anion, nitrate moves downward in most soils and can leach down to ground water when water is applied to the soil.

A great downward movement of NO;-N in the irrigation of sandy loam soil was responsible for increasing nitrate concentration in ground water (Narang and Singh, 1989). Well *et al.* (1990) reported that NO3-N concentration in shallow (1.2 m deep) ground water was always higher than drinking water and maximum permissible limit could be 10 mg L^{-1}.

NO_3-N concentration in river waters of all world was found to be ranged from 0.01 to 0.34 me L^{-1} (Ballestores *et a*l., 1988). Garcia-Serna *et al.* (1988) found that the NO_3-N content was greater with the irrigation water of conductivity of 2500μ Sc m^{-1}. The concentration of NO_3-N in irrigation water was within the range of trace to 0.13 mg L^{-1} at Shahzadpur Thana under Sirajgonj district (Rahman and Zaman, 1995). Another investigation showed that the content of NO_3-N in water at Pangsha Thana of Rajbari district ranged from 0.05 to 0.36 mg L^{-1} (Zaman and Mohiuddin, 1995). Shahidullah (1995) reported that NO_3-N content varied from trace to 0.49 mg L^{-1} in irrigation water at Phulpur Thana under Mymensingh district.

Water quality based on carbonate, bicarbonate, sulphate and chloride

Davis and De Wiest (1966) presented the data generated out of the analyses of waters through graph which indicated the concentration of HCO_3 was higher and that of SO_4 was lower. Hill (1940) and Piper (1944) showed that the concentration of HCO_3 was higher than other ions. Rao *et al.* (1982) cited that the concentrations of HCO_3, and Cl were dominant among the anions in ground water. Cl was dominant anion followed by SO_4 and the concentrations of CO_3 and HCO_3 were low in water samples collected from different wells (Ismail, 1984). Cl was the most abundant anion, followed by SO_4 and HCO_3 in 18 spring and 13 drainage canals and 5 subcanals water samples at Al-Ahsa Casis of Saudi Arabia as described by Hussain and Sadiq (1990). Rahman and Zaman (1995) mentioned that HCO_3^{-2} and Cl^- ions were dominant along with CO_3 and SO_4 ion that was low in water samples collected from surface and ground sources. Agarwal *et al.* (1982) reported that the running surface water contained variable amounts of anions in the form of HCO_3^{-2}, SO_4^{-2}, and Cl^-. In some river waters of Western United States, the contents of CO3, HCO_3 and Cl varied from 0.05 to 0.42, 0.63 to 5.20 and 0.12 to 7.65 meL^{-1} respectively (Richards, 1968). Zaman and Majid (1995) stated the concentrations of CO_3, HCO_3 and Cl and SO_4 in ground water of some villages of Modhupur ranged from 0.04 to 0.40, 0.80 to 2.52, 0.20 to 0.80 and 0.12 to 2.16 me L^{-1} respectively. Todd (1980) mentioned that irrigation water contained 0 to 50 mg L^{-1} carbonate and less than 500 mg L^{-1} bicarbonate. Helaluddin (1996) stated that the concentrations of HCO_3 and Cl in surface and ground water of Kagrachari aquifers ranged from 0.1 to 1.25 and 0.1 to 1.6 me L^{-1} respectively. The respective concentrations of CO_3, HCO_3, Cl and SO_4 in ground water ol' Pangslra were found within in limit of 0.16 to 1.12. 2.24 to 3.52. 0.24 to 2.25 and 0.13 to 0.27 me L^{-1} (Zaman and Mohiuddin, 1995). Quddus and Zaman (1996) stated that contents of CO_3, HCO_3 and Cl and SO_4 in surface and ground water in some villages of Meherpur ranged from 0.20 to 0.40, 2.60 to 3.10, 0.75 to 0.95 and traces to 7.20 me L^{-1} respectively.

2.9 Water quality based on sodium adsorption ratio (SAR)

Wilcox (1955) suggested a chart for classifying irrigation water into four classes to represent alkali hazard on the basis of sodium adsorption ratio (SAR) and electrical conductivity (EC). Richards (1968) proposed four types of irrigation waters in respect of SAR values and these were 'low sodium water" (S1), 'medium sodium water" (S2). `high sodium water' (S3) and 'very high sodium water' (S4).Water classification for salt values more than 26 was 'unsuitable' for irrigation purposes, SAR values more 10 to 26 were considered as 'good' and SAR values less than 10 were considered to be 'excellent' (Todd, 1980).

Costa *et al*. (1985) analyzed and classified 160 water samples for water quality assessment. It was found that 74.3% samples under categories C1S1 and were rated 'good' quality water, 22.7% falling to categories C4S1, C4S2, C3S1 and C3S2 and only 3% samples that belonged to the class (C3S4, C3S3 and C4S4 were considered 'unsuitable' for irrigation with restricted drainage. Sarir *at al.* (1981) analyzed 30 tube well water samples and classified 29 water samples as C3S1 and only one water sample as C4S1 on the basis of water quality assessment chart. Ground water samples of Madhupur were classified into two categories. Among them, 38 water samples belonged to C2S1 and the rest 7 samples belonged to C3S1 (Majid, 1989). Rao *et al.* (1982) studied 605 ground water samples for irrigation water collected from five taluka of Bijapur district, Karnataka, India and found high y SAR value (>10) in fairly large number of water samples of Bagalkot region. Singh and Narain (1984) stated that the seasonal fluctuation of quality of ground irrigation water was small at 26 sites in a tract of Agra district of North India. The SAR was maximised in June, minimisal in December and intermediate in February.

In Pakistan, the SAR of Faisalabad city sewage effluent used for irrigation ranged from 10.8 to 23.8 (Ibrahim and Salmon, 1992). Hussain *et al.* (1991) also studied the suitability of ground water collected from Punjab in Pakistan and the calculated SAR was 8.39. Abu-Sharar (1987) conducted a study on Arabian Gulf water for future use for irrigation revealed the SAR relatively high (59.89). The values of SAR of surface and ground water of Gazipur sadar and Shahzadpur thana were 0.50 to 0.94 and 0.56 to 0.85 and were graded as 'low sodium' water (Rahman, 1993 and Quayum. 1995) Quddus and Zaman (1996) investigated water samples from some villages of Meherpur and cited the SAR value to be varied from 0.21 to 0.49 and water were categorized under class S1, which means 'low sodium' water. Two studies were conducted separately by Mohiudddin (1995) and Shahidullah (1995) at Pangsha Thana under Rajbari district and at Phulpur thana of

Mymensingh district and reported that the values of SAR of ground water were 0.40 to 3.25 and 0.20 to 1.10 respectively. Parvathappa *et al.* (1990) mentioned that sodium adsorption ratio of irrigation waters significantly correlated with electrical conductivity. Irrigation water having EC 10,000 µS cm^{-1} and SAR 30 slightly increased the seed yield of *Brassica juncea* and *Eruca sativa* crops in comparison to irrigation water containing EC 1,000 µS crn $^{-1}$ and SAR 2.8 or 4.0 (Des and Lal, 1982). The biomass yield of makhna (*Euroyale forex*), growing in ponds in India was negatively correlated with the SAR and the pH of the water (Dutta *et al.*, 1986).

2.10 Water quality based on soluble sodium percentage (SSP)

Wilcox (1955) categorized irrigation water into four classes on the basis of soluble sodium percentage (SSP). These were 'excellent' (SSP < 20), 'good' (SSP = 20-40), 'permissible' (SSP = 40-60). 'doubtful' (SSP = 60-80) and 'unsuitable' (SSP > 80). Ahmed *et al.* (1993) observed that there was a significant correlation between SAR and SSP in ground waters of Muktagacha thana under Mymensingh district and also suggested that out of 30 water samples, 26 were under 'excellent' to 'good' classes and the rest were 'good' to 'injurious' classes. The values of SSP varied from 18.31 to 40.95 in ground water of Gazipur Sadar (Quayum, 1995). Another study conducted by Zaman and Mohiuddin (1995) A revealed that the SSP value in 15 ground water samples of Pangsha thana under Rajbari district were between 14.91 and 46.67 and they were graded as 'excellent', 'good' and 'permissible' classes.

Quddus and Zaman (1996) reported that the SSP values of 25 surface and ground water samples from some villages of Meherpur Sadar ranged from 8.14 to 14.17 and categorized all waters under 'excellent'class. The SSP values of 19 surfaces and ground water of Shahzadpur thana under Sirajgonj district were within the limit of 13.18 to 21.93. Fourteen samples lied under the category 'excellent' and rest 5 under 'good' (Rahman and Zaman, 1995).In another investigation, Zaman and Majid (1995) analyzed ground water samples from Madhupur thana and observed the SSP to be varied from 2.14 to 31.50. Twenty samples were 'excellent' and 3 remaining 'good'. Out of 41 water samples of Phulpur thana under Mymensingh, the SSP values ranged from 6.81 to 28.99 (Shahidullah, 1995). Among them, 33 samples were found 'excellent' and the rest 8 samples were under 'good' class.

2.11 Water quality based on residual sodium carbonate (RSC)

According to classification of Eaton (1950), irrigation water was divided into 3 classes on the basis of residual sodium carbonate (RSC). These were 'suitable' (RSC<1.25 me L^{-1}), 'marginal' (RSC =1.25 -2.50 me L^{-1}) and 'unsuitable' (RSC>2.50 me L^{-1}). On the basis of this classification, Biswas and Khan (1976) opined that out of 50 ground water samples of Dinajpur district, 45 samples were suitable for all crops, 3 samples could be used for selected crops (marginal class)and the rest 2 samples were 'unsuitable'. According to Eaton's classification the RSC values, obtained from 30 ground waters of Muktagacha, Mymensingh, revealed that 27 samples were 'good', 2 were 'marginal' and one was 'unsuitable' (Ahmed *at al.,* 1993). Another study showed that all the ground waters of Gazipur Sadar were under 'suitable' class (Quayum, 1995).

Zaman and Mohiuddin (1995) conducted a study on 45 ground water samples of Pangsha thana, Rajbari district and found 44 samples suitable for irrigation as the RSC values were below 1.25 me L^{-1} and one sample was 'marginal' for irrigation with RSC value 1.34 me L^{-1}. All 25 surface and ground water sample from some villages of Meherpur Sadar thana showed negative RSC value (-0.23 to -0.93) and thus were 'suitable' for irrigation (Quddus and Zaman, 1996). Zaman and Majid (1995) analyzed 23 ground water sample from some villages of Madhupur thana, Mymensingh and reported that 22 samples were free from residual sodium carbonate and the rest sample showed RSC value 0.38. The RSC value of 19 surface and ground water samples from Shahzadpur thana, Sirajgonj district were negative which meant all samples were free from residual sodium carbonate and were 'suitable' for irrigation (Rahman and Zaman, 1995). Out of 41 samples, 16 samples showed the negative value of RSC and reflected free from RSC and the rest 25 samples ranged from 0.01-0.63 and were graded as 'suitable' water classes (Shahidullah, 1995).

Ibrahim and Salmon (1992) conducted an investigation on chemical composition of Faisalabad city (Pakistan) sewage effluent and reported the RSC to be varied from 3.00 to 11.7me L^{-1}. Hussain *et al.* (1991) studied the chemical composition of underground waters from Punjab district in Pakistan to assess the suitability of underground waters for irrigation and stated that the mean RSC value (3.42me L^{-1}) were beyond 'permissible' limits. Rao *et al.* (1982) analyzed 605 groundwater samples from five taluka of Bijapur district Karnataka, India and found considerable number of water samples to very high salinity as well as of hazardous accumulation of residual sodium carbonate in Sindagi taluka. Singh and Sarma (1970) reported that water containing RSC value in the range of 2.89 to 7.52 me L^{-1} were utilized as irrigation source for wheat growth in Rajastan. Vinay *et al.* (1986) showed that the increasing concentration of RSC in irrigation water decreased the grain and straw yields of wheat. Increasing RSC levels of irrigation water decreased the yields of maize and wheat crops and also increased soil acidity as reported by Mumlidhar and Yadav (1991).

2.12 Water quality based on hardness (H_T)

Sawyer and McCarty (1967) categorized irrigation water into four classes based on hardness (H_T). These classes were soft (0-75 mg L^{-1} as $CaCO_3$); moderately hard (75-150 mg L^{-1} as $CaCO_3$) hard (150-300 mg L^{-1} as $CaCO_3$) and very hard (>300 mg L^{-1} as $CaCO_3$). Zaman and Mohiuddin (1995) investigated a study on 15 ground water of Pangsha thana under Rajbari district and observed the hardness (H_T) values to be ranged from 114.84 to 199.72 mg L^{-1} as $CaCO_3$. They found 9 samples 'moderately hard' and 6 samples 'hard'. The hardness value for 25 surface and ground water samples from some villages of Meherpur ranged from 166.47 to 201.38 mg L^{-1} as $CaCO_3$ (Quddus and Zaman, 1996). According to Sawyer and McCarty (1967), all 25 samples were under 'hard' class.)

The H_T values of all the collected water samples ranged from 94.88 to 184.27 mg L^{-1} as $CaCO_3$ at Phulpur thana of Mymensingh district and out of 41 p samples, 25 were rated 'moderately hard' and the rest 16 'hard' (Shahidullah, 1995). Rahman and Zaman (1995) analyzed 19 surface and ground water samples of Shahzadpur thana, Sirajgonj district and obtained hardness value to be vary from 159.83 to 324.20mg L^{-1} as CaCO3. They classified 15 samples 'hard' and 4 samples 'very hard'. Hardness resulted due to abundance of divalent cations such as Ca and Mg (Todd, 1980). According to Sawyer and McCalty's (1967) classification, irrigation waters collected from different underground sources of Gazipur Sadar thana were under "suit' class (Quayum, 1995).

From the aforesaid research work, it may be concluded that some investigations have been carried out in home and abroad on the evaluation of water p quality for irrigation but the assessment of water quality for drinking, livestock and industrial usages was measured and failed to reflect any conclusive idea of this aspect. In Bangladesh, some investigations have been conducted only in some selected sites of 10 districts. However, an attempt has been made to conduct systematic research in Rajbari as major industrial and agricultural based areas. Such investigations can help for better water management as scientific basis.

Chapter III

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

Water quality is an important factor in using water for various purposes because its quality bears great importance in successful crop production. The nature and concentration of various ions and the proportion of divalent and monovalent cations are of especial relevance in judging the water quality from agricultural point of view. Besides this view point, it is also important for drinking, domestic and industrial usage. Analyses of water from different sources to determine its chemical composition is of outmost importance to assess their suitability for irrigation, drinking, and industrial use and also for proper understanding of the soil and water management in agricultural production. Chemical analyses of collected water samples included determination of pH, electrical conductivity (EC), total dissolved solids (TDS), concentration of Ca, Mg, Na, K, CO, B, HCO_3^-, SO_4^{2-}, NO_3^-, P, B, Fe, Zn, Cu, Mn, As and Cl^-. With this objective in view, an attempt has been made to analyze water samples from different water sources of Rajbari.

3.1 Collection of Water Samples

Twenty samples from five water sources of Rajbari municipality under Rajbari district were randomly collected of which 4 from hand tubewells, 2 from deep tube wells, 5 from ponds, 9 from wells (locally known as 'kua'). The whole area of Rajbari was covered to collect the water samples. In the study area, there were many shallow tubes well for irrigating crops. The sites of water sampling for different water sources were shown in Fig. 1 The detailed information on different water sources have been reported in Table 1. Water samples were collected in one liter plastic containers.

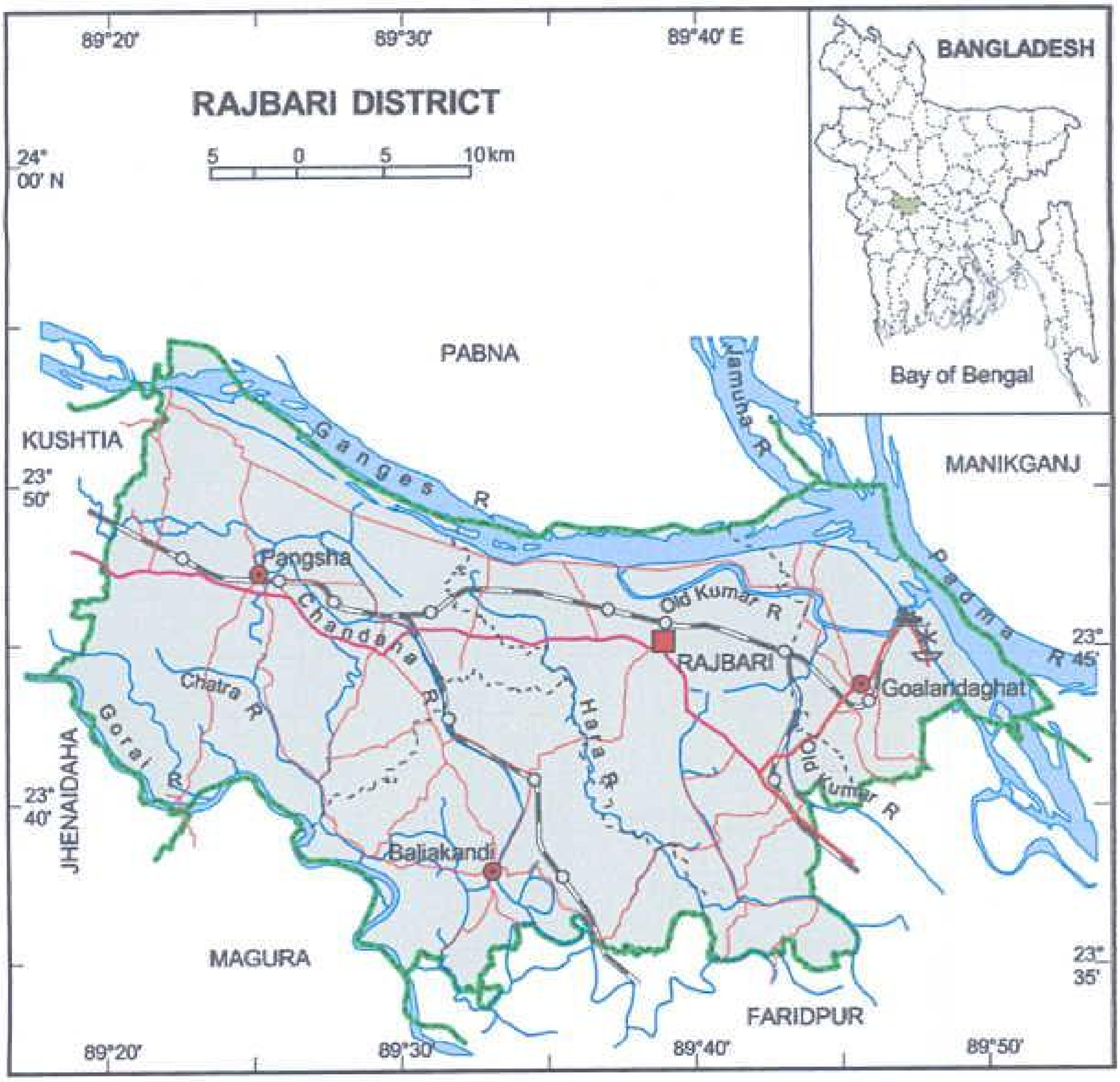

Figure 1. Water sampling sites of Rajbari along with map of Bangladesh

Parameters:

Table 1. Information of ground water sources of Rajbari districts

Sample No.	Sampling Location			Sources	Depth (m)	Date of Installation	Duration of year
	Village	Union	Upazila				
1	Mallapotti	Goalando	Goalando	STW	50.48	22-02-1989	15
2	Bahadurpur	Uzanchar	Goalando	STW	35.37	10-04-2002	6
3	Goalandobazar	Goalando	Goalando	HTW	41.57	20-02-2003	7
4	Canalghat	Daulatdia	Goalando	STW	48.58	15-05-1996	11
5	Daulatdia	Daulatdia	Goalando	STW	37.90	05-07-2005	5
6	Katakhali	Sotobakla	Goalando	HTW	49.50	20-01-1994	12
7	Antarmore	Borat	Rajbari	STW	32.60	10-05-1997	13
8	Urakanda	Borat	Rajbari	STW	31.35	06-02-1992	17
9	Godarbazar	Mizanpur	Rajbari	STW	31.65	03-08-1998	11
10	Daurapara	Chandani	Rajbari	STW	35.32	12-06-1995	14
11	Notunbazar	Khankhanapur	Rajbari	STW	28.95	01-04-2000	8
12	Patindha	Bahadurpur	Pangsha	DTW	89.50	04-06-1997	10
13	Zoshai	Zoshai	Pangsha	DTW	93.58	25-08-1996	11
14	Shangram	Bahadurpur	Pangsha	HTW	43.52	19-07-2004	6
15	Charpara	Habashpur	Pangsha	HTW	41.49	20-04-2005	7
16	Rasulpur	Sonapur	Baliakandi	STW	30.65	25-02-2006	3
17	Baharpur	Baharpur	Baliakandi	STW	35.85	05-07-2007	2
18	Arkandi	Baharpur	Baliakandi	STW	33.95	24-06-2009	12
19	Paturia	Baharpur	Baliakandi	STW	45.50	01-05-1994	17
20	Bongram	Baliakandi	Baliakandi	STW	46.84	25-07-2003	8

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

These containers were cleaned with dilute hydrochloric acid 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. In case of hand tube well and deep tube well, water samples were collected at running condition and sufficient water samples were pumped out prior to sampling. In case of river, water samples were drawn from the mid stream and few centimeters below the surface. The collected samples ware sealed immediately to avoid exposure to air. The water carried to the laboratory of Bangladesh Agricultural Research Institute (BARI), Gazipur for testing. The samples were analyzed as quickly as possible on arrival at the laboratory. Water sampling techniques were followed as outlined by Hunt and Wilson (1986) and Clesceri *et al.*, (1989).

3.2 Analytical Methods of Water Analyses

3.2.1 pH

The pH values of water samples were determined electrometrically using digital pH meter (model WTW pH 521) after Ghosh *et al.* (1983).

3.2.2 Electrical conductivity (EC)

The electrical conductivity (EC) of water samples were determined electrometrically using digital conductivity meter (model TWV/LF 522) following the procedure mentioned by Ghosh *et al.* (1983).

3.2.3 Total dissolved solids (TDS)

Total dissolved solids (TDS) was determined by evaporating a measured aliquot of filtered water samples to dryness and weighing the solid residue according to the method outlined by Chopra and Kanwar (1980).

3.2.4 Calcium

Complexometric titration method was used for estimating the calcium from (the collected water samples using disodium ethylene diamine tetra acetate ($Na_2H_2C_{10}H_{12}O_6N_2.2H_2O$) as a complexing agent at pH 12 in presence of calcon indicator ($C_{20}H_{13}N_2NaO_5S$). Sodium hydroxide (NaOH) was first added to the collected water samples for the precipitation of magnesium as insoluble magnesium hydroxide [$Mg\ (OH_2)$]. Potassium ferrocyanide [$K_4Fe\ (CN)_6.\ 3H_2O$], hydroxylamine-hydrochloride ($NH_2OH.HCl$) and triethanolamine ($C_6H_{15}NO_3$) were added to eliminate the interference of various non-target ions like Fe, Mn, Zn, Cu and Ni. Calcium was estimated titrimetrically following the procedures of Page *et al.* (1982).

3.2.5 Magnesium

Magnesium was estimated by complex metric method of titration using disodium ethylene diamine tetraacetate ($Na_2H_2C_{10}H_{12}O_8N_2.2H_2O$) as a chelating agent in presence of Eriochrome Black T indicator ($C_{20}H_{12}N_3NaO_7S$) with adjusting the required pH 10. For the determination of magnesium alone, calcium was first precipitated from the collected water samples as calcium tungstate ($CaWO_4$) with tungstate solution ($Na_2WO_4.2H_2O$). Potassium ferrocyanide [$K_4Fe\ (CN)\ _6,\ 3H_2O$] hydroxylamine-hydrochloride ($NH_2OH.HCl$) and triethanolamine ($C_6H_{15}NO_3$) were also used to eliminate the competition of various non-target ions like Fe, Cu, Zn, Mn and Ni by the EDTA molecule in the reaction. Magnesium was analyzed titrimetrically following the method of Page *et al.* (1982).

3.2.6 Potassium and sodium

Potassium and sodium were estimated with the help of flame emission spectrophotometer (Galen Kamp Cat. No. 23/FH-500) at 768 nm (for K) and at 589 nm (for Na). The sample was aspirated into a gas flame and air pressure was fixed at 10 psi. The desired spectral line was isolated using interference filters. The per cent emissions were recorded following the procedure mentioned by Golterman (1971) and Ghosh *et al.* (1983).

3.2.7 Iron, zinc, copper and manganese

Iron, zinc, copper and manganese were analyzed by Atomic Absorption Spectrophotometer (Hitachi, Model, 170-30) at the wave lengths of 248.3 nm, 213.8 nm, 324.8 nm and 279.5 nm respectively in the laboratory of Soil Science division, Bangladesh Rice Research Institute (BRRI) following the procedure described by Clesceri *et al.* (1989);

3.2.8 Phosphorus

Phosphorus was estimated calorimetrically from water samples using stannous chloride as a reducing agent (Clesceri *et al.*, 1989). In this method, heterophony complexes were thought to be formed by the co-ordination of molybdate ions and phosphorus. Blue colour was developed by the reduction of heteropolycomplexes by stannous chloride. The colour intensity was measured at 600 nm wavelength with a spectrophotometer (Coleman Junior Model No. 6A) within 15 minutes aider stannous chloride addition following the procedure outlined by Jackson (1958).

3.2.9 Boron

The concentration of boron in water was analyzed calorimetrically using cur cumin oxalic acid. Water samples containing boron was acidified and evaporated in presence of curcumin forming red colored product (rosocyanine). The colour intensity was read with a spectrophotometer (Coleman Junior Model No. 6A) at 540 nm wavelength following the methods of Allen *et al.* (1974) and Ghosh *et al.* (1983).

3.2.10 Sulphate-sulphur

Sulphate-sulphur of water sample was determined turbid metrically using barium chloride ($BaCl_2.2H_2O$) as turbidimetric reagent. Sulphate ions reacted with barium chloride to form the turbidity of barium sulphate. Readings were taken in spectrophotometer after 30 minutes at 425 nm wavelength (Wolf, 1982 and Tandon, 1993).

3.2.11 Nitrate-nitrogen

Nitrate-nitrogen was determined by phenoldisulphonic acid method with the help of a spectrophotometer (Coleman Junior Model No. 6A) at 420 nm wavelength. The water sample was evaporated to dryness over hot water bath and after cooling, the yellow colour was developed by the reaction between nitrate and phenoldisulphonic acid followed by the addition of ammonia (Page *et al.*, 1982 and Ghosh *et al.*, 1983).

3.2.12 Chloride

Chloride of water samples was determined by argent metric method of titration using potassium chromate indicator (K_2CrO_4) which worked in a neutral or slightly alkaline solution (pH 7-10). Silver chloride (AgCl) was quantitatively precipitated before red silver chromate (Ag_2CrO_4) was formed.

The reactions were mentioned below

$$AgNO_3 + NaCl \longrightarrow AgCl + NaNO_3$$

$$2AgNO_3 + 2\,K_2CrO_4 \longrightarrow Ag_2Cro_4 + 2KNO_3$$

Chloride was determined titrimetrically following the method as outlined by Ghosh *et al.* (1983) and Clesceri *et al.* (1989).

3.2.13 Carbonate and bicarbonate

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

$$2\ Na_2CO_3 + H_2SO_4 \longrightarrow 2\ NaHCO_3 + Na_2SO4$$

$$2NaHCO_3 + H_2SO_4 \longrightarrow Na_2SO_4 + 2\ CO_2 + 2H_2O$$

3.3 Evaluation of Irrigation Water Quality

The evaluation of irrigation water quality is important because the important characteristics of irrigation water have been utilized to classify water for their suitability for irrigation purpose and also indicate their potentiality to foster soil conditions detrimental to crop growth. The following quality factors related to water class rating for irrigation were computed from the data generated out of chemical analyses of water samples. The equations were –

3.3.1 Sodium Adsorption Ratio (SAR)

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

3.3.2 Potassium Adsorption Ratio (PAR):

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

3.3.3 Soluble Na percentage (SSP):

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

3.3.4 Hardness or Total Hardness (H_T):

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

Where concentrations were expressed as me L^{-1} for calculating all quality factors but in case of hardness, ions were expressed as mg L^{-1}.

3.4 Statistical Analyses

Statistical analysis of the data generated out of the chemical analyses of water samples, were done with the help of a scientific calculator (Casio-fx-991MS,S.V.P.A.M) following the standard procedure as described by Gomez and Gomez (1984). Correlation studies were also performed following the standard method of computer programme (SPSS).

3.5 Checking the Correctness of Analyses

The accuracy of chemical analyses of water samples were checked by means of the following procedures. Electrical conductivity (EC), pH, total dissolved solids (TDS) and major anion-cation constituents were indications of water quality. The differences between the sum of cations and anions and the measured or calculated TDS to EC ratio were required for checking the correctness of water analyses. The correctness of analyses of water samples were checked following the methods described by Clesceri *et al.* (1989).

3.5.1 Anion-cation balance

As all potable waters are electrically neutral, the sum of anions and cations expressed as meL^{-1} must be balanced. The per cent difference between anion and cation lies between acceptable limits (5-10%). The per cent difference of anion- cation balance was calculated on the basis of 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 measured values of TDS and EC are indispensable to compare with the calculated values of TDS and EC for checking correctness of analyses. The TDS values were calculated from the sum of major cationic and anionic constituents (in mg L^{-1}) and mentioned below:

3.5.3 Total dissolved solids (TDS) = $CO_3^{2-} + HCO_3^- + Na^+ + K^+ + Ca^{2+} + Mg^{2+} + SO_4^{-2} + NO_3^- + Cl^- + SiO_3 + F$

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

3.5.4 Electrical conductivity (EC) = $100 \times \sum$ cation or anion, me L^{-1}

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

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

$$0.9 < \frac{\text{Calculated EC}}{\text{Measured EC}} < 1.1$$

Chapter IV

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

In the study area , the ionic concentrations analyzed viz., Ca, Mg, Na, K, Fe, Zn, Cu, Mn, P, B, SO_4^{-2}, NO_3^-, HCO_3^-, and Cl^- were present in variable quantities in different water sources. The advantage of water testing is initially judged from the nature and extent of its relationship with soil and crop. The experimental findings described in the foregoing chapter are discussed here in the light and support of relevant research reports wherever applicable. The concentrations of major ions (Ca, Mg, Na, K, C1, CO_3^{--} and HCO_3^-) were presented by vertical bar diagrams (Fig.2); The obtained results are described and discussed under the following headings:

4.1 pH

The pH values of water samples varied from 6.85 to 7.33 (Table 2) and indicated that the waters were slightly acidic to alkaline. Out of 20 samples, only 14 STW water sample, 2 DTW water sample, 5 pond water samples and 7 well water samples were below pH 7. These 3 samples were slightly acidic in nature and this might be due to the presence of lower concentrations of Ca, Mg, Na and HCO_3. These 3 water samples would be suitable for acid loving crops. The remaining 17 samples under the study showed higher pH values above 7.0. These 17 samples were slightly alkaline in nature and this might be due to the presence of higher amounts of Ca, Mg, Na and HCO_3. Among the different water sources; DTW water showed higher pH and pond waters showed lower pH. Ayers and Westcot (1985) mentioned that normal pH range of irrigation usually varied from 6.0 to 8.5. It indicated that pH values of all water samples under test were within the normal range and these waters might not be harmful for soils and crops. Similar observations were also reported by Quayurn (1995) and Razzaque (1995).

Table 2. Concentrations of pH, EC, TDS, Ca, Mg, K, Na, Fe, Zn, Mn, Cu, P, B, SO_4, NO_3, HCO_3, and Cl water sources in Rajbari.

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})	Zn (mg L^{-1})	Mn (mg L^{-1})	Cu (mg L^{-1})	P (mg L^{-1})	B (mg L^{-1})	SO_4 (mg L^{-1})	NO_3 (mg L^{-1})	HCO_3 (mg L^{-1})	Cl (mg L^{-1})
01	7.15	848	827.6	63.5	35.2	41.8	0.65	0.48	Trace	0.07	0.18	0.09	0.5	4.65	Trace	470.36	52.6
02	7.23	665	665.2	48.00	37.5	36.7	1.95	0.42	Trace	0.04	0.15	0.11	0.8	1.75	Trace	373.45	65.45
03	7.05	565	625.3	35.49	29.58	53.2	2.19	0.48	Trace	0.04	0.14	0.03	0.08	6.75	Trace	255.79	34.28
04	7.05	654	758.7	47.15	44.51	41.1	3.98	0.35	Trace	Trace	0.15	0.05	0.05	1.75	Trace	325.48	39.65
05	7.12	512	678.4	59.48	35.93	31.5	2.24	0.28	Trace	Trace	0.15	0.04	0.7	0.95	4.75	248.65	53.57
06	7.16	675	339.8	30.97	27.29	36.6	1.59	0.28	Trace	Trace	0.12	0.07	1.1	2.85	1.98	329.45	9.5
07	7.16	778	752.8	35.65	27.14	31.5	1.52	0.39	0.03	Trace	0.15	0.04	0.65	3.78	23	338.95	32.19
08	7.09	990	652.2	44.5	35.65	35.5	1.98	0.28	Trace	0.05	0.09	0.08	2.75	1.65	9.85	257.98	27.94
09	6.85	835	272.1	36.48	35.89	43.8	3.65	0.36	Trace	Trace	0.08	0.08	2.63	6.85	8.5	365.35	68.49
10	6.99	985	476	74.25	55.45	45.9	2.65	0.48	Trace	Trace	0.07	0.05	2.5	3.75	25.7	258.75	43.75
11	7.04	465	395.7	39.45	35.75	30.7	4.75	0.25	0.05	Trace	0.12	0.04	1.8	5.56	8.85	195.45	65.58
12	6.85	702	578.5	38.5	40.95	42.5	3.48	0.19	Trace	Trace	0.07	0.04	0.04	1.68	Trace	325.15	53.85
13	7.21	415	478.8	42.42	35.5	50.5	1.85	0.47	Trace	Trace	0.11	0.08	1.65	2.95	6.85	200.5	75.5
14	7.18	935	625.7	105.5	60.5	50.6	5.85	0.49	Trace	Trace	0.08	0.09	1.5	3.77	Trace	175.5	65.85
15	7.09	548	645.5	92.75	39.85	36.5	1.55	0.35	0.06	Trace	0.06	0.02	0.5	1.65	5.92	210.45	75.46
16	7.25	660.5	762.4	102.5	29.5	31.8	2.49	0.45	Trace	Trace	0.1	0.07	5.65	1.89	5.85	145.58	39.59
17	7.11	625	455.7	25.5	24.4	58.7	3.45	0.49	Trace	Trace	0.15	0.07	2.5	3.77	15.5	225.75	62.75

Table 2. (Continued)

Sl. No.	pH	EC (µS cm^{-1})	TDS (mg L^{-1})	Ca (mg L^{-1})	Mg (mg L^{-1})	K (mgL^{-1})	Na (mg L^{-1})	Fe (mg L^{-1})	Zn (mg L^{-1})	Mn (mg L^{-1})	Cu (mg L^{-1})	P (mg L^{-1})	B (mg L^{-1})	SO_4 (mg L^{-1})	NO_3 (mg L^{-1})	HCO_3 (mg L^{-1})	Cl (mg L^{-1})
18	7.25	775	596.5	30.45	25.23	17.95	2.25	0.12	Trace	Trace	0.04	0.02	2.75	1.65	6.85	259	42.8
19	7.25	745	613.5	27.59	28.5	19.45	1.56	0.15	Trace	Trace	0.02	0.008	1.45	0.98	7.75	266	46.8
20	7.33	553	555.5	49.65	24.45	27.05	1.58	0.26	Trace	Trace	0.02	0.06	4.45	4.85	6.5	235.5	76
Range	6.85 to 7.33	415 to 990	272.2 to 827.6	25.5 to 105.5	24.4 to 60.5	17.95 to 58.7	0.65 to 5.85	0.12 to 0.49	0.03 to 0.06	0.04 to 0.07	0.02 to 0.18	0.01 to 0.11	0.04 to 5.65	0.95 to 6.85	1.98 to 25.7	145.6 to 470.4	9.5 to 76.0
S($\bar{x}$)	7.12	696.6	587.8	51.49	35.44	38.15	2.57	0.35	0.047	0.050	0.103	0.057	1.71	3.18	9.85	273.2	51.6
SD	0.13	165.5	147.1	24.36	9.64	10.68	1.28	0.12	0.015	0.014	0.047	0.028	1.49	1.83	6.86	78.38	18.1
%CV	1.76	23.75	25.01	47.29	27.18	28.0	49.60	31.43	32.60	28.0	45.85	45.01	8.72	54.4	69.7	28.69	35.1

4.2 Electrical conductivity (EC)

The electrical conductivity (EC) of different sources of water samples under investigation ranged from 415.00 to 990.0 µS cm^{-1} (Table2). Richards (1968) categorized irrigation water into four salinity classes with respect to EC. On the basis of this classification, 13 samples of 'medium salinity' (C2) water and 7 samples were of 'high salinity' (C3) water. Similar type of EC result was also reported by Costa *et al.* (1985) and Raju and Goud (1990). The EC values of different sources of waters under study area were comparatively higher than that of other areas of Bangladesh as reported by Zaman and Mohiuddin (1995); Rahman and Zaman (1995) and Quddus and Zaman (1996). Out of five sources, well water indicated higher EC (516 to 1231 µS cm^{-1}) and pond water recorded lower EC (185 to 497µS cm^{-1}). It. was noted that among the sources, pond water was of best quality with respect to electrical conductivity. Therefore, water of such quality can be used safely for irrigation without hazardous effect on soils and crops.

4.3 Total dissolved solids (TDS)

The amount of total dissolved solids (TDS) of water from different sources under study ranged from 121 to 813 mg L^{-1} (Table 2). Waters under test contained less than 1000 mgL^{-1} TDS and these waters were considered as 'fresh water' (Carroll, 1962; Freeze and Cherry, 1979). It clearly demonstrated that the waters would not affect the osmotic pressure of the soil solution and cell sap of the plants. Similar observations were also expressed by Mohiuddin (1995) and Zaman and Rahman (1996). All the samples under study area were recorded medium to high TDS value due to medium or high ionic concentration in water sources. Out of five sources, well waters indicated higher TDS values (347 to 813 mg L^{-1}) and pond waters recorded lower TDS values (123 to 293 mg L^{-1}). This finding confirmed the views of Bohn *et al.* (1985) that ground waters were usually higher in TDS than surface waters. waters.

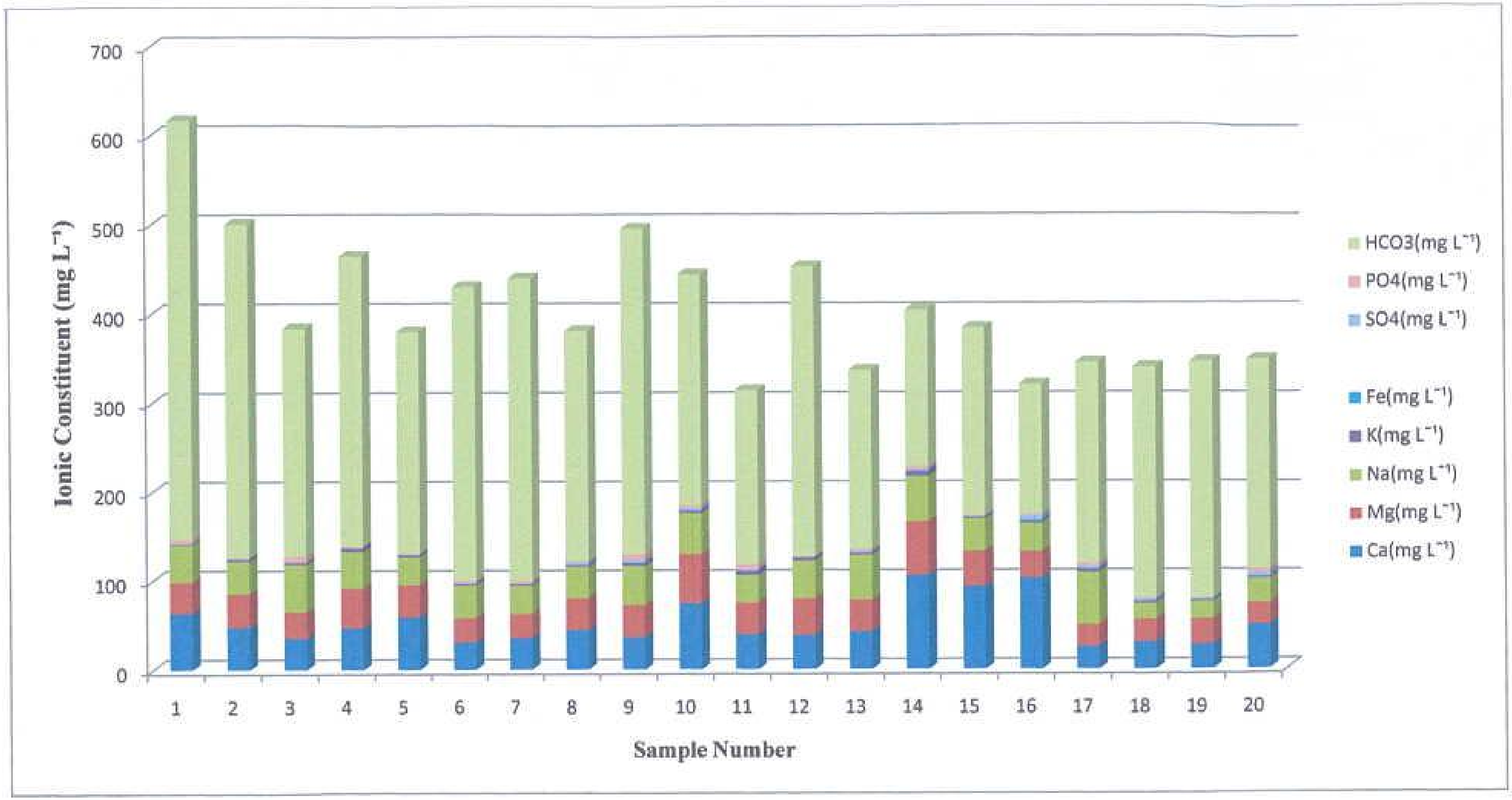

Fig. 2 Bar diagrams for representing major ionic constituent of ground waters

4.4 Ionic constituents

In the study, major ions like Ca^{2+}, Mg^{2+}, K^+, Na^+, CO_3^{2-}, HCO_3^- and Cl^- were of dominant quantities but the remaining ions were also detected in minor amounts. The estimated amounts of these ions present in all the samples in relation to irrigation water quality have been described and discussed as follows:

4. 4.1 Calcium

The concentration of calcium (Ca) was found within the range 25.50 to 105.50 mg L^{-1} with the mean value of 51.49 mg L^{-1} (Table 2). Out of the 20 samples, 14 samples were found below the mean and the rest 6 samples were above the mean value. The standard deviation (SD) and co-efficient of variation (CV) were 24.36 and 47.29% respectively (Table 2). The highest concentration (105.50 mg L^{-1}) was found at Shangram Bahadhurpur in Pangsha upazila (sample no. 14). The lowest value (25.50 mg L^{-1}) was observed at Baharpur in Khoksha upazila (sample no. 17). The concentration of Ca in ground water was largely dependent on solubility of $CaCO_3$; and $CaSO_4$. 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 1 water samples can safely be used for irrigation and they would not affect the soils.

4. 4.2 Magnesium

Groundwater samples collected from Rajbari district, magnesium (Mg) content was found within the range of 24.40 to 60.50 mg L^{-1} with the mean value of 35.44 mg L^{-1} (Table 2). Out of 20 samples, 8 samples (40%) were found below the average value and the rest 12 samples (60%) recorded above the mean value. The calculated standard deviation (SD) and co-efficient of variation (CV) were 9.64 and 27.18% 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.

4.4.3 Sodium

The concentration of sodium (Na) in different water samples were within the range of 17.95 to 58.70 mg L^{-1} and the mean value was 38.14 mg L^{-1}. About (48.78%) samples were below the mean value and rest (51.22%) samples were above the mean. The standard deviation (SD) and coefficient of variation (CV %) were 10.68 and 28 %, respectively (Table 2). Ground waters generally contain less than 40 mg L^{-1} Na (Ayers and Westcot, 1985). The recorded Na content in all the ground waters under test was far below this 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.

4.4.4 Potassium

The concentration of potassium (K) in collected water samples ranged from 0.65 to 5.85 mg L^{-1} with 2.56 mg L^{-1} as mean value. 57% values were below the mean, 20 % were above the mean and 23% were equal to the mean value. The standard deviation (SD) and coefficient of variation (CV %) were 1.28 and 49.60%, 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 (KNO_3) in the aquifers (Karanath, 1987). The detected quantity of K in all the collected groundwater samples had no significant influence on water quality for "irrigation".

4.4.5 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% of (20 samples) were below the mean, 1 sample was equal to mean value and rest (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}).

4.4.6 Copper

All water samples contained very little amount of copper (Cu) and varied from trace to 0.18 mg L^{-1}. Mean value of this element is 0.11. Out of 20 samples, 17 samples contained 0.06 to 0.18 mg L^{-1} Copper. Standard deviation (SD) and co-efficient of variation (CV %) were 0.014 and 28%, 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, none of the waters under investigation were not problematic for irrigation.

4.4.7 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, none of the waters under test were toxic for long-term irrigation.

4.4.8 Boron

Detected amount of boron (B) varied from 0.02 to 0.18 mg L^{-1} having mean value of 0.11 mg L^{-1} About 3 samples were below the mean value and the rest 17 samples values were found above the mean value. The obtained standard, deviation (SD) and coefficient of variation (CV) were 0.047 and 45.85%, 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 Westcott, 1985). In the study area, all the ground water samples were 'suitable' for irrigation based on content as per appendix VIII.

4.4.9 Phosphate

The phosphate (PO_4) content of all collected ground waters varied from 0.95 to 6.85 mg L^{-1} with the mean value of 3.18 mg L^{-1} (Table 2). Out of the 20 samples, 8 samples at were below the mean value and the rest 12 samples were above the mean value. The obtained standard deviation (SD) and co-efficient of variation (CV) were 1.49 and 8.72%, respectively (Table 2). The status of PO_4 in 8 groundwater samples was found within the recommended limit as per Ayers and West cot (1985) but 10 samples (nos. 1, 3, 6, 7, 8, 9, 12, 14, 17, 18) were "doubtfull." for long-term irrigation and exceeded the acceptable limit (2.00 mg L^{-1}).

4.4.10 Sulphate

In all the ground waters, sulphate (SO_4) content varied from 0.04 to 5.65 mg L^{-1} with the mean value of 1.71 mg L^{-1} (Table 2). The standard deviation and coefficient of variation were 1.49 and 8.72%, 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 , being without any toxic effect 'on soils and crops grown in the study area.

4.4.11 Carbonate

Groundwater samples collected from the study area contained carbonate ($C0_3^{2-}$) ranging from trace to 25.70 mg L^{-1}. Among the collected amount of $C0_3^{2-}$ was not detectable in 7 samples. The mean value was 9.85 mg L^{-1}. The computed standard deviation was 6.86 and coefficient of variation was 69.72%, respectively. In respect of $C0_3^{2-}$ content, 13 ground water samples were toxic for irrigation because $C0_3^{2-}$ content exceeded the recommended limit as mentioned in Appendix VII.

4.4.12 Bicarbonate

The concentration of bicarbonate ($HC0_3^-$) in water samples were within the range of a 132.51 to 466.87 mg $L^{-1}$and the mean value was 284.38 mg L^{-1}. Out of 20 samples, 51.22% 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 $HC0_3^-$ content exceeded the recommended limit as mention in Appendix VII.

4.4.13 Chloride

Chloride (Cl^-) content varied from 9.50 to 75.98 mg L^{-1}. The mean value was 51.58 mg L^{-1}. About 51.22% values were below the mean value and rest 48.78 %were above the mean value. The standard deviation and co- efficient of variation were 18.07 and 35.04%, 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, 1987).

4.5 Groundwater Quality Determining Indices

4.5.1 Sodium adsorption ratio

The computed sodium adsorption ratios (SAR) of groundwater samples were 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 of 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 the 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 and 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.

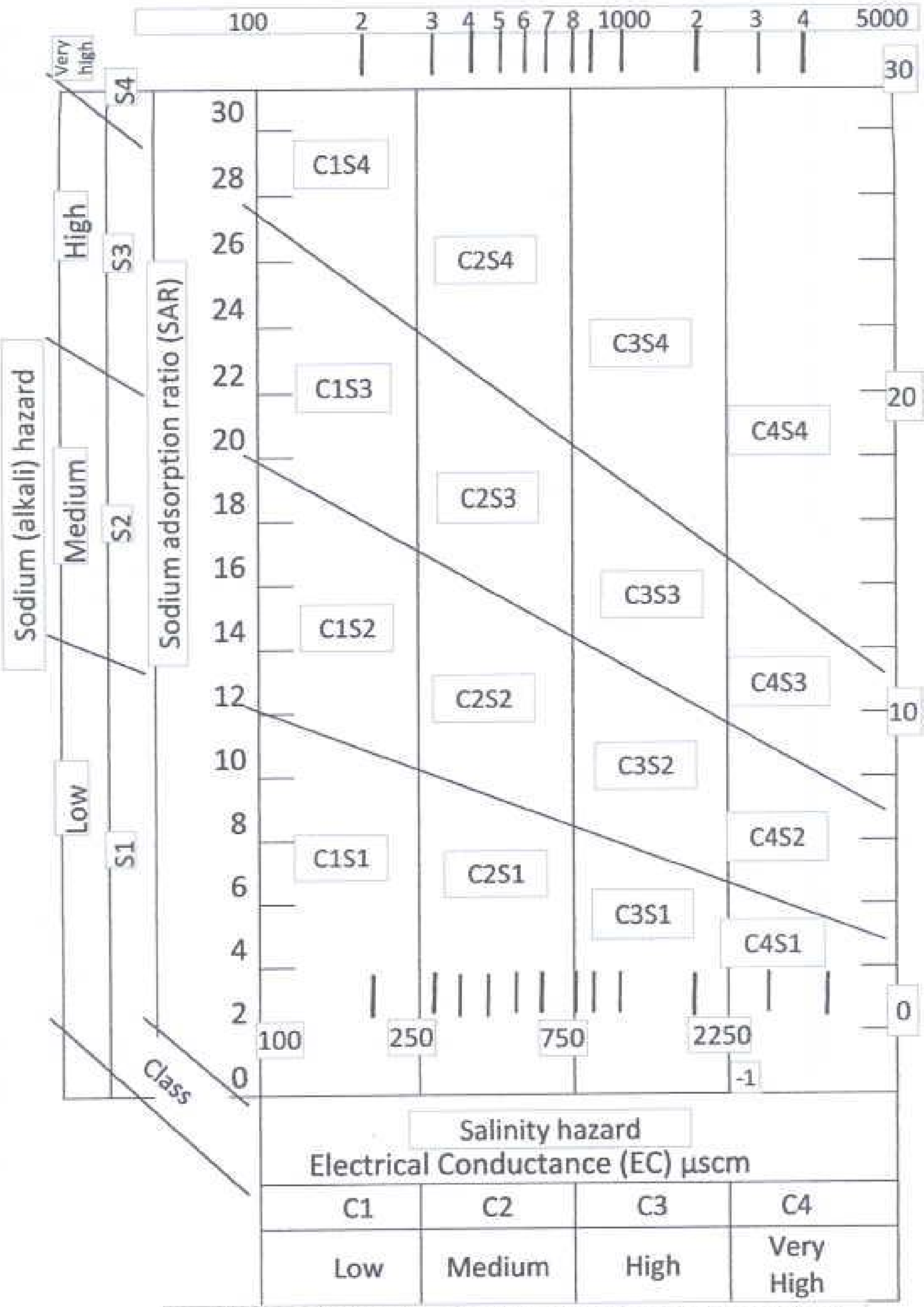

Fig. 3 Diagram for the classification of irrigation waters (Richards, 1968)

4.5.2 Soluble sodium percentage

The soluble sodium percentage (SSP) of all 20 water samples varied from 20.60 to 55.47. The obtained mean value was 32.66 (Table 3). About 56.09% values were below the mean. The standard deviation and co-efficient of variation were 8.42 and 25.78 %, respectively. According to the water classification proposed by Wilcox (1955), 19 samples were rated as ` good' (SSP = 20 to 40%) and the rest 1 sample was rated 'permissible' (SSP = 40 to 60%) in Appendix I. In the study area, the ground waters might safely be applied for irrigating agricultural crops.

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

Sample No.	B (mg L^{-1})		EC (µS cm^{-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	
01	0.5	Ex	848	Per	827.6	FW	5.95	Ex	30.07	Good	1.87	Mar	303.07	VH	C3S1
02	0.8	Ex	665	Good	665.2	FW	5.61	Ex	31.1	Good	1.05	Suit	273.75	H	C2S1
03	0.08	Ex	565	Good	625.3	FW	9.32	Ex	45.96	Good	0.15	Suit	210.00	H	C2S1
04	0.05	Ex	654	Good	758.7	FW	6.07	Ex	32.98	Good	-0.65	Suit	300.36	VH	C3S1
05	0.7	Ex	512	Good	678.4	FW	4.55	Ex	26.1	Good	-0.91	Suit	296.01	H	C2S1
06	1.1	Ex	675	Good	339.8	FW	6.78	Ex	39.58	Good	1.75	Mar	189.31	H	C2S1
07	0.65	Ex	778	Per	752.8	FW	5.63	Ex	34.48	Good	1.68	Mar	200.39	H	C2S1
08	2.75	Ex	990	Per	652.2	FW	5.6	Ex	31.83	Good	0.79	Suit	257.41	H	C2S1
09	2.63	Ex	835	Per	272.1	FW	7.27	Ex	39.58	Good	2.31	Mar	238.34	H	C2S1
10	2.5	Ex	985	Per	476	FW	5.7	Ex	27.22	Good	2.04	Mar	412.97	VH	C3S1
11	1.8	Ex	465	Good	395.7	FW	5	Ex	32.01	Good	3.47	Mar	245.2	H	C2S1
12	0.04	Ex	702	Good	578.5	FW	6.74	Ex	36.63	Good	-0.55	Suit	264.14	H	C2S1
13	1.65	Ex	415	Good	478.8	FW	8.09	Ex	40.19	Per	-2.09	Suit	251.6	H	C2S1
14	1.5	Ex	935	Per	625.7	FW	5.55	Ex	25.36	Good	0.31	Suit	511.8	VH	C3S1
15	0.5	Ex	548	Good	645.5	FW	4.48	Ex	22.29	Good	-0.69	Suit	395.26	VH	C3S1
16	5.65	Ex	660.5	Good	762.4	FW	3.91	Ex	20.6	Good	-1.08	Suit	377.2	VH	C3S1
17	2.5	Ex	625	Good	455.7	FW	11.8	Ex	55.47	Good	-0.62	Suit	163.79	H	C2S1

Table 3. (Continued)

Sample No.	B ($\mu S\ cm^{-1}$)		EC ($\mu S\ cm^{-1}$)		TDS ($mg\ L^{-1}$)		SAR		SSP (%)		RSC ($mg\ L^{-1}$)		Hardness ($mg\ L^{-1}$)		Alkalinity & Salinity hazard class
	Value	Class	Value	Class	Value	Class	Value	Class	Value	Class	Value	Class	Value	Class	
18	0.04	Ex	775	Per	596.5	FW	3.4	Ex	26.62	Good	1.35	Suit	179.568	H	C2S1
19	0.02	Ex	745	Good	613.5	FW	3.67	Ex	27.25	Good	-0.58	Suit	185.825	H	C2S1
20	0.02	Ex	553	Good	555.45	FW	4.44	Ex	27.87	Good	-2.86	Suit	224.37	H	C2S1

Legend: Ex=Excellent; FW=Fresh Water; Per= Permissible; Suit=Suitable; Unsuit= Unsuitable; Mar=Marginal; H= Hard; VH=Very Hard; C1=Low Salinity; C2=Medium Salinity; C3= High Salinity; S1=Low Alkanity.EC, B, TDS, SAR, PAR, SSP, RSC, and H_T

Classification based on Appendix I, II, III, IV, V and VI.

Alkanity and Salinity hazard classification based on Figure3.

4.5.3 Residual sodium carbonate

The computed residual sodium carbonate (RSC) of ground water samples ranged from 9.50 to 371.66 mg L^{-1} with mean value of 193.12 mg L^{-1} (Table 3). Out of the 20 samples, about 53.66 % samples were below the mean value and the rest 46.34 % were above the mean value. The standard deviation and co-efficient of variation (CV) were 92.61 and 47.96 %, respectively. 9 groundwater samples under test, contained negative value and rest of 11 groundwater samples contained positive value. According to Eaton (1950) and Ghosh *el 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.

4.5.4 Total hardness

The total hardness (H_T) of water samples was within the range of 163.79 to 511.80 mg L^{-1} it with a mean value of 274.02 mg L^{-1} (Table 3). The computed standard deviation and co-efficient of variation were 90.09 and 32.88%, respectively. Sawyer and McCarty (1967) classified irrigation water into 4 classes based on hardness as mentioned in Appendix VI. According to this classification, 6 samples were `very hard' and the rest 14 samples were `hard'. Hardness resulted due to presence of appreciable amount of divalent cations like Ca and Mg (Todd, 1980).

4.6 Water Quality Rating for Drinking Usage

The relative suitability of drinking water standards on the basis of TDS, As, Cl, B, Fe, Mn and $S0_4$ as `per USEPA (United States Environmental Protection Agency) 1975 were presented in Appendix VIII. Among the 20 water samples, 9 samples were `suitable' and N the rest 11samples 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, 14 samples were `suitable' but the rest 6 samples were `unsuitable' for drinking due to higher quantities of Mn (> 0.05 mg L^{-1}). Out of the 20 samples, 7 samples 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 F e content of those waters exceeded the acceptable limit, (Fe = 0.30 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 formed `unsuitable' for drinking due to the exceeded the recommended limit of TDS (500 mg L^{-1}) as per USEPA (1975). As regards to B, $S0_4$ and Cl ions, all waters were suitable for it drinking because the concentrations of these ions were less than the recommended limits (Appendix VIII).

4.7 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 20 samples, 17 were fit but only 2 samples were toxic to livestock consumption because HCO_3^- as content exceeded the recommended limit and TDS status of all the ground waters were below the specified limits. Considering Mn ion, 19 were `suitable' but the rest 1 sample was `unsuitable' for livestock usage due to higher quantities of Mn (> 0.05 mg L^{-1}). Out of the 20 samples, only 5 samples were hazardous for livestock consumptions because of higher amount of Fe (>0.30 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 mg L^{-1}) as per ESB (1972).

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

Based on pH, TDS, H_T, Fe, Mn, Cl and $S0_4$ 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). All the waters would be suitable for tanning, rayon manufacture, aquaculture, poultry and all samples but one were found unsuitable for laundering Among the 20 samples, 16 samples were found suitable for confectionery and 4 were found suitable for brewing while the recommended limit of confectionery and brewing is from · 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 sample (Sl.No. 8). Out of 20 samples 12 and 8 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 20 samples, all samples were suitable for tanning industries and 17 samples are suitable for aquaculture. Only 3 samples 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, $S0_4$ 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 on the basis of Mn content of which were less than the recommended limit (Appendix XI). Among the 20 samples, all samples were suitable based on TDS, hardness, Fe and Mn content (Appendix XI) for brewing, paper & pulp, textile and tanning accept one sample which was unsuitable for paper & pulp. Out of 20 samples, 13 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 7 samples were suitable 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 found unsuitable for poultry, were suitable for brewing, paper & pulp, sugar industries and unsuitable for aquaculture and air conditioning, 16 water samples were suitable for poultry use, 3 water samples were suitable for ice manufacture and 18 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 ground water for irrigation drinking, livestock, poultry, aquaculture, and industrial usage based on Cl, Mn and Fe

Sample No.	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,SG	IR,LS,AQ,AC,CB IM,BW,PP,LD	TN,TX	IR,LS,LD,DR	PL,AQ.AC,BW SG,CF,PP,TN,CB
2.	IR,DL,PL,BW,CB,TX	LS,AQ,SG	IR,LS,AQ,AC,CB IM,BW,PP,LD	TN,TX	IR,LS,LD,DR	PL,AQ.AC,BW SG,CF,PP,TN,CB
3.	IR,DR,PL,CB,TX	LS,AQ,SG	IR,LS,AQ,AC,CB IM,BW,PP,LD	TN,TX	IR,LS,LD,DR	PL,AQ.AC,BW SG,CF,PP,TN,CB
4.	IR,DR,PL,CB,TX	LS,AQ,SG	IR,LS,AQ,AC,CB IM,BW,PP,LD	TN,TX	IR,LS,LD,DR	PL,AQ.AC,BW SG,CF,PP,TN,CB
5.	IR,DR,PL,CB,TX	LS,AQ,SG	IR,LS,AQ,AC,CB IM,BW,PP,LD	TN,TX	IR,LS,LD,DR	PL,AQ.AC,BW SG,CF,PP,TN,CB
6.	IR,DR,PL,CB,TX	LS,AQ,SG	IR,LS,AQ,AC,CB IM,BW,PP,LD	TN,TX	IR,LS,LD,DR	PL,AQ.AC,BW SG,CF,PP,TN,CB
7.	IR,DR,PL,CB,TX	LS,AQ,SG	IR,LS,AQ,AC,CB IM,BW,PP,LD	TN,TX	IR,LS,LD,DR	PL,AQ.AC,BW SG,CF,PP,TN,CB
8.	IR,DR,PL,CB,TX	LS,AQ,SG	IR,LS,AQ,AC,CB IM,BW,PP,LD	TN,TX	IR,LS,LD,DR	PL,AQ.AC,BW SG,CF,PP,TN,CB
9.	IR,DR,PL,CB,TX	LS,AQ,SG	IR,LS,AQ,AC,CB IM,BW,PP,LD	TN,TX	IR,LS,LD,DR	PL,AQ.AC,BW SG,CF,PP,TN,CB
10.	IR,DR,PL,CB,TX	LS,AQ,SG	IR,LS,AQ,AC,CB IM,BW,PP,LD	TN,TX	IR,LS,LD,DR	PL,AQ.AC,BW SG,CF,PP,TN,CB
11.	IR,DR,PL,CB,TX	LS,AQ,SG	IR,LS,AQ,AC,CB IM,BW,PP,LD	TN,TX	IR,LS,LD,DR	PL,AQ.AC,BW SG,CF,PP,TN,CB
12.	IR,DR,PL,CB,TX	LS,AQ,SG	IR,LS,AQ,AC,CB IM,BW,PP,LD	TN,TX	IR,LS,LD,DR	PL,AQ.AC,BW SG,CF,PP,TN,CB

Table 4. (Continued)

Sample No.	C (mgL^{-1})		Mn (mgL^{-1})		Fe (mgL^{-1})	
	Suit	Unsuit	Suit	Unsuit	Suit	Unsuit
13.	IR,DR,PL,BW,TX	LS,AQ,SG,BW	IR,LS,AQ,AC,CB IM,BW,PP,LD	TN,TX PP,LS	IR,LS,LD,DR	PL,AQ,AC,BW SG,CF,PP,TN,CB
14.	IR,DR,PL,CB,TX	LS,AQ,SG	IR,LS,AQ,AC,CB IM,BW,PP,LD	TN,TX	IR,LS,LD,DR	PL,AQ,AC,BW SG,CF,PP,TN,CB
15.	IR,DR,PL,CB,TX	LS,AQ,SG	IR,LS,AQ,AC,CB IM,BW,PP,LD	TN,TX	IR,LS,LD,DR	PL,AQ,AC,BW SG,CF,PP,TN,CB
16.	IR,DR,PL,BW,TX	LS,AQ,SG	IR,LS,AQ,AC,CB IM,BW,PP,LD	TN,TX	IR,LS,LD,DR	PL,AQ,AC,BW SG,CF,PP,TN,CB
17.	IR,DR,PL,CB,TX	LS,AQ,SG,BW	IR,LS,AQ,AC,CB IM,BW,PP,LD	TN,TX	IR,LS,LD,DR	PL,AQ,AC,BW SG,CF,PP,TN,CB
18.	IR,DR,PL,CB,TX	LS,AQ,SG	IR,LS,AQ,AC,CB IM,BW,PP,LD	TN,TX	IR,LS,LD,DR	PL,AQ,AC,BW SG,CF,PP,TN,CB
19.	IR,DR,PL,CB,TX	LS,AQ,SG	IR,LS,AQ,AC,CB IM,BW,PP,LD	TN,TX	IR,LS,LD,DR	PL,AQ,AC,BW SG,CF,PP,TN,CB
20.	IR,DR,PL,CB,TX	LS,AQ,SG	IR,LS,AQ,AC,CB IM,BW,PP,LD	TN,TX	IR,LS,LD,DR	PL,AQ,AC,BW SG,CF,PP,TN,CB

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

Table 5. Suitability of the water for livestock purpose

Constituents	Recommendation maximum limits (mgL^{-1})	Obtained Range value for the sample water ($mg\ L^{-1}$)	Remark
Boron(B)	5.00	0.04-5.65	19 Suit ,1 Not Suitable
Iron (Fe)	0.30	0.12-0.49	8 Suit ,12 Not Suitable
Manganese (Mn)	0.05	0.04-0.07	All Suitable
Copper (Cu)	0.50	0.02-0.18	All Suitable
Nitrate + Nitrite + (NO_3-N + NO_2-N)	100.00	1.98-25.7	All Suitable
Chloride (Cl)	30.00	9.50-76.0	1 Suit ,19 Not Suitable
Total dissolved solids (TDS)	10,000.00	587.8	Suitable

Sources: EBS (Environmental Studies Board)1972. National Academy of Sciences , National Academy of engineering, U.S.A.

Table 6. Suitability of the water for irrigation purpose

Constituents	Recommendation maximum limits ($mg L^{-1}$)	Obtained Range value for the sample water ($mg L^{-1}$)	Remark
Chloride(Cl)	250.0	9.5-76.0	All Suitable
Iron (Fe)	0.30	0.12-0.49	8 Suit , 12 not Suitable
Manganese (Mn)	0.05	0.04-0.07	All Suitable
Copper (Cu)	1.00	0.02-0.18	All Suitable
Nitrate (NO_3)	45.00	1.98-25.7	All Suitable
Sulfate (SO_4)	250.0	0.95-6.85	All Suitable
Boron(B)	1.00	0.04-5.65	8 Suit , 12 not Suitable
Total dissolved solids (TDS)	500.00	272.2-827.6	5 Suit, 15 not Suitable

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

4.9 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 4.46 to 10.4 (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 0.48 to 2.53 and 1.00 to 1.21, respectively but the ratio of calculated TDS to EC also ranged from 0.28 to 0.96 (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 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 SAR (Fig.4) pH vs. H_T(Fig.5), EC vs pH (Fig.6), EC vs TDS (Fig.7) , EC vs H_T(Fig.8), HT vs TDS (Fig.9), SAR vs SSP (Fig.10), EC vs RSC (Fig.11), SSP vs H_T(Fig.12), RSC vs H_T (Fig.13),Ca vs HCO_3(Fig.14) and Mg vs HCO_3(Fig.15) were shown in Table 6 and 7. Among the combinations the following combinations SAR vs SSP , Ca vs HCO_3 and Mg vs HCO_3were indicated significant as positive correlations while 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 qualities factors have been illustrated in (Table 8). 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.

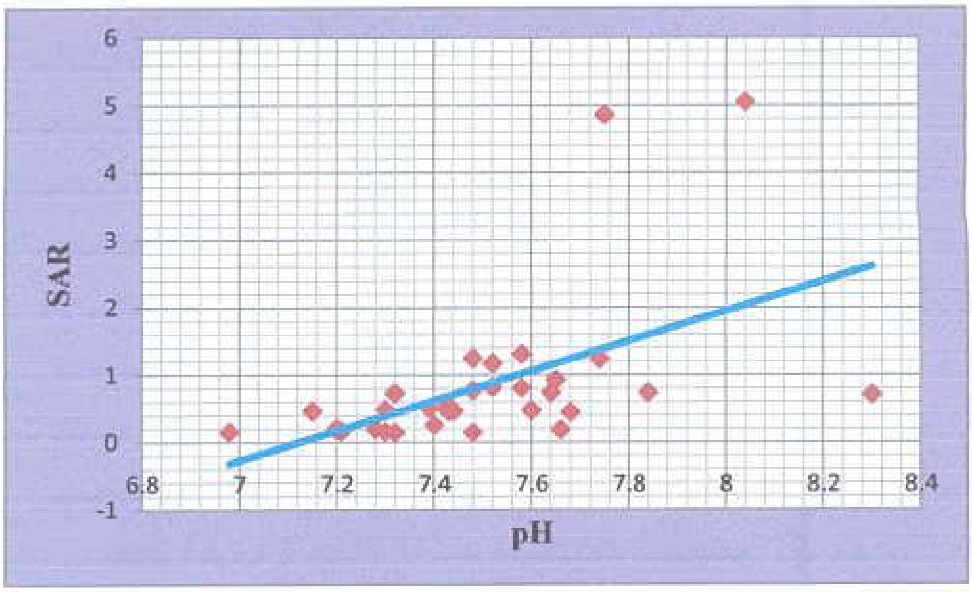

Fig. 4 Relationship between pH and SAR

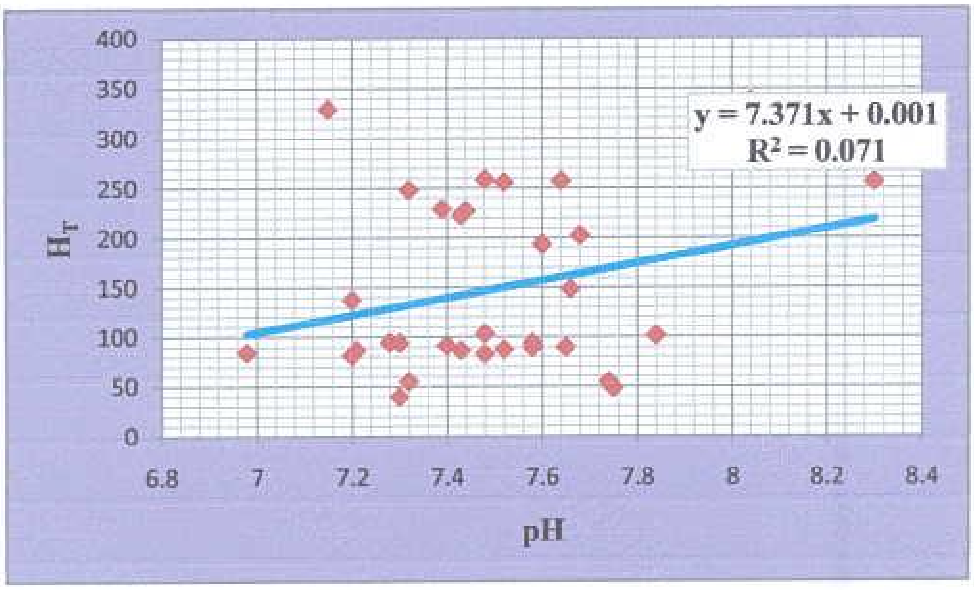

Fig. 5 Relationship between pH and H_T

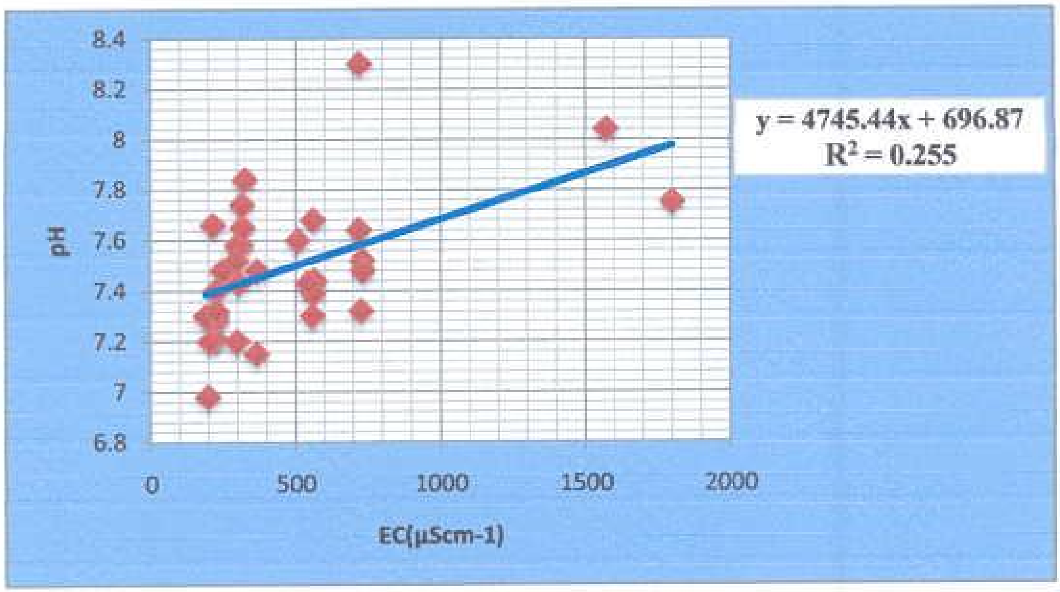

Fig. 6 Relationship between EC(μScm^{-1}) and pH

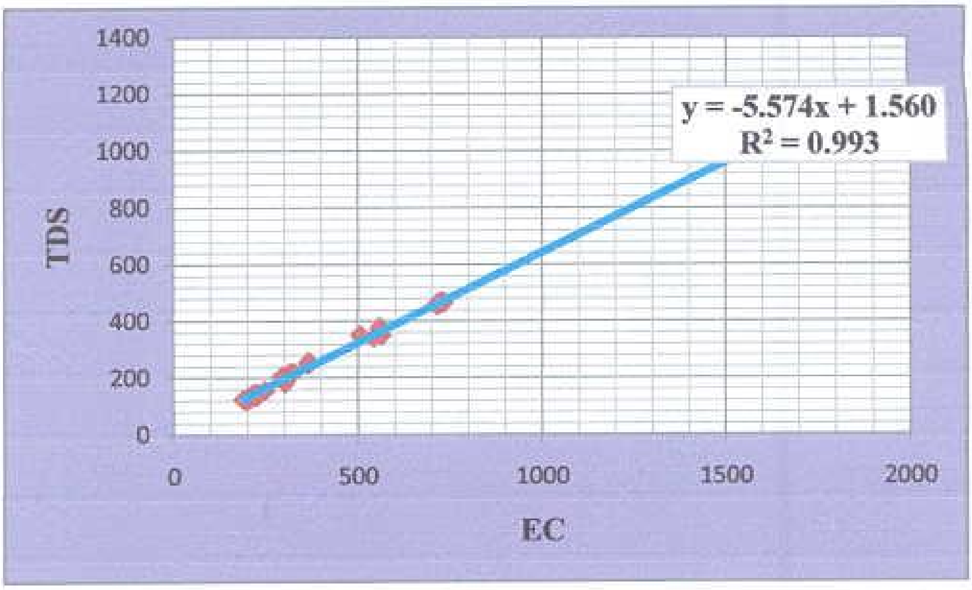

Fig. 7 Relationship between EC(μScm^{-1}) and TDS

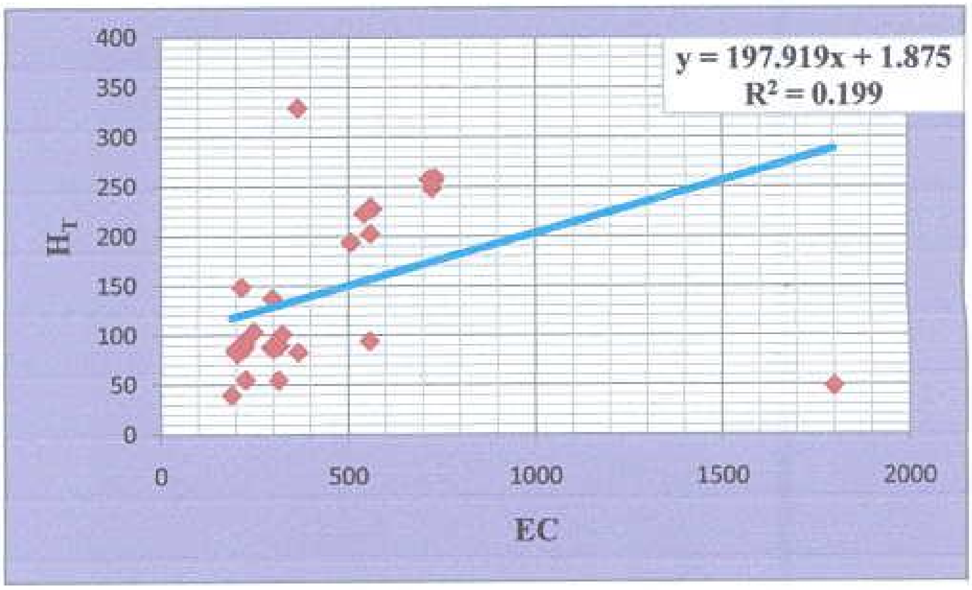

Fig. 8 Relationship between EC (μScm^{-1}) and H_T

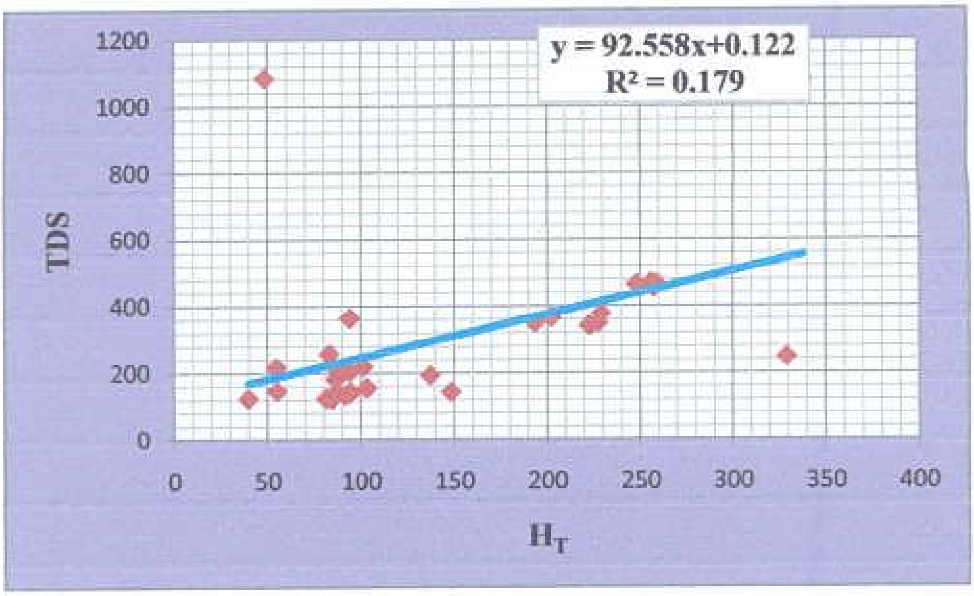

Fig. 9 Relationship between H_T and TDS

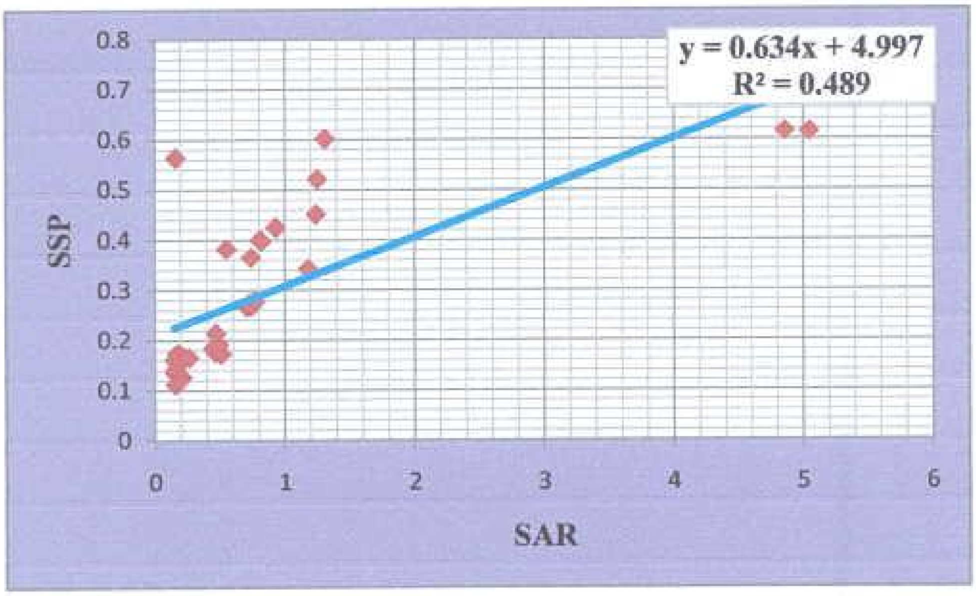

Fig. 10 Relationship between SAR and SSP

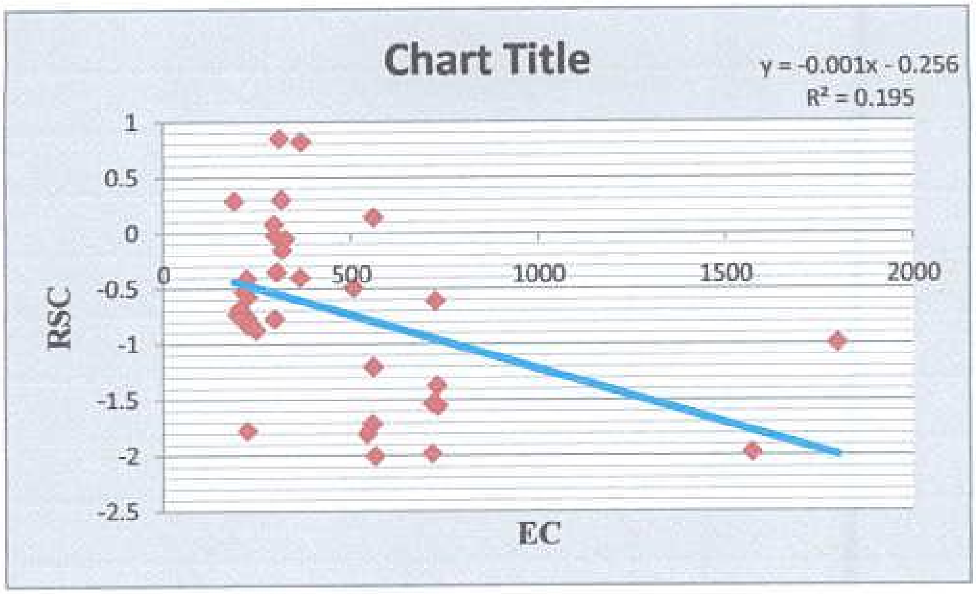

Fig. 11 Relationship between EC(μScm^{-1}) and RSC

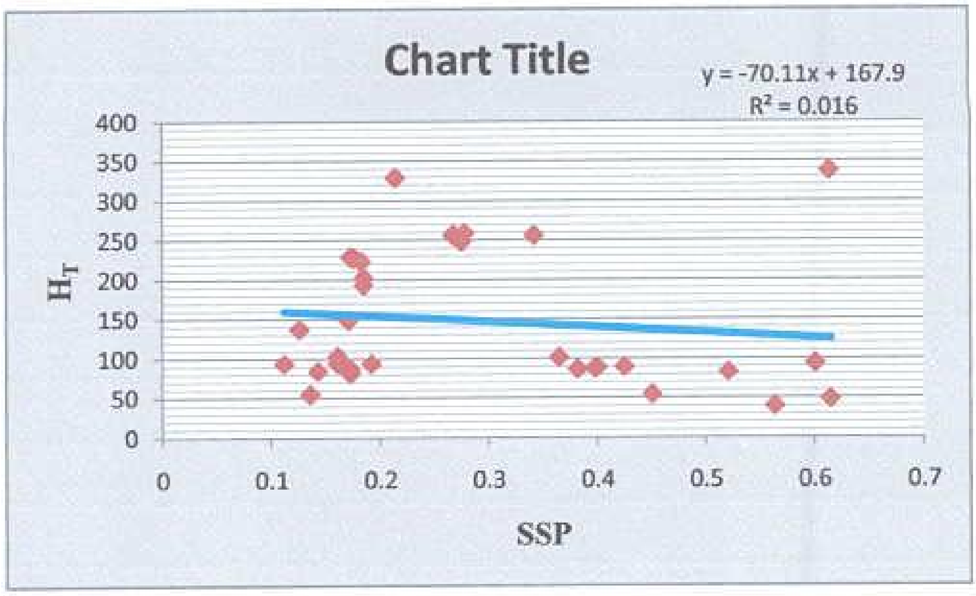

Fig. 12 Relationship between SSP and H_T

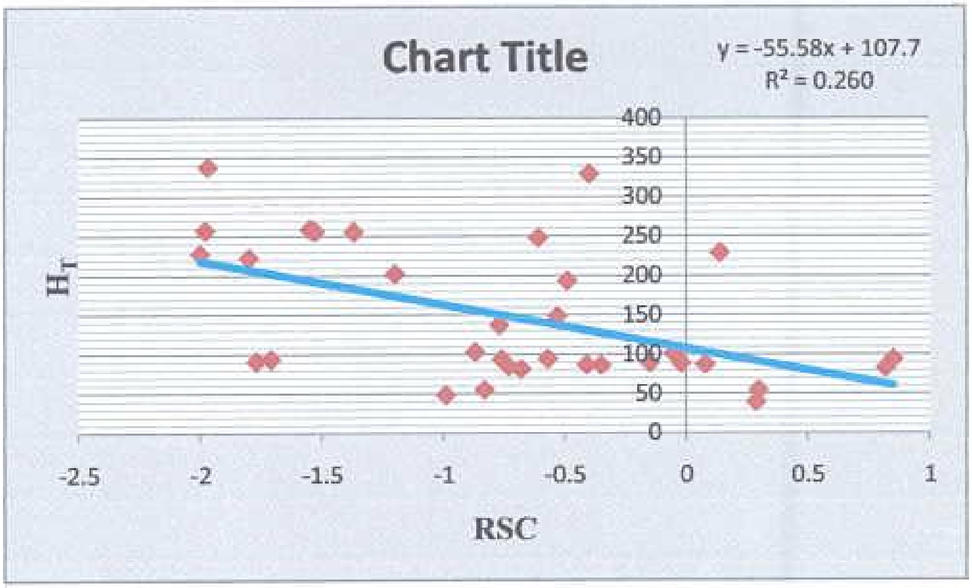

Fig. 13 Relationship between RSC and H_T

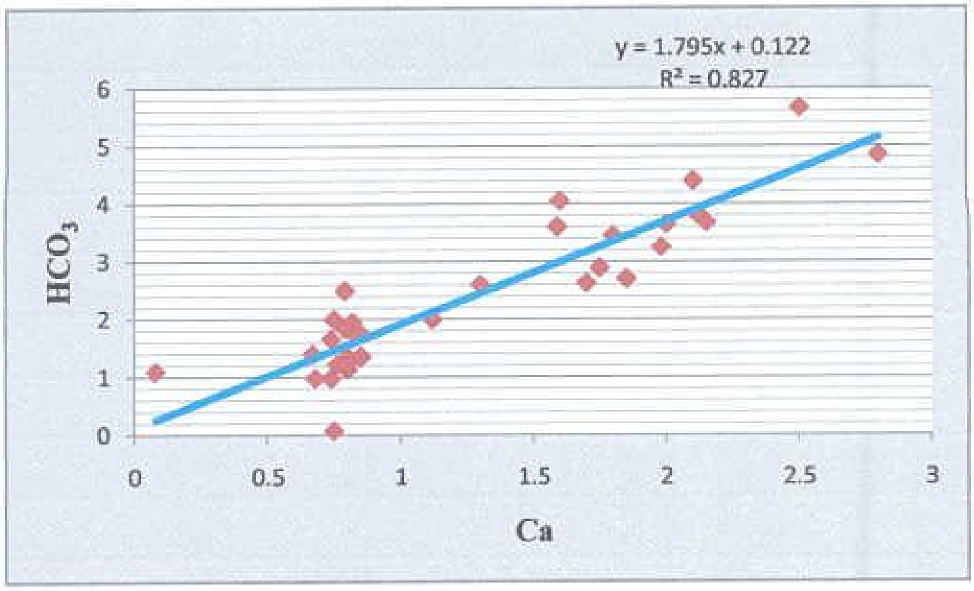

Fig. 14 Relationship between Ca and HCO_3

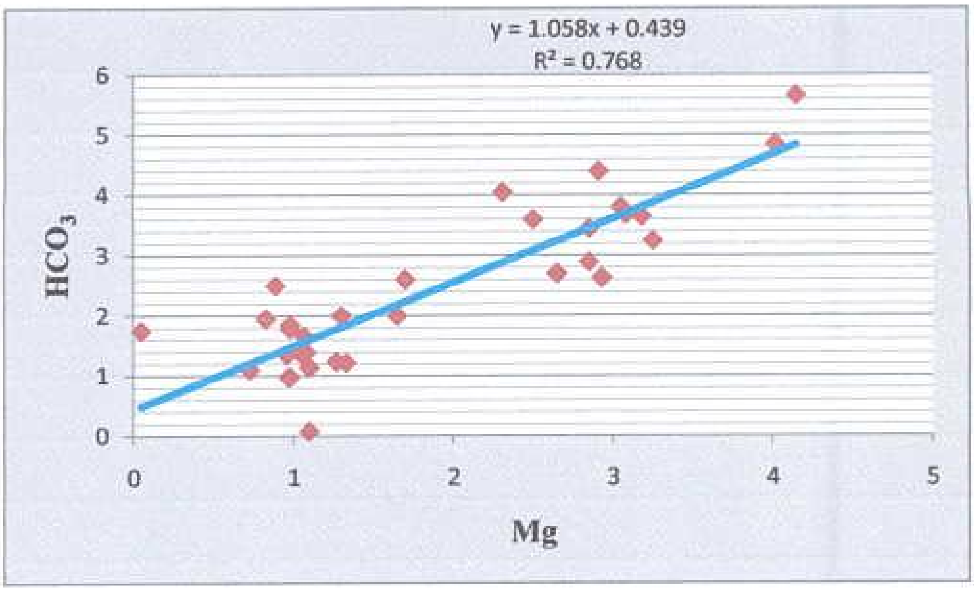

Fig. 15 Relationship between Mg and HCO_3

The results in Table 8 showed that significant major ionic combinations were Ca vs. Mg(r =0.594); Ca vs Mn (r = 0.794), Ca vs Cu (r = 0.878), Mg vs. K(r = 0.550), Mg vs.Mn (r = 0.99). Mg vs Cu, (r = -0.229), Na vs Fe (r = 0.773), Na vs Mn (r = 0.658), Na vs Cu (r = - 0.181), K vs Cu (r = -0.952), Na vs B (r = - 0.444), Fe vs Cu (r = 0.150), Cl vs Mn (r = 0.198) Mn vs. SO4 (r = 0.084), Cu vs. B (r = 0.441) and Cu vs SO4 (r = 0.024) revealing synergistic relationships but rest combinations indicated antagonistic behavior.

Table 7. Checking correctness of ground water analysis

Sl. No.	Anion-Cation-balance			Total dissolved solids (mgL^{-1})		Ratio of measured TDS to calculated TDS	Electrical Conductivity (EC)		Ratio of measured EC to calculated EC	Ratio of measured or calculated TDS to calculated EC
	∑Cation meL^{-1}	∑Anion meL^{-1}	Difference %	Measured	Calculated		Measured	Calculated		
01	7.94	9.2	7.36	827.59	664.1	1.25	848	794.16	1.07	1.04
02	7.17	7.98	5.38	665.21	563	1.18	665	716.74	0.93	0.93
03	6.6	5.16	12.3	625.25	410.47	1.52	565	660.48	0.86	0.95
04	7.95	6.45	10.4	758.65	501.89	1.51	654	795.42	0.82	0.95
05	7.39	5.6	13.8	678.35	436.07	1.56	512	739.17	0.69	0.92
06	5.45	5.69	2.14	339.75	437.36	0.78	675	545.3	1.24	0.62
07	5.45	6.48	8.59	752.76	489.97	1.54	778	545.27	1.43	1.38
08	6.79	5.07	14.4	652.21	413.35	1.58	990	678.68	1.46	0.96
09	6.81	7.97	7.88	272.12	562.11	0.48	835	680.85	1.23	0.4
10	10.4	5.53	30.6	475.98	506.42	0.94	985	1039.4	0.95	0.46
11	6.4	5.09	11.4	395.65	380.48	1.04	465	640.33	0.73	0.62
12	7.27	6.86	2.94	578.5	504.38	1.15	702	727.04	0.97	0.8
13	7.32	5.45	14.7	478.75	413.12	1.16	415	732.14	0.57	0.65
14	12.7	4.76	45.3	625.65	463.76	1.35	935	1266.2	0.74	0.49
15	9.58	5.59	26.4	645.5	462.47	1.4	548	958.37	0.57	0.67
16	9.03	3.62	42.8	762.35	357.26	2.13	660.5	902.62	0.73	0.84
17	5.95	5.52	3.72	455.65	416.05	1.1	625	594.7	1.05	0.77

Table 7. (Continued)

Sl. No.	Anion-Cation-balance			Total dissolved solids (mgL^{-1})		Ratio of measured TDS to calculated TDS	Electrical Conductivity (EC)		Ratio of measured EC to calculated EC	Ratio of measured or calculated TDS to calculated EC
	∑Cation meL^{-1}	∑Anion meL^{-1}	Difference %	Measured	Calculated		Measured	Calculated		
18	4.46	5.51	10.5	596.5	384.43	1.55	775	446.18	1.74	1.34
19	4.64	5.71	10.3	613.5	397.63	1.54	745	463.92	1.61	1.32
20	5.74	6.09	3.02	555.45	420.7	1.32	553	573.57	0.96	0.97

Table 8. Regression and Correlation analysis of quality criteria

Quality criteria	Correlation co-efficient (r)	Regression Equation
pH vs SAR	-0.367 ^{NS}	Y = 7.391x + 0.122
pH vs H_T	-0.078 ^{NS}	Y= 7.371x +0.0001
EC vs pH	-0.189 ^{NS}	Y= 4745x +696.87
EC vs TDS	0.113 ^{NS}	Y= 5.574x +1.560
EC vs H_T	0.300 ^{NS}	Y= 197.919x +1.875
H_T vs TDS	0.277 ^{NS}	Y= 92.55x +0.122
SAR vs SSP	0.937**	Y= -0.634x +4.997
SSP vs H_T	-0.585**	Y= -70.11x +167.9
RSC vs H_T	-0.583**	Y= -55.85x +107.7
Ca vs HCO_3	0.910**	Y= 1.795x +0.122
Mg vs HCO_3	0.895**	Y= 1.058x +0.439

Legend:

** Correlation is significant at the 1% level
* Correlation is significant at the 5% level
^{NS} Non Significant
Tabulated value of 'r' with 18df=0.4438 at 5% level and 0.5614 at 1% level of significance

Table 9. Relationship between water quality factors

Parameters	pH	EC	TDS	SSP	RSC	H_T	SAR
pH	1	-0.189 ^{NS}	0.357 ^{NS}	-0.334 ^{NS}	-0.218 ^{NS}	-0.078 ^{NS}	-0.367 ^{NS}
EC		1	0.113 ^{NS}	-0.194 ^{NS}	0.194 ^{NS}	0.300 ^{NS}	-0.144 ^{NS}
TDS			1	-0.450*	-0.007 ^{NS}	0.277 ^{NS}	-0.355 ^{NS}
SSP				1	0.371 ^{NS}	-0.585**	0.937**
RSC					1	-0.583**	0.194 ^{NS}
H_T						1	-0.292 ^{NS}
SAR							1

Legend:

** Correlation is significant at the 1% level
* Correlation is significant at the 5% level
^{NS} Non Significant
Tabulated value of 'r' with 18df=0.4438 at 5% level and 0.5614 at 1% level of significance

Tabled 10. Correlation co-efficient (r) among ions

	PH	EC	TDS	CA	MG	NA	K	FE	MN	CU	B	SO_4	PO_4	CO_3	HCO_3	CL
PH	1	-.18 ^{NS}	.357 ^{NS}	.129 ^{NS}	-.37 ^{NS}	-.43 ^{NS}	-.40 ^{NS}	-.031	-.724	.060	-.125	.361	-.298	-.316	-.257	.013
EC		1	.113	.181	.406	.024	.090	.079	-.830	.580	-.162	.107	-.007	.507	.310	-.357
TDS			1	.377	.050	-.201	-.293	.133	-.468	.939	.271	-.171	-.416	.089	.135	-.156
CA				1	.592**	.111	.191	.429	.794	.878	-.084	.232	-.140	-.028	-.375	.228
MG					1	.384	.550*	.335	0.99**	.229	-.024	-.251	-.041	.398	-.077	.198
NA						1	.339	.773**	.658	-.181	.444*	-.245	.416	.328	.002	.166
K							1	.090	.197	-.952*	-.025	.014	.209	.128	-.358	.238
FE								1	-.454	.150	.542*	-.009	.393	.476	-.019	.145
MN									1	.(a)	-.929	.084	-.376	-.985	-.910	.994
CU										1	.441	.024	.077	.(a)	.712	.075
B											1	-.434	.158	.198	.391	-.209
AS												.183	.181	-.029	.250	.155
SO_4												1	.069	-.084	-.479*	.094
PO_4													1	.266	.126	.178
CO_3														1	.218	-.108
HCO_3															1	-.214
CL																1

- Legend:

  ** Correlation is significant at the 1% level

  * Correlation is significant at the 5% level

  ^{NS} Non Significant

  Tabulated value of 'r' with 18df =0.4438 at 5% level and 0.5614 at 1% level of significance

Table 11. 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	NO_3
Irrigation	19	-	-	7	9	7	8	9	11	9	-	Nil	-	-
Drinking	12	-	-	15	-	10	16	-	19	9	-	-	-	-
Livestock	5	-	11	-	8	12	-	11	9	-	-	-	-	-
Aquaculture	25	-	7	-	-	9	12	-	-	-	-	-	-	-
Poultry	-	15	15	-	-	18	-	-	-	-	-	-	-	-
Industrial Usage	-													
Air conditioning	-	-	-	-	-	7	-	-	-	-	-	-	-	-
Brewing	5	-	10	-	-	-	-	-	-	-	-	-	-	-
Carbonated beverage	6	-	-	7	-	-	2	-	-	-	-	-	-	-
Confectioner	2	-		-		2	-	-	-	-	-	-	-	-
Ice manufacture	13	15	-	-	-	-	-	-	-	-	-	-	-	-
Laundering	8	-	-	-	-	-	16	-	-	-	-	-	-	-
Rayon manufacture	7	-	-	-	10	-	-	-	-	-	-	-	-	-
Sugar industries	-	-	-	-	2	-	3	-	-	-	-	-	-	-
Tanning	11	15	9	-	-	-	-	-	-	-	-	-	-	-
Textile	-	-	-	-	8	-	7	-	-	-	-	-	-	-
Pepar and pulp	-	-	-	-	-	10	-	-	-	-	-	-	-	-

4.10 Salient Features of the Investigation

It is evident from above discussion that out of the 20 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, if appropriate sustainable measures should be adopted for the remediation of these waters.

Chapter V

Summary and Conclusion

CHAPTER V

SUMMARY AND CONCLUSION

The study was conducted to assess the degree of ionic toxicity of different water sources in Rajbari aquifers under Rajbari district. Twenty water samples were collected from different locations in order to study the chemical constituents of water and to classify the waters on the basis of their suitability for irrigation, drinking, industrial and livestock usages. Water samples were mainly classified on the basis of pH, electrical conductivity (EC), total dissolved solids (TDS), boron, iron, arsenic, sodium adsorption ratio (SAR), soluble sodium percentage (SSP), residual sodium carbonate(RSC) and hardness (H_T). The pH values of water samples were within the range of 6.85 to 7.33 indicating the slightly acidic to alkaline and were not problematic for successful crop production. EC values of water samples were within the range of 415.0 to 990.0 $\mu S\ cm^{-1}$ and were rated as 'excellent', 'good' and 'permissible' categories. Out of 20 samples, 13 samples were 'good' and the rest of 7 samples were belonged to 'permissible' categories.

All the samples were graded as 'fresh water' in respect to TDS because all waters contained less than 1000 mg L^{-1} TDS. The concentrations of total cations (4.46 to 10.4me L^{-1}) and total anions (3.62 to 9.2 me L^{-1}) under study were within the safe limit for soils and crops. The concentration of B in different water sources ranged from trace to 5.65 mgL^{-1}, which were within 'safe' limit (<1.0 mg L^{-1}) for all types of crops and were classified as 'excellent' indicating no toxicity.

The concentrations of Zn, Fe, As and Cu of all the samples were within the 'safe' limit and also the toxicities of these ions were not found in the study area but the concentration of Mn of 20 samples (except sample no. 1, 3, 5 and 15) were within 'safe' limit in respect of irrigation quality. Only 7 samples were restricted for irrigating sensitive crops in respect to Cl ion toxicities. Water samples were of 'excellent' class regarding SAR values, as the SAR values ranged from 0.20 to 2.96. On the combined. basis of SAR and EC, all samples were graded as 'low', 'medium' and 'high' salinity (C1, C2 and C3) and low alkali hazards (S1) class, combined expressed as C1S1 C3S1 and C2S1 (rest of samples). Out b of 20 water 19 samples were belonged to 'good' and the rest 1 samples were 'permissible' categories based on SSP. According to RSC, Out of 20 water samples were belonged to 'marginal' and the rest 14 samples were 'suitable' categories based on RSC. The ranging of RSC from -2.86 to 3.47 me L^{-1}. As regards to hardness, 6 samples were 'very hard'; 14 samples were 'hard'. Out of 20 samples, 'only 17 samples were found 'suitable' for irrigation considering all the criteria. The ionic concentrations of water samples analyzed were in the descending order of magnitude as HCO_3 > Cl > Na> Ca >Mg > K >SO_4> Mn> NO_3>P> Zn> Fe > B >Cu>CO_3>As. As regards to TDS value, all waters were suitable for most of the industrial purposes except confectionary. With respect to pH values, all the samples would be suitable only for tanning. As per Cl content, all samples were found suitable for carbonated beverage and no sample was found appropriate for sugar industries. On the basis of SO_4, content, all samples would not create any problem for any industries. On the basis of iron concentration, all samples were suitable for every industry. As per Mn content, all waters were suitable for air-conditioning and textile industries.

All water samples were found 'suitable' for drinking on the basis of the analytical results of Cl, Fe, Zn, Cu, NO_3 and SO_4 but g out of 20 samples; only 7 samples were unsuitable for drinking based on Mn content. The only 10 samples were also found unsuitable for livestock consumption regarding to Mn content but other constituents of waters like As, B, Cu, Fe and Zn were within the safe limit causing no specific ionic toxicity. The SSP—SAR, RSC-SSP, SAR-pH SSP-pH and SAR-EC combination indicated significant positive correlation while RSC-EC combination revealed a negative significant correlation. To the contrary, the relationship between EC-pH, RSC-pH, SSP-EC, and RSC-SAR were found insignificant. As and Cd of ground water should be determined in the study area.

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Appendices

APPENDICES

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

Water class	Electrical Conductivity(EC) (μScm^{-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. V. 1995. Classification and use of irrigation water. USDA. Circular no. 969. Washington D. C.P.19.

Appendix II. Water classification on the based on B concentration

Water class	Boron (mgL^{-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.Z and Cherry, J.A 1979.Ground. Prentice Hall Inc. Englewood Cliffs. New Jersey 07632.p.84.

Appendix IV. Water Class rating based on SAR

Water Class	Sodium Absorption 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 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 sanity Engineers.2nd.edn. McGraw Hill, New Yark.P.518

Appendix VII. Recommended maximum concentration of quality factor and different ions 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 Westcott, D.W.1985. Water Quality for Agriculture .FAO Irrigation and Drainage paper **29**(Rev.1):40-96.

Appendix VIII. Recommended concentration different ions for drinking water.

Constituents	Recommendation limits (mg L^{-1})
Arsenic(As)	0.01
Chloride(Cl)	250.0
Iron (Fe)	0.30
Manganese (Mn)	0.05
Copper (Cu)	1.00
Nitrate (No3)	45.00
Sulfate (SO_4)	250.0
Boron(B)	1.00
Total dissolved solids (TDS)	500.00

Source: USEPA (United States Environment 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	Recommendation limits (mgL^{-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: EBS (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)	10-40
Iron (Fe)	<0.001
Manganese (Mn)	<0.01
pH	6.50-8.00
Sulfate (SO_4)	<50
Total dissolved solids (TDS)	<400

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

Note : Concentrations are 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	0.50
Brewing	6.5-7.0	500-1500	-	60-100	-	0.10	0.10
Carbonated beverage	-	850	200-250	250	250	0.1-0.2	0.20
Confectionary	>7.0	50-100	70	-	-	0.1-0.2	0.20
Ice Manufacture	-	170-1300	-	-	-	0.20	0.20
Laundering	6.0-6.8	-	0-50	-	-	0.2-1.0	0.20
Paper pulp	-	100-200	100	-	-	0.10	0.05
Rayon Manufacture	7.8	-	55	-	-	-	-
Sugar	-	-	-	20	20	0.10	-
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: USEPA (United States Environment Protection Agency) Federal Register **40**(248):59566-59588.December 24,1975.