CORRELATION AMONG THE WATER QUALITY PARAMETERS OF DRINKING WATER SOURCES AT SELECTED ARSENIC AFFECTED AREAS

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by

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The project entitled "**Correlation among the Water Quality Parameters of Drinking Water Sources at Selected Arsenic Affected Areas"** submitted by **Sharif Mos. Ferdausy,** Roll No.: **9604127P,** Session: **December, 1995** has been accepted as satisfactory in partial fulfillment of the requirement for the Degree of Master of Engineering in Civil & Environmental Engineering on 29th June, 2005

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Ferdausy

Sharif Mos. Ferdausy

Dedicated

to

my Father

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ABSTRACT

Ensuring safe drinking water is one of the prime objectives of the Government and the others who are working in the water supply sector in Bangladesh. Hazigang is one of the worst arsenic affected Upazilas where water of 98% shallow tubewells contains arsenic at elevated level. So Bangladesh Arsenic Mitigation Water Supply Project has taken the GPS based Water Quality Survey at this upazila. Water samples of 86 Deep hand tubewells have been analyzed to assess the drinking water quality in relation to Bangladesh standard (DoE-1997) and WHO Guideline value (1993). In addition, elements related to human health together with the geochemical conditions that give rise to excess and deficiency have also been considered. 76 samples contain high iron but all the 86 samples are free from fecal coli form. However, 10 samples show high turbidity as per DoE-1997. Concentration of some potentially toxic elements such as Ba, Al and Pb are higher than acceptable limit in groundwater of the investigated areas.

ChapaiNawabganj is another Upazila where TWs are arsenic affected. Out of 25 Water samples from Deep TWs 7 are containing arsenic higher than the BD standard. 17 TWs contain Iron, 24 TWs Manganese, 22 TWs Calcium and 25 TWs contain Barium higher than BD Standard.

In Vadaria Upazila of Pirojpur District 32 samples were collected from Deep TWs. Out of them 27 are contain Chloride, 5 Iron and 32 contain Barium higher than the BD standard. However, no sample crossed maximum level of Arsenic in this Upazila.

Faridganj and Bakerganj are other two arsenic affected upazilas where about 80%-90% shallow tubewells are severely contaminated by arsenic. So ITN, BUET has selected these two upazilas for Water Quality testing. 6 Deep tubewells at each upazila have been analyzed by ITN. Out of the 6 samples all have high arsenic concentration, 5 have Ba concentration higher than permissible limit, however, no water sample at Bakerganj has iron higher than the drinking standard. But at Faridganj upazila out of 6 tubewells 3 have higher iron concentration and only 1 water source cross the maximum permissible limit of arsenic.

Other Water Quality Parameters also show same scattered values at these five upazilas. So, it is not so clear that if there is any correlation among the parameters or not. In this context, it is important to conduct national baseline survey to analyze the abundance and distribution of key elements of health significance present in groundwater.

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LIST OF ABBREVIATIONS

AIT	Asian Institute of Technology
APHA	American Public Health Association
AWWA	American Water Works Association
BBS	Bangladesh Bureau of Statistics
BGS	British Geological Survey
BOD	Biochemical Oxygen Demand
BUET	Bangladesh University of Engineering and Technology
COD	Chemical Oxygen Demand
DANIDA	Danish International Development Agency
DPHE	Department of Public Health Engineering
DWASA	Dhaka Water Supply and Sewerage Authority
ECR	Environmental Conservation Rule
IRCWD	International Reference Centre for Waste Disposal
ITN	International Training Network
MCL	Maximum Contaminant Level
NGO	Non Governmental Organization
NTU	Nephelomatric Turbidity Unit
ORP	Oxidation-Reduction Potential
ppm	Parts per million
ppb	Parts per billion
SS	Suspended Solid
TDS	Total Dissolved Solid
UNICEF	United Nations International Children's Emergency Fund
USPHS	United States Public Health Services
WHO	World Health Organization
WSS	Water Supply and Sanitation

Chapter – 1

Introduction

CHAPTER 1: INTRODUCTION

1.1 Background of the Study

In the 1980's and 1990's, Bangladesh made enormous strides in supplying its population with safe drinking water through the provision of shallow tubewells. This resulted in achieving a coverage rate of 97% of the total population of the country with access to an improved water source and a significant reduction in diarrhoeal disease. However, arsenic contamination of many of these shallow tubewells has resulted in the coverage estimate being revised down to 74% and the emergence of new health problem from arsenic poisoning.

Arsenic contamination of groundwater in Bangladesh was first identified in 1993. After this, a countrywide survey was conducted by DPHE with support from the British Geological Survey in the late 1990s, which showed that 27% of shallow tubewells across the country had arsenic concentrations above the Bangladesh standard of 50μg/l. It was estimated that about 35 million people were exposed to arsenic above the standard. The survey also indicated that the distribution of arsenic contamination highly scattered and identified 269 upazilas as 'hotspots' where large numbers of shallow tubewells were arsenic contaminated.

Besides Bangladesh and India, arsenic contamination of drinking water, both surface and groundwater, has been reported in a number of Asian countries including China, Mongolia, Taiwan and Thailand (Dong et al., 1998; Fen et al., 1998; Chen, 1998; Chiou et al., 1998; Choprapawor, 1998). Cases of arsenic contamination of water sources have also been found in Chile, Mexico, Argentina, Hungary, United Kingdom and the United States (Csanady et al., 1998; Leonardi et al., 1998; Hering, 1998). However, the present arsenic contamination scenario in Bangladesh and India appears to be the worst case so far detected worldwide, both in terms of area and population affected.

To combat the arsenic crisis, various initiatives have been taken over the last few years by the various organizations including the Government, the Non Government

Organizations (NGOs), the donor agencies and private entrepreneurs. These initiatives primarily focus on identification of tubewells producing arsenic contaminated water, awareness building among users, and identification of suitable alternative sources of drinking water (e.g., surface water, rain water and deep tubewell water). But there are a few studies on the relation among arsenic and other water quality parameters

Much of Bangladesh's surface water is microbially unsafe to drink. Since independence in 1971, about 8,000,000 to 12,000,000 tubewells have been installed to supply microbially safe drinking water to the people of Bangladesh. Today 97% of Bangladeshis drink well water (WHO, 2001; WHO, 2000). Unfortunately, a vast area of this densely populated country contains groundwater with As concentrations above the World Health Organization (WHO) drinking water guideline of 0.01 mg/L (UNICEF, 2002). Chronic arsenic poisoning attributed to groundwater ingestion was first diagnosed in 1993. The total number of Bangladeshis diagnosed with chronic arsenic poisoning is expected to be millions (BGS, 1999). These diagnoses include melanosis, leukomelanosis, keratosis, hyperkeratosis, nonpitting edema, gangrene, and skin cancer (Hindmarsh et al., 2002).

The 1997 United States Agency for International Development (USAID) field program produced the first national-scale map of As concentration in tubewell water of Bangladesh. This map indicates that approximately 45% of Bangladesh's area contains groundwater with As concentrations greater than the 0.05 mg/L Bangladesh national drinking water standard. The 1997 USAID field program also suggested the principal sources of As in Bangladesh's groundwater might be the reductive dissolution of non-pyrite minerals, and the anion exchange of sorbed arsenate or sorbed arsenite (Maynard, Frisbie, and Hoque, 1997; Frisbie, Maynard, and Hoque, 1999).

In addition, the 1997 USAID field program discovered that millions of Bangladeshis may be drinking unsafe levels of other toxic metals besides As (Maynard, Frisbie, and Hoque, 1997; Frisbie, Maynard, and Hoque, 1999).

The contention that Bangladeshis are exposed to other toxic metals besides As was strengthened by the finding of severe melanosis, keratosis, and other symptoms of chronic arsenic poisoning especially among children (Sarkar, 1998).

During 1983 and 1987 Dr. K.C. Shaha, Professor of Dermatology (retired) of School of Tropical Medicine, Calcutta conducted surveys in the seven districts of west Bengal of India. In 1983 Dr.Shaha identified patients poisoned by arsenic who had been drinking tubewell water having an As concentration of0.06-1.25 PPM and a mean concentration of 0.32 PPM. According to Dr. Shaha's survey the time required for the symptoms of arsenic poisoning to appear varies from six months to two years and is dependent of age (Example-Photographs Plate 1). In 1996 the Asian Arsenic Network (AAN) conducted skin examinations on 167 people from the West Bengal of India who had drunk tubewell water for a period of 4 months to 45 years. The largest group (63) drank the tubewell water for 6-10 years. One hundred sixty three people out of one hundred sixty seven (97.6 %) ranging from 3-80 years were found to have skin lesions related to arsenic poisoning. Based on Dr. Shaha's survey, the AAN estimated that arsenic contamination in West Bengal started around 1980-1981. No such survey is known to have been conducted in Bangladesh. However, in West Bengal evidence of As poisoning have been found after six months of drinking of arsenic contaminated water. Infants and the young are more vulnerable than adults. High concentration may cause poisoning within a shorter period of time.

Apart from Arsenic Problem, there are other water quality issues in Bangladesh. This includes microbial quality of mitigation options, toxins from cyanobacteria and a number of other chemicals including manganese, boron and iron. The Government of Bangladesh is using the new WHO Guidelines for Drinking-Water Quality to improve risk assessment and risk management and has developed approaches for assessing the health risks associated with different mitigation options. It is expected that water safety plans will also be developed in Bangladesh. There is a need for further work in ensuring safe drinking water and in identifying appropriate responses to arsenic, including characterization of the deep aquifer.

1.2 Objectives of the Study

The proposed study is aimed at:

- ☐ Determination of the correlation, if any, among ground water quality parameters of drinking water sources in the study areas.
- ☐ Determination of temporal variation of As and other Water Quality parameters, if any, in the study areas.
- ☐ Determination of variation of As and other Water Quality parameters with depth, if any, in the study areas.

1.3 Scope of the Study

The severity of the Prevailing As Contamination is causing concern around the country and among the Global communities. From the perspective of treatment of groundwater with objective to provide arsenic free water to the people it is necessary to determine whether or not there exists any correlation ship among the different water quality parameters. In addition, from management perspective any definite information on the correlation between the arsenic concentration in water and the depth of the well is of much importance. This study therefore, is an attempt to investigate whether or not there exists any co-relation among the water quality parameters. However, the absence of any such relationship may also provide valuable information regarding the approach towards treatment as well as management of the groundwater resources.

1.4 Methodology

The objective of the research work is to determine the correlation among ground water quality parameters of drinking water sources and the temporal variation of ground water quality parameters. Data Collected from field will be analyzed with the help of statistical soft wares like MS Excel, SPSS etc. and subsequent co-relation tables, charts, graphs etc. will be prepared. Secondary data will be collected from 'Office of The Project Director, Bangladesh Arsenic Mitigation Water Supply Project', 'ITN- Bangladesh', NGOs and other Government organizations.

1.5 Organization of the Thesis

This Project Report consists of five Chapters. Chapter one is the Introductory chapter includes Background, Objectives, Scope of the Study and brief Methodology. Chapter two presents a brief discussion on Literature Review for the Study which includes mainly sources of Drinking water, Different water quality parameters with their effects and specially the toxic characteristics of Arsenic. Chapter three describes the Methodology used for the Study and taken analysis. Chapter four presents the findings of the study. And Chapter five that is the concluding chapter includes some recommendations & limitations of the work.

Chapter – 2

Literature Review

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

2.1.1 *Sources of Drinking Water in Rural Areas of Bangladesh*

The sources of rural areas are:

- ☐ Surface water in ponds, haor, baor, canals, lakes and rivers
- ☐ Ground water in shallow and deep aquifer and
- ☐ Rain water

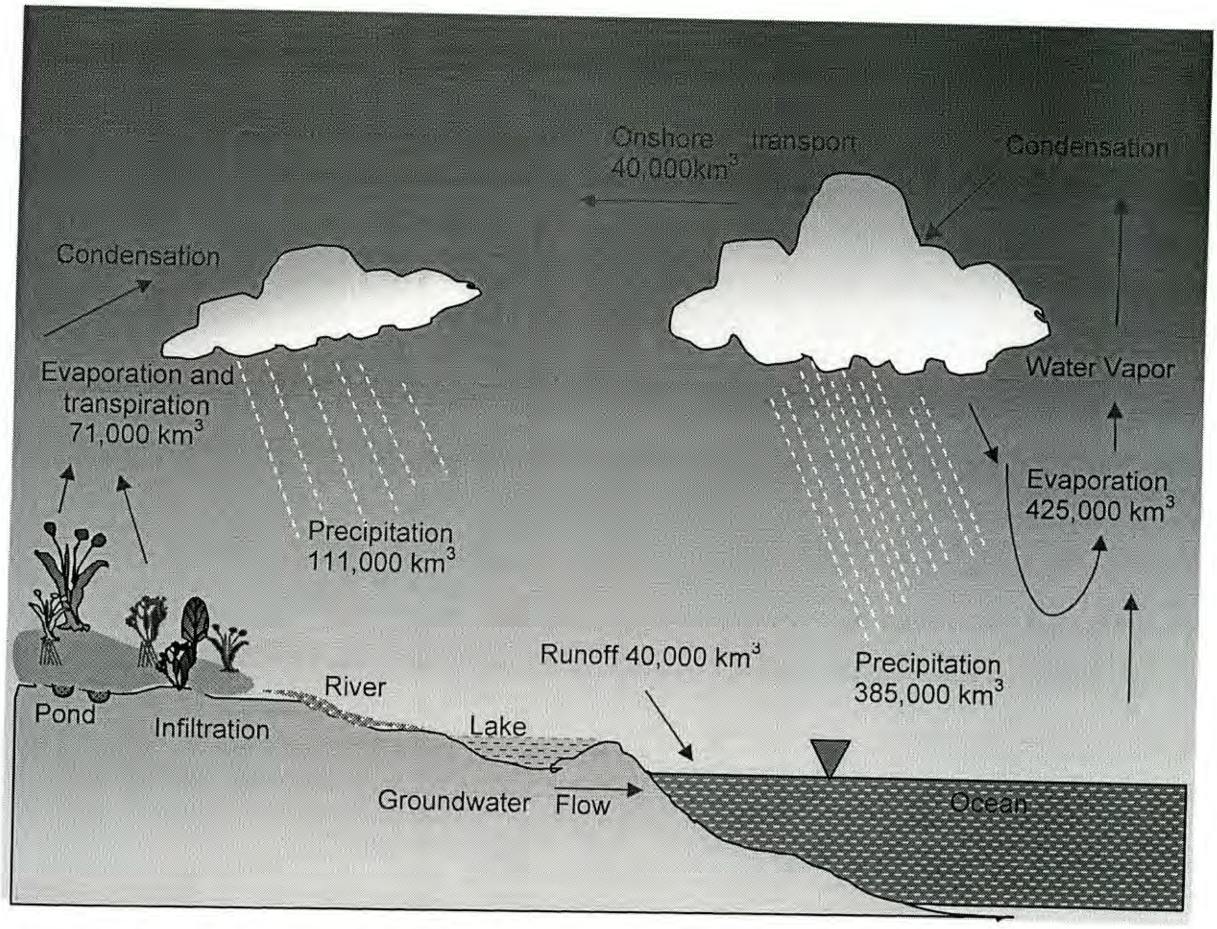


Figure 2.1 :- Hydrological Cycle

If we look into the hydrological Cycle (figure 2.1) same water circulates from oceans to air, air to land, over land surfaces or underground and back to the oceans.

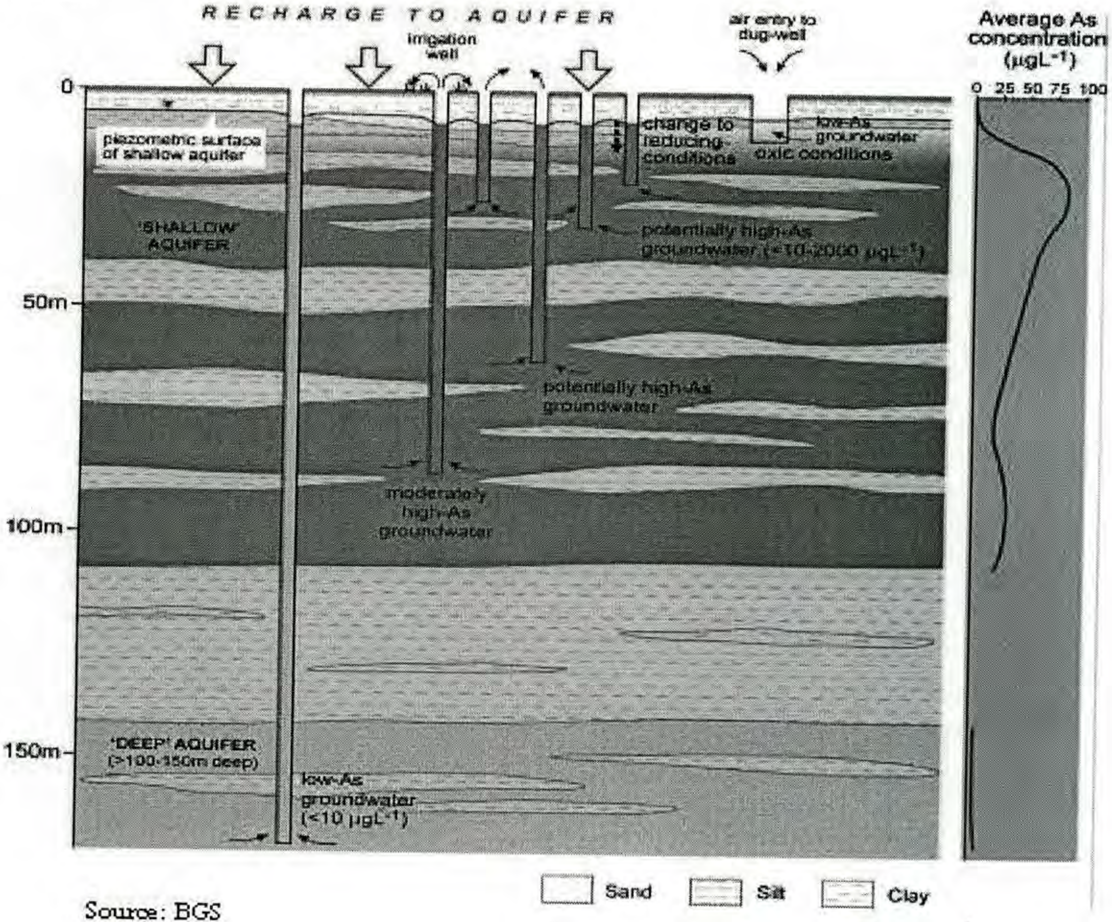
2.1.2 *Ground water*

Ground water is the most preferred water source in Bangladesh. Because of:

- ☐ Abundant availability with physically clean
- ☐ Good quality (free from diseases producing micro-organism)
- ☐ Simple and low treatment
- ☐ Constant temperature
- ☐ Little or no suspended solids

Classification of Aquifer

Based on the depth of water bearing formation, two types of aquifer exist in Bangladesh. These are shallow and deep aquifer. Ground water is available in both aquifers.



Source: BGS

Figure 2.2 :- Typical hydro geological cross section and aquifer classification

Shallow Aquifer

Water bearing strata that lies at shallow depth (depth is area depended within 100 m) below ground surface with an over laying thin layer of clay/silt blanket (thickness of clay/silt layer is also area depended). Water abstracted by hand tube well from this aquifer is known as shallow hand tube well. Most of the shallow tube well (STW) in the rural areas is contaminated by arsenic concentration exceeding Bangladesh standard of 50 ppb.

Deep Aquifer

A water bearing strata (below ground surface) situated under an impervious clay layer of 50 m to 150 m thick which protect the deep ground water against inflow of possible contaminated water from upper aquifer. Thickness and depth below ground surface are area depended. Water abstracted by hand tube well from this aquifer is called as deep tube well.

New Classification of Aquifer

Table 2.1 :– Old and New Classifications of Aquifer Systems in Bangladesh (Source: Groundwater Task Force – 2002)

Based on Depth (old)		Based on age (new)			Arsenic contamination
Name	**Depth (m –GL)**	**Name**	**Depth (m - GL)**	**Age (years)**	
Upper or 1st aquifer	0-50	Type 1 and 2 aquifer	0-100	<100	High arsenic levels
Main, lower or 2nd aquifer	50-150				
Clay layer?	> 150	Type 3 aquifer	100-200	3,000	Mainly arsenic free, but vulnerable for pollution
Deep or 3rd aquifer		Type 4 aquifer (deep aquifer)	> 100-200	20,000	Arsenic free and protected where the red clay is present

Previously aquifer was classified based on the depth. Shallow and deep aquifers as mentioned earlier are the examples of this type of classification.

A new classification of aquifers is done based on the age of the water. This type of classification can predict the water quality in a better way. The following table shows both old and new type of classifications.

Characteristic of Aquifers in Bangladesh

In the shallow aquifer, ground water flows form north to south with localized outflow into the major rivers. Ground water gradient varies from 1:1000 in the northwest to 1:13,000 in central Bangladesh to less than 1:20,000 in the coastal area. Permeability of the aquifers are very high and vary from 10 to 200 m/day. Transmissibility of the main aquifer ranges from 10 to 10,000 m^3/day with an average value of 2,000 m^3/day. Although the aquifer has high transmissibility, the horizontal flow of ground water is very low because of the low ground water gradient.

Ground Water Quality

The ground water is usually bacteriologically safe and free from turbidity. However the presence of different dissolved minerals causes water quality related problems. The common water quality related problems in Bangladesh are

- ☐ Presence of Arsenic
- ☐ Excessive dissolved iron
- ☐ Salinity problem in the coastal belt
- ☐ Presence of other metals and chemicals beyond permissible limit such as hardness

Other Problems

- ☐ Lowering of the ground water table
- ☐ Stone layer in some areas.

2.1.3 Technologies for Drinking Water Supply in Rural Areas

Technologies used for supplying drinking water in rural areas are mainly point source type. Recently piped water supply system is introduced in few villages by DPHE, RDA Bogra and few NGOs. Here, we may classify technologies into two categories, namely: -

- Point Source
- Piped Water Supply System

Point Source

Surface water based technologies are:

- Pond/River Sand Filter
- Infiltration Well

Groundwater Based Technologies are

Tube wells are widely used to abstract ground water. Dug well/Ring well is also used to tap water from very shallow depth.

Tube Well Technology

A large variety of tube wells have been designed for abstraction of groundwater and are being used all over the world. The tube wells designed and developed including those being used in Bangladesh may be grouped under three categories:

- Shallow tube wells,
- Deep-set intermediate technology and
- Deep tube wells.

Shallow tube well technology

In shallow tube well technology, hand pumps are operated in a suction mode. A suction pump draws water from a shallow depth by creating a vacuum in the suction pipe. The suction hand pumps can practically extract water from up to a depth of 7.5 m static water level. This category of hand pumps includes:

- No. 6 hand pump tube well,
- Rower pump tube well and

☐ Disco pump tube well.

No. 6 Hand pumps tube well: In Bangladesh the most common and popular technology used for abstraction of groundwater is the No. 6 hand pump tube well. The name of the tube well is based on its barrel diameter in inches About 3-4 million public and private No. 6 hand pump tube wells are already in use throughout the country and a very high percentage of these tube wells is in operational condition at present.

2.1.4 Community Based Public Water Supply

Table 2.2 :- Types of Public Water Supplies

Classification	Description	Examples
Type I Community Public Water Supply	Provides year-round service to not less than 25 residents OR not less than 15 living units	Municipalities, Apartments, Nursing Homes, Mobile Home Parks
Type II Non-transient Non-community Public Water Supply	Serves not less than 25 of the SAME people for at least six months per year	Schools, Industries, Places of Employment
Type II Transient Non-community Public Water Supply	Serves not less than 25 people OR not less than 15 connections for at least 60 DAYS per year	Hotels and Restaurants (with less than 25 employees), Campgrounds
Type III Public Water Supply	Anything not considered a Type I or Type II water supply; serves less than 25 people AND 15 connections, or operates for less than 60 days per year	Small Apartment Complexes and Condominiums, Duplexes, all Others
Private Water Supply	Serves a single living unit	Single Family Home

Type II non-community water supplies are also classified according to their water production. Type IIa water supplies have an average production during the maximum month equal to or greater than 20,000 gallons per day. Type IIb water supplies produce less than 20,000 gallons per day during the peak month.

2.2 Water Quality

Pure water is not available in nature nor it is desirable for water supply. The

impurities present in natural water may be grouped into the following four categories:

- ☐ Impurities of mineral origin
- ☐ Impurities organic origin
- ☐ Living impurities
- ☐ Radioactive impurities.

These impurities may be present in suspension, solution or pseudo-solution. Some of the water quality parameters respond to human senses of sight (turbidity, colour), taste (salty, offensive) and smell but the presence of pathogens and poisons in drinking water cannot be identified by human senses.

The most important parameter of drinking water quality is the bacteriological quality, i.e. presence of pathogenic organisms. The water-borne diseases are caused by the ingestion of pathogens with drinking water. Control of most water-borne diseased in hinged upon availability of enough water for domestic and personal cleanliness.

Many individuals, communities and industries depend on groundwater for their water supplies. For Australia as a whole, about 20 per cent of total water use is supplied by groundwater. As with surface waters, quality is determined by natural conditions and human activities. It is affected by the nature of the rainfall and surface waters before they enter the ground. Once below the surface, the water is affected by the nature of the soils and rocks through which it passes. Many naturally occurring substances, such as nitrate, can affect groundwater quality and determine its suitability or otherwise for different uses.

As well, groundwater quality is affected by pollutants of urban, industrial and agricultural origins. The same problems that affect surface waters also affect groundwaters, though they can take many years to become evident and are almost impossible to deal with. From agricultural activities, these include chemical pesticides and herbicides, and nutrients (especially nitrates) from fertilisers. Municipal and industrial waste dumps are a major cause of concern, with all kinds of substances being leached from them. Other sources of concern include organic pollutants, benzene from petrol (US studies have indicated that 25-35 per cent of underground petrol tanks leak), and cleaning fluids (from dry cleaning establishments).

2.2.1 Water Quality Parameters

What are water quality parameters?

Things which can be measured in some way or another, to see if there is change, are called `parameters'. Water quality parameters are things which can be measured to find out the quality of the water in a water body.

Measurement of these parameters is undertaken by the Water and Rivers Commission, local waterways management authorities, local governments, local school groups, industries and farmers to help understand water quality changes. Monitoring water quality can provide a good indicator or whether waterways and catchments management initiatives are effective.

There is no single test by which the safety of drinking water can be determined. Water contains many elements and only one of them can be the reason for rejection of the water for human consumption. Elevated levels of certain elements can be the result of natural progresses (eg salinization, arsenic contamination) or caused by man-made pollution (microbiological contamination and pollution by industry or agriculture).

Major elements (Na, Ca, Mg, K, HCO3, Cl, SO4, NO3, Si) make up 99% of the solute content of natural water and the remaining 1% constitutes a large number of trace elements that occur in the water. Some of these elements are toxic and undesirable even in small quantities while others are essential for human or animal health but become harmful at higher concentrations. Other elements are not harmful but lead to rejection of the water because of taste or color when certain level is exceeded.

Besides the major elements and trace elements in natural water there are also the microbiological contaminants (such as bacteria or viruses) and organic chemicals (such as pesticides, insecticides, and herbicides) that may affect the safety of the water. Tests for nitrate and bacteria are often used as general indicators for the safety of well water.

Table 2.3 :- The full set of parameters that generally describes the quality of the water includes the following groups:

Group	**Parameters**
Physical & Aggregate Properties	Colour, Taste, Odour, P^H, Temperature, Turbidity, Conductivity, Salinity, Hardness, Alkalinity, Oxidation-Reduction Potential (ORP), Total Dissolved solid (TDS) & Suspended solids.
Inorganic No-metallic Constituents	Chloride, Fluoride, Nitrogen (Ammonia), Nitrogen (Nitrate), Dissolved Oxygen (DO), Sulphide, Sulphate, Phosphate.
Metals	Arsenic, Aluminium, Barium, Calcium, Chromium, Cadmium, Copper, Iron, Potassium, Sodium, Manganese, Magnesium, Lead, Mercury, Nickel, Selenium, Zinc.
Microbiological Parameters	Faecal Coliform, Total Coliform.

Other heavy metals should be tested if deep tube wells are installed in landfills or near the landfills.

If there is any possibility of surface water or groundwater to be contaminated by agricultural activities it is needed to extend the tests for pesticides and insecticides.

For water sources that are threatened by industrial pollution, additional analysis may be needed on contaminants that are selected on the basis of the type of industry and type of contamination that is expected.

However, it is not always possible (and needed) to analyze all the parameters. Therefore, 3 sets of parameters are suggested herewith. The first one is the complete set (38 elements), the second one is a reduced set (21 parameters) and the third set comprises a small number of parameters to monitor expected impacts in a specific case. The choice of Set A, B or C will depend on the frequency and the type of needed information.

Table 2.4 :- Water Quality Parameters.

Set A: Proposed full set of water quality parameters			
No.	**Parameter**	**No.**	**Parameter**
	Visual parameters	19	Sulphata(SO_4)
01	Color/Taste/odor	20	Zinc(Zn)
	Physical parameters		**Parameters of health significance (WHO 1993)**
02	Temperature		
03	P^H	21	Arsenic(As)
04	Electronic conductivity	22	Barium(Ba)
05	Suspended solids	23	Cadium(Cd)
06	Eh/ORP (groundwater)	24	Chromium(Cr)
07	Alkalinity (HCO_3)	25	Copper(Cu)
08	Total dissolved Solids (TDS)	26	Fluoride(F)
09	Turbidity	27	Iodine(I)
	Substances that may give rise to complaints from consumers (WHO, 1993)	28	Lead(Pb)
		29	Manganese(Mn)
		30	Mercury(Hg)
10	Aluminium(Al)	31	Nickel(Ni)
11	Ammonium(NH_4)	32	Nitrate(NO_3)
12	Calcium(Ca)	33	Selenium(Se)
13	Chloride(Cl)		**Optional parameters**
14	Sulphide(H_2S)	34	Phosphate(P)
15	Iron(Fe)	35	Faecal coliform(Surface water)
16	Magnesium(Mg)	36	Total coliform(surface water)
17	Potassium(K)	37	Nitrite(NO_2)
18	Sodium(Na)	38	Hardness

Set B: Proposed reduced set of water quality parameters			
No.	**Parameter**	**No.**	**Parameter**
	Visual parameters	11	Chloride (Cl)
1	Colour/Taste/Odor	12	Iron (Fe)
	Physical parameters	13	Mangnesium (Mg)
2	Temperature	14	Potassium (K)
3	p^H	15	Sodium (Na)
4	Electric conductivity (EC)	16	Sulphate (SO_4)
5	Suspended solids		**Parameters of health significance (WHO 1993)**
6	Alkalinity (HCO_3)		
7	Eh/ORP (groundwater)	17	Arsenic (As)
8	TDS	18	Manganese (Mn)
	Substances that may give rise to complaints from consumers (WHO, 1993)	19	Nitrate (NO_3)
			Optional parameters
		20	DO (surface water)
9	Ammonium (NH_4)	21	Faecal coliform (surface water)
10	Calcium (Ca)		
Set C: Selected parameters for a specific water supply system and/or water source			
Set C comprises parameters that are selected to monitor specific trends or impacts, based on the baseline water quality and risk assessment of quality changes during over time (either man made or natural). This set complies with the water safety plan approach.			

2.2.2 Source and significance of selected water quality parameters

Alkalinity: The alkalinity of water is a measure of its capacity to neutralize acids. The alkalinity is due primarily to salts of weak acids and strong bases. Such substances act as buffers to resist a drop in pH resulting from acids addition. Alkalinity is thus a measure of the buffer capacity. Most of the alkalinity in natural waters is caused by three major classes of materials: bicarbonate, carbonates, and hydroxides.

Hardness (Water Hardness): Hard waters are generally considered to be those waters that require considerable amounts of soap to produce foam or lather and that also produce scale in hot water pipes, heaters, boilers, and other units in which the temperature of water is increased materially. Hardness is caused by multivalent metallic cation. Such cations are capable of reacting with soap to form precipitates and with certain anions present in water to form scale. The principal hardness causing cations are divalent calcium and magnesium, strontium, ferrous ions, and manganous ions. Hard water normally originates in areas with thick topsoil and limestone formations and groundwater rich in H_2CO_3 and D_2O. Groundwater is generally harder than surface water.

Water hardness is caused by the polyvalent metallic ions dissolved in water. Hardness commonly is reported as an equivalent concentration of calcium carbonate ($CaCO_3$). The concept of hardness comes from water supply practice. It is measured by soap requirements for adequate lather formation and as an indicator of the rate of scale formation in hot water heaters and low-pressure boilers. A commonly used classification is given below:

Classification of Water by Hardness Content

Concentration Hardness Description $CaCO_3$, (mg/l) (g/g)

0-75 ⇨ 0-5 soft

75-150 ⇨ 5-9 moderately hard

150-300 ⇨ 9-18 hard

300 and up ⇨ 18 and up very hard

Hardness is sometimes expressed as grains per gallon (g/g). To convert milligrams per liter (mg/l) or parts per million (ppm) to grains per gallon (g/g), use the formula below:

(mg/l) or (ppm) = g/g 17.1

Natural sources of hardness principally are lime stones which are dissolved by percolating rainwater made acidic by dissolved carbon dioxide. Industrial sources include discharges from operating and abandoned mines.

Hardness in fresh water frequently is distinguished as carbonate and noncarbonated fractions. The carbonate fraction is chemically equivalent to the bicarbonates present in water. Since bicarbonates generally are measured as alkalinity, the carbonate hardness usually is considered equal to the alkalinity. When water containing bicarbonate or "temporary" hardness is heated, carbon dioxide is driven off, converting the bicarbonate into carbonates which precipitate to form the hard scale found in cooking utensils, pipes, hot water tanks, and boilers. This scale reduces the capacity of pipes to carry water and does not transmit heat well. Detergents minimize the adverse effects of hard water in washing and other processes, and proper water softening entirely eliminates the hard water problem.

When hardness exceeds 180mg/l, it generally causes problems, and a water softener should be considered. Water softened to zero hardness is corrosive. It is therefore desirable to blend a proportion of nonsoftened water with extremely soft water.

Chloride: Chloride is widely distributed in nature, generally in the form of sodium (NaCl), potassium (KCl) and calcium ($CaCl_2$). Chlorides occur in natural waters in widely varying concentrations. Upland and mountain supplies are quite low in chlorides, whereas rivers and groundwater usually have a considerable amount. Sea and ocean waters represent the residuals resulting from partial evaporation of natural waters that flow into them, and chloride levels are very high. Chlorides gain access to natural waters in many ways. The solvent power of water dissolves chlorides from topsoil and deeper formations. In addition, ocean and seawater invasion of rivers, and intrusion of seawater into fresh groundwater aquifers also contribute chloride to natural waters. Wastewater influents and many industrial wastes also add considerable chlorides to receiving streams. Taste thresholds for chloride (as Na, K, Ca) are in the range of 200-300 mg/l. High chloride concentrations are corrosive to metals in the water distribution system, particularly in water of low alkalinity. Higher chloride content in inland water usually indicates sewage pollution.

The SMCL of 250 mg/l for chloride is the level above which the taste of the water may become objectionable to the consumer. In addition to the adverse taste effects, high chloride concentration levels in the water contribute to the deterioration of domestic plumbing, water heaters, and municipal waterworks equipment. High chloride concentrations in the water may also be associated with the presence of sodium in drinking water. Elevated concentration levels of sodium may have an adverse health effect on normal, healthy persons. In addition, a small segment of the population may be on severely restricted diets requiring limitation of their sodium intake. For the preceding reasons, the SMCL for chloride represents a desirable and reasonable level for protection of the public welfare.

Nitrate: Nitrates are widely present in substantial quantities in soil (fertilizer, bacterial decomposition of organic matter), in most waters, and in plants, including vegetables. Fertilizer use decayed vegetable and animal matter, domestic effluents, sewage sludge disposal on land, industrial discharges, leachates from refuse dumps, and atmospheric washout all contribute to these ions in water sources. Nitrate is toxic when presenyt in excessive amounts in water and may cause "methamoglobinaemia" in infants. While this problem does not arise in older age groups, there is a possibility that certain forms of cancer might be associated with very high concentrations.No diseased have definitely been proven to be caused by water containing less than 10 mg/l nitrate-N.

Iron: Iron in surface water is generally present in the ferric (Fe III) state. The presence of iron in natural waters can be attributed to the dissolution of rocks and minerals, acid mine drainage, landfill leachates, sewage, or discharge from iron-related industries. Iron in water may cause hardness, undesirable taste in beverages, staining of clothes and plumbing fixtures, encrustation in water mains, and may impart a reddish brown color to water. Iron in water is frequently accompanied by heavy growths of iron bacteria which exaggerate the staining, pipe clogging, and other problems.

Sodium: The sodium ion is ubiquitous in water owing to the high solubility of its salts and the abundance of mineral deposits. Seawater contains relatively high levels of sodium. Groundwater may be contaminated from saline intrusion near coastal areas. In general, sodium salts are not acutely toxic because of the efficiency with which mature kidneys excrete sodium. Excessive intake of sodium chloride, however, causes vomiting. Infants with severe gastrointestinal infections can suffer from fluid loss leading to dehydration and raised sodium levels in the plasma.

Arsenic: Many arsenic (As) compounds are water soluble and thus contamination of water may occur. Most of the arsenic found in water derives from geological formations, industrial discharges, mining operations, the use of arsenical insecticides, and from the combustion of fossil fuels. The toxicity of arsenic compounds depends on the chemical and physical form of the compound, the route by which it enters the body, the dose and duration of exposure, etc. Inorganic arsenic is more toxic than organic arsenic; trivalent inorganic arsenic is more hazardous than the pentavalent form. Severe poisoning can arise from ingestion of arsenic as little as 100 mg arsenic trioxide; chronic effects may result from accumulation of arsenic in body at low intake level. The gastrointestinal tract, nervous system, the respiratory tract, and the skin can be severely affected. The concentration of arsenic in excess of allowable limits has been found in shallow tubewells in many locations Bangladesh. The recommended allowable limit of arsenic is 0.05 mg/l in Bangladesh.

Most of the arsenic produced is a by-product of the smelting of copper, lead, and zinc ores. Arsenic has been found in both groundwater and surface waters from both natural processes and industrial activities, including smelting operations, use of arsenical pesticides, and industrial waste disposal. Arsenic compounds have been shown to produce acute and chronic toxic effects which include systemic irreversible damage. The trivalent (+3) compounds are the most toxic and tend to accumulate in the body. Chronic animal studies have shown body weight changes, decreased blood hemoglobin, liver damage, and kidney damage. Arsenic has been classified in EPA's Group A (human carcinogen), based upon evidence of human carcinogenicity through inhalation and ingestion exposure. Arsenic is regulated because of its potential adverse health effects and its widespread occurrence.

Chromium: Most rocks and soils contain small amounts of chromium. Because of its low solubility chromium concentrations found in water are usually low. However, contamination of water by chromium may result from industrial wastes (chrome plating, textile, ceramic, glass and tannery industries; etc.).

Chromium is a naturally occurring metal that in drinking water forms compounds with valences of +3 and +6, with the trivalent state being the more common. Although chromium is not currently mined in the United States, wastes from old mining operations may enter surface and groundwater through runoff and leaching. Chromate wastes from plating operations may also be a source of water contamination. Fossil fuel combustion, waste incineration, cement plant emissions, chrome plating, and other metallurgical and chemical operations may result in releases of chromium to the atmosphere. Chromium III and chromium VI have greatly differing toxicity characteristics. Chromium III is a nutritionally essential element. Chromium VI is much more toxic than Chromium III and has been shown to produce liver and kidney damage, internal hemorrhage, and respiratory disorders. Also, sub chronic and chronic exposure to Chromium VI in the form of chromic acid can cause dermatitis and ulceration of the skin. Chromium has been classified in EPA's Group A (human carcinogen), based upon positive inhalation data for Chromium VI in humans and animals. However, since chromium has not been shown to be carcinogenic through ingestion exposure, the compound is regulated based upon chronic toxicity data. Chromium exposure at high levels has been shown to result in chronic toxic effects in animals and humans by ingestion; thus it is regulated.

Lead: Lead is used widely for a variety of purposes. From led plumbing and lead lined storage tanks, high lead levels can result when the water is aggressive, soft, or has a low P^H. Lead in high doses has been recognized for centuries as a cumulative general metabolic poison. Lead is highly toxic and is also considered a probable carcinogen. Lead has been identified as being a cause of brain and kidney damage. In youngsters it may result in mental retardation and even convulsions in later life.

***Zinc*:** Zinc most commonly enters the domestic water supply from deterioration of galvanized iron and dezincification of brass. Zinc in water also may result from industrial waste pollution. It is an essential and beneficial element in human growth. Concentrations above 5 mg/l can cause a bitter astringent taste and opalescence in alkaline waters.

***Antimony*:** Antimony occurs naturally in soils, groundwater and surface waters and is often used in the flame retardant industry. It is also used in ceramics, glass, batteries, fireworks and explosives. It may get into drinking water through natural weathering of rock, industrial production, municipal waste disposal or manufacturing processes. This element has been shown to decrease longevity, and altered blood levels of cholesterol and glucose in laboratory animals such as rats exposed to high levels during their lifetimes. EPA has set the drinking water standard for antimony at 0.006 ppm to protect against the risk of these adverse health effects. Drinking water which meets the EPA standard is associated with little to none of this risk and should be considered safe with respect to antimony.

***Barium*:** Barium is a naturally occurring metal found in many types of rock, such as lime stones and sandstones, and soils in the eastern United States. Certain geologic formations in California, Arkansas, Missouri, and Illinois are known to contain barium levels about 1,000 times higher than those found in other portions of the United States. Areas associated with deposits of coal, petroleum, natural gas oil shale, black shale, and peat may also contain high levels of barium. Principal areas where high levels of barium have been found in drinking water include parts of Iowa, Illinois, Kentucky, and Georgia. Acute exposure to barium in animals and humans results in a variety of cardiac, gastrointestinal, and neuromuscular effects. Barium has been classified in EPA's Group I) (not classifiable), based upon inadequate data from animal studies. Barium exposure has been associated with hypertension and cardiotoxicity in animals. For this reason and because of the widespread occurrence of barium in drinking water, it is regulated.

***Cadmium*:** Cadmium is found in very low concentrations in most rocks, as well as in coal and petroleum and often in combination with zinc. Geologic deposits of cadmium can serve as sources to groundwater and surface water, especially when in contact with soft, acidic waters. Cadmium uses include electroplating, nickel-cadmium batteries, paint and pigments, and plastic stabilizers. It is introduced into the environment from mining and smelting operations and industrial operations, including electroplating, reprocessing cadmium scrap, and incineration of cadmium containing plastics. The remaining cadmium emissions are from fossil fuel use, fertilizer application, and sewage sludge disposal. Cadmium may enter drinking water as a result of corrosion of galvanized pipe. Landfill leachates are also an important source of cadmium in the environment. Acute and chronic exposure to cadmium in animals and humans results in kidney dysfunction, hypertension, anemia, and liver damage. The kidney is considered to be the critical target organ in humans chronically exposed to cadmium by ingestion. Cadmium has been classified in EPA's Group B1 (probable human carcinogen), based upon evidence of carcinogenicity In humans through inhalation exposure. However, since cadmium has not been shown to be carcinogenic through ingestion exposure, the compound is regulated based upon chronic toxicity data. Because of cadmium's potential adverse health effects and widespread occurrence in raw waters, it is regulated.

***Copper*:** Copper, a reddish-brown metal, is often used to plumb residential and commercial structures that are connected to water distribution systems. Copper contaminating drinking water as a corrosion by-product occurs as the result of the corrosion of copper pipes that remain in contact with water for a prolonged period. Copper is an essential nutrient, but at high doses it has been shown to cause stomach and intestinal distress, liver and kidney damage, and anemia. Persons with Wilson's disease may be at higher risk of health effects due to copper contamination resulting from the corrosion of plumbing materials. Public water systems serving over 50,000 people or fewer that have copper concentrations below 1.3 parts per million in more than 90 percent of tap water samples (the USEPA action level) are not required to install or improve their treatment. Any water system that exceeds the action level must. Also monitor its source water to determine whether treatment to remove copper in source water is needed.

***Fluoride*:** Federal regulations require that fluoride, which occurs naturally in your water supply, not exceed a concentration of 4.0 mg/l in drinking water. This MCL has been established to protect public health. Exposure to drinking water levels above 4.0 mg/l for many years may result in some cases of crippling skeletal fluorosis, which is a serious bone disorder. Fluoride in children's drinking water at levels of approximately 1 mg/l reduces the number of dental cavities 60-65 percent below rates in communities with little or no fluoride. However, some children exposed to levels of fluoride greater than about 2.0 mg/l may develop dental fluorosis. Dental fluorosis, in its moderate and severe forms, is a brown staining and/or pitting of the permanent teeth. Because dental fiuorosis occurs only when developing teeth (before they erupt from the gums) are exposed to elevated fluoride levels, households without children are not expected to be affected by this level of fluoride. Federal law also requires that notification take place when monitoring indicates that the fluoride exceeds 2.0 mg/l. This is intended to alert families about dental problems that might affect children under nine years of age. Families with children under the age of nine with fluoride exceeding 2.0 mg/l are encouraged to seek other sources of drinking water for their children to avoid the possibility of staining and pitting.

***Selenium*:** Selenium occurs in U.S. soils in the western states. The more alkaline soil tends to make selenium more water-soluble, and increased plant uptake and accumulation occur. Most of the commercial selenium has toxic effects at high dose levels and Is nutritionally essential at low levels. Acute and chronic toxic effects have been observed in animals. In humans, few data exist on acute toxicity. In animals, selenium deficiency results in congenital white muscle disease and other diseases. Selenium has been classified in EPA's Group D (not classifiable), based upon inadequate data in animals and humans. Selenium exposure at high levels results in chronic adverse health effects, and thus it is regulated.

***Color*:** In some instances, color may be objectionable to some people at as low as 5 CU. Color may be indicative of large quantities of organic chemicals, inadequate treatment, high disinfectant demand, and the potential for production of excess amounts of disinfectants' by-products such as trihalomethanes. Natural color may be caused by decaying leaves, plants, and soil organic matter. It may also result from the presence of such metals as copper, iron, and manganese (which also have SMCLs), as well as color from industrial sources. While color itself is not usually objectionable from the standpoint of health, its presence is aesthetically objectionable and suggests that the water may need additional treatment. Experience has shown that rapid changes in color levels lead to greater consumer complaints, as opposed to a relatively constant color level.

***Manganese*:** The SMCL was set to prevent aesthetic and economic damage. Excess manganese produces a brownish color in laundered goods and impairs the taste of tea, coffee, and other beverages. Concentrations may cause a dark brown or black stain on porcelain plumbing fixtures. As with iron, manganese may form a coating on distribution pipes. These may slough off, causing brown blotches on laundered clothing or black particles in the water.

***Odor*:** Odor is an important quality factor affecting the drinkability of water. Odors for certain substances in water may be detected at extremely low concentrations. This may be indicative of the presence of organic and inorganic pollutants that may originate from municipal and industrial waste discharges or from natural sources. The Threshold Odor Number (T.O.N.) of water is the dilution factor required before the odor is minimally perceptible. A (T.O.N.) of 1 indicates that the water has characteristics comparable to odor-free water, while a (T.O.N.) of 4 indicates that a volume of the test water would have to be diluted to four times its volume before the odor became minimally perceptible. For precise work, a panel of five or more testers is required, and the (T.O.N.) is based on the greatest amount of dilution which elicits a positive odor response from one of the testers. The (T.O.N.) level of 3 was determined to be appropriate because most consumers find the water at this limit acceptable. Determination of odor below this level is difficult because of possible interferences from other sources and variability of the sensing capabilities of the personnel performing the test. Therefore, the SMCL of 3 (T.O.N.) has been set.

***pH*:** This is a numerical expression that indicates the degree to which water is acidic or alkaline. These various degrees are represented on a scale of 0 to 14, with 0 being most highly acidic, 14 most alkaline, and 7 neutral. High pH levels are undesirable since they may impart a bitter taste to the water. Furthermore, the high degree of mineralization associated with alkaline waters will result in the encrustation of water pipes and water-using appliances. The combination of high alkalinity and calcium with low pH levels may be less corrosive than water with a combination of high pH, low alkalinity, and calcium content. High pH levels also depress the effectiveness of disinfection by chlorination, thereby requiring the use of additional chlorine or longer contact times. A range of 6.5 - 8.5 was determined as that which would achieve the maximum environmental and aesthetic benefits.

***Sulfate*:** High concentrations of sulfate in drinking waters have three effects: (1) water containing appreciable amounts of sulfate (SO_4) tends to form hard scales in boilers and heat exchangers; (2) sulfates because taste effects; and (3) sulfates can cause laxative effects with excessive intake. The laxative effect of sulfates is usually noted in transient users of a water supply because people who are accustomed to high sulfate levels in drinking water have no adverse response. Diarrhea can be induced at sulfate levels greater than 500 mg/l but typically near 750 mg/l. While sulfate imparts a slightly milder taste to drinking water than chloride, no significant taste effects is detected below 300 mg/l. Sulfate cannot readily be removed from drinking water, except by distillation, reverse osmosis, or electro dialysis, but these are expensive. As with water having high levels of chloride, it is recommended that either an alternative source be used or that the high sulfate water be diluted with a lower sulfate containing water.

Total Dissolved Solids (TDS): Total Dissolved Solids (TDS) may have an influence on the acceptability of the water in general and, in addition, high TDS value may be an indication of the presence of excessive concentration of some specific substance, not included in the Safe Drinking Water Act, which would make the water aesthetically objectionable to the consumer. The life of home hot water heaters decreases by approximately one year for each additional 200 mg/l of TDS in water above the typical household level of 220 mg/l. The SMCL of 500 mg/l for TDS is reasonable because it represents an optimum value commensurate with the aesthetic level to be set as a desired water quality goal.

2.2.3 Health Hazards of Drinking Water Contaminants

Chemicals in drinking water which are toxic may cause either acute or chronic health effects. An acute effect usually follows a large dose of a chemical and occurs almost immediately. Examples of acute health effects are nausea, lung irritation, skin rash, vomiting, dizziness, and, in the extreme, death. The levels of chemicals in drinking water, however, are seldom high enough to cause acute health effects. They are more likely to cause chronic health effects, effects that occur after exposure to small amounts of a chemical over a long period. Examples of chronic health effects include cancer, birth defects, organ damage, disorders of the nervous system, and damage to the immune system. Evidence relating chronic human health effects to specific drinking water contaminants is very limited. In the absence of exact scientific information, scientists predict the likely adverse effects of chemicals in drinking water using laboratory animal studies and, when available, human data from clinical reports and epidemiological studies. USEPA classifies compounds for carcinogenicity potential according to the "weight of evidence" approach as stated in the Agency's Guidelines for Carcinogen Risk Assessment. These Guidelines specify five carcinogenicity classifications: Group A - Human carcinogen (sufficient evidence from epidemiological studies). Group B - Probable human carcinogen. Group B1 – At least limited evidence of carcinogenicity in humans. Group B2 - Usually a combination of sufficient evidence in animals and inadequate data in humans. Group C - Possible human carcinogen (limited evidence of carcinogenicity in the absence of human data). Group D - Not classifiable (inadequate human and animal evidence of carcinogenicity). Group E - Evidence of no carcinogenicity for humans (no evidence of carcinogenicity in at least two adequate animal tests in different species or in both epidemiological and animal studies). The possible health effects of a contaminant in drinking water differ widely, depending on whether a person consumes the water over a long period, briefly, or intermittently. Thus, MCLs and monitoring requirements for systems serving permanent populations (Public Community Water Systems and Non-transient Non-community Water Systems) may be more stringent than those regulations for systems serving transient or intermittent users (Public Non-community Water Systems). Maximum contaminant levels are based, directly or indirectly, on an assumed drinking water rate of two liters per person per day. MCLs for organic and inorganic contaminants (except nitrate) are based on the potential health effects of long-term exposure, and they provide substantial protection to virtually all consumers. The uncertainty in this process is due in part to the variations in the knowledge of and the nature of the health risks of the various contaminants.

Maximum Contaminant Levels Standards (MCLs)

Standards set under authority of the SDWA are called Maximum Contaminant Levels (MCLs). An MCL is the highest amount of a specific contaminant allowed in the water delivered to any customer of a public water system. An MCL may be expressed in milligrams per liter (mg/l), which is the same for the purposes of water quality analysis as parts per million (ppm). The MCLs can also be expressed as micrograms/liter (ug/l) which is equivalent to parts per billion (ppb). One thousand micrograms per liter (1000 ug/l) is equivalent to one milligram per liter (1 mg/l). MCLs have been set by the USEPA and the DEP to provide a margin of safety to protect the public health.

Impurities in drinking water that are regulated and have an adverse health impact are grouped into five categories: inorganic chemical contaminants, organic chemical contaminants, microbiological contaminants, radiological contaminants, and turbidity. The process of settling primary standards (MCLs) for drinking water contaminants is based on three criteria: (1) the contaminant causes adverse health effects; (2) instruments are available to detect it in drinking water; and (3) it is known to occur in drinking water. The regulatory agency first looks at all the toxicological data on a contaminant, usually obtained from chronic and subchronic animal studies. Occasionally human clinical or epidemiological data are also available. Experts use this information to estimate the concentration of a drinking water contaminant that may be toxic and the concentrations, if any, which may cause no adverse effects. For chemicals which do not cause cancer, officials set standards using a figure calculated from animal studies called the Reference Dose (Rfd), formerly called the Acceptable

Daily Intake or ADI. The Rfd is the estimate of the daily dose of a substance that a person can ingest over a lifetime without suffering any adverse health effects and it includes a conservative safety margin. Regulators use the Rfd to establish a Maximum Contaminant Level Goal (MCLG) for a contaminant. The MCLG is the concentration of a contaminant that experts believe a person can drink safely over a Lifetime. It is based entirely on health considerations and, as a health goal, is set at a level where no adverse health effects should occur. The MCL, the primary standard enforced by the USEPA, is set as close as possible to the MCLG. In setting an MCL, USEPA professionals consider, In addition to health effects, the feasibility and the combined cost of analyzing water for a contaminant and for treating water to remove the contaminant. Therefore, the MCL is often less stringent than the MCLG; however, by statute, the MCL must be set as close as is feasible to the MCLG. In setting MCLs for chemicals believed to cause cancer, a different risk assessment is used, and USEPA regulators assume that no concentration is safe. Consequently, the MCLG is set at zero. But, a zero level is not always possible to achieve, nor is it possible to measure because of the sensitivity of the analytical equipment. USEPA incorporates cost and treatability considerations into the MCLs for carcinogens as with the non-carcinogenic MCLs; these MCLs must be set as close as is feasible to the MCLG.

Setting drinking water standards is an imperfect process, rarely based on conclusive human evidence. Data relating human health effects to chemicals in drinking water are limited, and scientists have to rely on mathematical modeling for predicting the effects of drinking small amounts of chemicals for many years. In addition, regulatory decisions frequently incorporate economic, political, and social considerations. Therefore, it is important to understand that primary standards or MCLs for drinking water contaminants do not guarantee that water with a contaminant level below the standard is risk-free; nor do they mean that water with a higher level is unsafe. Specific limits have not yet been set for every toxic, carcinogenic, or undesirable contaminant that might enter a public water supply. While the need for continued attention to chemical contaminants in water is recognized, the regulations are limited by available scientific and engineering data on which those judgments of safety can be made.

2.2.4 *Drinking Water Standards*

Table 2.5 :- Drinking Water Standards based on Bangladesh and WHO:

Sl #	**Water quality parameters**	**Unit**	**Bangladesh Standard**	**WHO guideline values, 1993**
A.	**Physical & Aggregate Properties**			
1	pH		6.5-8.5	
2	Colour	Hazen Unit	15	15
3	Temperature	^0C	20-30 ^0C	
4	Taste			
5	Odour	mg/l	Odour less	
6	Turbidity	JTU	10	5
7	Conductivity			
8	Salinity			
9	Alkalinity (HCO_3-)			
10	Hardness (as $CaCO_3$)	mg/l	200-500	
11	Oxidation-Reduction Potential (ORP)			
12	Total Dissolved Solid (TDS)	mg/l	1000	1000
13	Suspended Solid (SS)	mg/l	10	
B.	**Inorganic Non-metallic Constituents**			
14	Phosphate	mg/l	6	
15	Chlorine (Residual)	mg/l	0.2	0.6-1.0
16	Chloride	mg/l	150-600	250
17	Iodine	mg/l		
18	Fluoride	mg/l	1	1.5
19	Nitrogen (Ammonia)	mg/l	0.5	1.5
20	Nitrogen (Nitrate)	mg/l	10	50
21	Nitrogen (Nitrite)	mg/l	<1	3
22	Dissolved Oxygen (DO)	mg/l	6	
23	Sulfide	mg/l	0	

Sl #	Water quality parameters	Unit	Bangladesh Standard	WHO guideline values, 1993
24	Sulfate	mg/l	400	250
C.	**Aggregate Organic Constituents**			
25	Chemical Oxygen Demand (COD)	mg/l	4	
26	Biochemical Oxygen Demand $(BOD)_{5days}$	mg/l	0.2	
D.	**Metal**			
27	Arsenic	mg/l	0.05	0.01
28	Aluminum	mg/l	0.2	0.2
29	Barium	mg/l	0.01	0.7
30	Calcium	mg/l	75	
31	Chromium	mg/l	0.05	0.05
32	Cadmium	mg/l	0.005	0.003
33	Copper	mg/l	1	1
34	Iron	mg/l	0.3-1	0.3
35	Lead	mg/l	0.05	0.01
36	Manganese	mg/l	0.1	0.1
37	Magnesium	mg/l	30-35	
38	Mercury	mg/l	0.001	0.001
39	Nickel	mg/l	0.1	0.02
40	Potassium	mg/l	12	
41	Selenium	mg/l	0.01	0.01
42	Sodium	mg/l	200	200
43	Zink	mg/l	5	3
E.	**Microbiological Test**			
44	Fecal Coliform	N/100ml	0	0
45	Total Coliform	N/100ml	0	0

2.3 ARSENIC - a toxic element

Arsenic is a metalloid belonging to the group V-A element of periodic table. Its atomic weight is 74.92 and atomic number is 33. This toxic and carcinogenic element occurs in both inorganic and organic compounds. The common inorganic forms are trivalent As^{3+} (i.e. arsenite) and pentavalent As^{5+} (i.e. arsenate). The organic arsenic compounds, such as Methyl arsenic acid and Dimethyl arsenic acid are not common in groundwater. Inorganic arsenic compound is more toxic that organic, where as trivalent inorganic arsenic compound is more hazardous than pentavalent.

Arsenic was evaluated in the first edition of the WHO Guidelines for drinking water quality (GDWQ) in 194 and the guideline value of .05mg/l was recommended for drinking water (WHO, 1984). Based on new information and new risk assessment this toxic element was re-evaluated in the second edition of the GDWQ in 1993. The previous value was reduced to 0.01mg/l. (H.G. Gorchev, quoting WHO, 1993, 1996). Considering the recommended standard of GDWQ as a basis for setting the drinking water standard Bangladesh authority has determined acceptable limit of arsenic concentration at 0.05mg/l.

2.3.1 Background

In the 1980's and 1990's, Bangladesh made enormous strides in supplying its population with drinking water through the provision of shallow tubewells. This resulted in Bangladesh achieving a coverage rate of 97% of the population wit access to an improved water source and a significant reduction in diarrhoeal disease. However, arsenic contamination of many of these shallow tubewells has resulted in the coverage estimate being revised down to 74% and the emergence of new health problem from arsenic poisoning.

Groundwater drawn from alluvial aquifers located within Quaternary deposit of Bangladesh used for drinking water is polluted with naturally occurring arsenic. It adversely affects the health of millions of people. Studies of arsenic contamination indicate that more people may be affected by arsenic poisoning in Bangladesh in near future than anywhere in the world.

Within the arsenic contaminated areas, some aquifers also contain acceptable concentrations. Unfortunately, the concentrations are highly variable over relatively small distances. So it is essential to chemical investigation and quality analysis of well yield for conforming the presence of arsenic and its relation to other water quality parameters.

Arsenic contamination of groundwater in Bangladesh was first identified in 1993. After this, a countrywide survey was conducted by DPHE with support from the British Geological Survey in the late 1990s, which showed that 27% of shallow tubewells across the country had arsenic concentrations above the Government of Bangladesh standard of 50µg/l. It was estimated that about 35 million people were exposed to arsenic above the standard. The survey also indicated that the distribution of arsenic contamination was uneven and identified that 269 Upazilas were 'hotspots' where large numbers of shallow tubewells were arsenic contaminated.

In response to the identified problem of arsenic contamination, a number of Government programmes were initiated with support from development partners, as well as a number of NGO projects. These include the large World Bank and SDC support Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP), the DPHE-Unicef program, the WHO-Unicef UNF program and a number of NGO supported Projects.

2.3.2 *Chemistry of Arsenic*

Arsenic occurs in water in several different forms, depending upon the pH and the redox potential, Eh. The most common oxidation states in the natural water are arsenic (III) and arsenic (V). The inorganic forms of arsenic is dominant than organic forms.

Arsenic (V) is the thermodynamically stable and dominating of the inorganic arsenic species in oxic waters, whereas arsenic (III) is the stable and dominating form of the inorganic arsenic species under unoxic conditions.

As(III) would be the most dominant arsenic species in contaminated aquifer.

The redox reaction of the As(III)/As(V) system can be described by the following equation

$$H_3AsO_4 + 2H+ + 2e^- \longrightarrow H_3AsO_3 + H_2O$$

The arsenic and arsenious acids are dissociated according to the equations:

Arsenious Acid Dissociation;

$$H_3AsO_3 \longrightarrow H^+ + H_2AsO_3^-$$

$$H_2AsO_3^- \longrightarrow H^+ + HAsO_3^{2-}$$

$$HAsO_3^{2-} \longrightarrow H^+ + AsO_3^{3-}$$

Arsenic Acid Dissociation;

$$H_3AsO_4 \longrightarrow H^+ + H_2AsO_4^-$$

$$H_2AsO_4^- \longrightarrow H^+ + HAsO_4^{2-}$$

$$HAsO_4^{2-} \longrightarrow H^+ + AsO_4^{3-}$$

Table 2.6 :- Key arsenic reactions in ground water regimes:

Ground Water	Key reactions
Aerobic Zone	$Mn^{2+} \longrightarrow Mn^{4+} \longrightarrow MnO_2.HAsO_4$ $Fe^{2+} \longrightarrow Fe^{3+} \longrightarrow Fe(OH)_3.HAsO_4$ $HAsO_2 \longrightarrow HAsO_4^{2-}$ $HPO_4^{2-} \longleftrightarrow HAsO_4^{2-}$
Anaerobic with no H_2S zone	$HAsO_4^{2-} \longrightarrow HAsO_2$ $Fe(OH)_3.H_2AsO_4 \longrightarrow Fe^{2+} + HAsO_2$ $MnO_2.H_2AsO_4 \longrightarrow Mn^{2+} + HAsO_2$
Anaerobic with H_2S zone	$HAsO_2 + Hs^{-} \longrightarrow As_2S_3$ or AsS $Fe^{2+} \longrightarrow FeS.HAsO_2$

2.3.3 The DPHE/BGS National hydrochemical Survey

In January 1998 a project began and has been funded throughout by the UK Department for International Development (DFID). The Department of Public Health Engineering (DPHE) of the Ministry of Local Government, Rural development and Cooperatives has acted as the lead agency for the Government of Bangladesh (GoB) but other GoB Departments have been closely involved, principally the Bangladesh Water Development Board (BWDB). A report on the findings of the Rapid Investigation Phase was published in January 1999 (DPHE/BGS/MML, 1999). During the course of this project, the seriousness and scale of the groundwater arsenic problem in Bangladesh has become apparent. Many Gob agencies, NGO, international organizations and donors have now become involved and the GoB and the World Bank have begun a large-scale arsenic mitigation program.

The DPHE/BGS National hydrochemical Survey of tubewells attempted to apply a form of stratified random sampling over the whole of Bangladesh (excluding the Chittagong Hill Tracts) with the stratification designed to ensure a reasonably uniform spatial distribution of sampling sites.

The final data set for this survey consisted of samples from 3534 tubewells from 61 of the 64 districts of Bangladesh and from 433 of the 496 upazilas. The Sampled area was approximately 129,000 km^2, compared with a total area for Bangladesh of about 52,000 km^2. The sample density was about 8 samples peer Upazila or approximately one sample per 37 km^2. This is perhaps 0.03-0.05% of all Bangladesh tubewells. The majority of the sites sampled were Government (DPHE)-installed wells. These are believed to be representative of all wells. Project staff in close collaboration with local DPHE staff undertook sample collection. Arsenic was measured in the BGS laboratories in most cases by atomic fluorescence spectrometry with hydride generation. All but four of the 3534 samples were also analyzed for a wide variety of other elements by inductively coupled plasma-atomic emission spectrometry. A small subset of these samples was also analyzed for a range of trace elements using inductivity-coupled plasma-mass spectrometry to see of there were any other trace elements that were a cause for concern. A survey of 113 BWDB Water-Quality Monitoring Network sites was carried out for arsenic and a wide range of other determinands including anions and trace elements.

Three Special Study Areas were established in the three-sadar upazilas of Nawabganj, Faridpur and Lakshmipur districts in order to undertake sampling at a greater sample density and with a greater range of determinands than was possible in the national survey. Additional determilnands included field parameters such as pH, redox potential and dissolved oxygen, a wide range of trace elements and the stable isotopes of oxygen, hydrogen, carbon and a few cases, sulphur. These study areas were also where the water quality monitoring piezometers were installed and where a regular water level and water-quality monitoring programme was undertaken. Where possible, sampling pizometers were installed at 10 m intervals down to 50 m and sampled every two-week for up to 12 months.

A village survey was undertaken in the mouza of Mandari in Lakshmiur sadar Upazila. This was known to be in a high arsenic region of Bangladesh. The wells sampled were selected randomly. Mandari consists of a number of para or family settlements spread fairly uniformly over an area of approximately 6 km2. The population of Mandari is thought to be about 2500. The aim of this survey was to examine the variation of arsenic at the village scale, the scale at which the actual compliance testing would have to take place.

2.3.4 Scale of the groundwater arsenic problem

Arsenic concentrations ranged from less than 0.25 μg/l to more than 1600 μg/l. The high arsenic region in the south and east of Bangladesh. The DPHE/BGS survey showed that 25% of all the tubewells sampled contain in excess of 50μg/l arsenic, the Bangladesh drinking water standard. In addition, 9% of the tubewells exceeded 200μg/l, 1.8% exceeded 500μg/l and 0.1% exceeded 1000μg/l. Few shallow groundwater from the south of the country were 'arsenic free' (i.e. contained less than 3μg/l).

On the other hand, 24% of samples fell below the instrumental detection limit for arsenic, normally 0.25 or 0.5 μg/l. The minimum arsenic concentration is likely to be in the mg/l range. Concentrations of less than 1μg/l are common in northern Bangladesh. They are also typical of the deep aquifer and the water derived from aquifers in the older sediments of the Madhupur and Barind tracts.

The median arsenic concentration found in all of the tubewells sampled was 4μg/l and the maximum concentration found was 1670μg/l. The mean concentration was about 55μg/l. This value depends to some extent on the concentration of arsenic assumed in the large number of wells containing less than the detection limit. The concentration of arsenic in these less than detection limit samples were assumed for statistical purposes to be half the detection limit.

There were important differences between 'shallow' wells and 'deep' wells (defined here as greater than or equal to 150 m depth), as well as between samples from recent alluvium and older alluvium. Arsenic contamination was essentially confined to ground waters from the sallow aquifer.

Of the wells sampled in the DPHE/BGS National Hydrochemical Survey, 9% were 'deep'. Most of these deep wells were either from the southern coastal belt or from the sylhet area. There are very few deep wells in the rest of the country. Of the shallow tubewells, 27% contained in excess of 50μg/l and 46% in excess of the WHO guideline value for arsenic. Only 3 out of the 327 deep well samples exceeded 50μg/l and 16 exceeded 10μg/l. Eight of the 61 sampled districts had no samples exceeding the Bangladesh standard for arsenic (50μg/l) and all districts except Thakurgaon had at least one well exceeding the WHO guideline value for arsenic.

The worst affected ddistricts were (percentage of sampled wells with greater than 50μg/l in parentheses): Chandpur (90%), Munshiganj (83%), Goopalganj (79%), Madaripur (69%), Satkhira (67%), Comilla (65%), Faridur (65%), Meherpur (60%), Bagerhat (60%) and Lakshmipur (56%). Percentages are the percentage of all wells sampled.

The least-affected districts were: Thakurgaon, Barguna, Jaipurhat, :a;monirhata, Natore, Ni;phamari, Panchagarh, Patuakhali (all 0%), Rangpur (1%), Dinajpur (2%), Naogaon (2%), Gaazipur (2%), Cox's Bazar (2%), Bhola (4%), Nawabganj (4%), Jhalakathi (6%), Rajshahi (6%), Gaibandha (7%), Tangail (9%) and Kurigram (9%).

The District-wise average arsenic concentration varies from 1μg/l in Thakurgaon to 366μg/l in Chandpur. This reflects a very large difference in the average arsenic dose likely to be taken in from drinking water by the people of thee two districts.

2.3.5 Causes of the arsenic contamination

In order to understand the development of high-arsenic groundwater in Bangladesh, we have to rely on our scientific knowledge of the likely process involved, the inferred past history of the aquifers and the present-day evolution of groundwater quality in comparable environments. There is as yet no consensus amongst scientists about the precise cause of the arsenic problem in Bangladesh but below we indicate what we believe to be a plausible scenario that is consistent with most of the known facts. There is still a great deal of uncertainty about the timescale over which the events may have occurred.

- ☐ Everything points to the arsenic being of natural origin although it is not yet possible to exclude the possibility that modern agricultural practices will have no influence on the groundwater for many years, certainly since before the recent extensive abstraction of groundwater.

- ☐ Both the arsenic content of Bangladesh sediments (0.4-10 mg/kg) and their mineralogy are typical of young alluvial and deltaic sediments that contain a wide variety of minerals reflecting their diverse source rocks. There is no need to speculate on a unique geological source of high arsenic rocks somewhere upstream of Bangladesh. However, certain types of sedimentological processes have probably been more important in concentrating arsenic in some parts of the delta system than in others. In particular, colloidal-sized iron oxides with their strongly sorbed arsenic and platey, easily suspended, micaceous minerals appear to have been concentrated in the lower part of the delta.

- ☐ Even 'ordinary' sediments such as these contain sufficient arsenic to give rise to the groundwater arsenic problem observed because of the very low drinking-water guideline value for arsenic and the high solid/solution ratios found in aquifers.

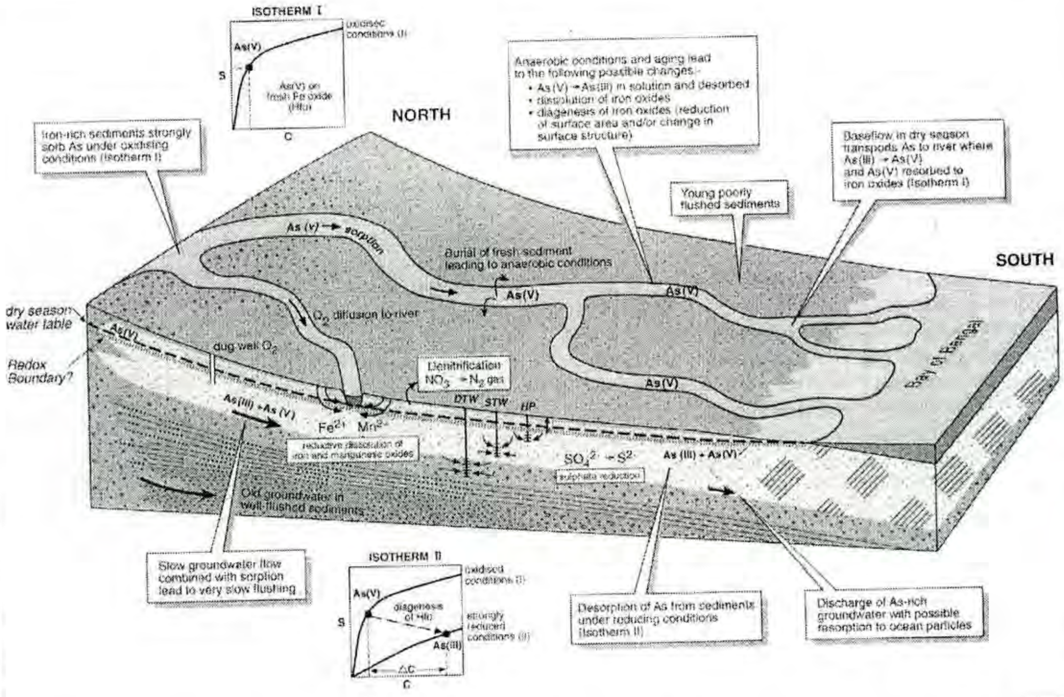


Figure 2.3 : - Arsenic groundwater in Bengal Basin (Source: BGS & DPHE Hydrochemical Survey Report, Vol. 1)

- The development of strongly reducing conditions is believed to the trigger that has been responsible for the release of naturally-occurring arsenic from the sediment into the groundwater. This arises from the rapid consumption of dissolved oxygen by the oxidation of fresh organic matter in the recently-buried sediments. Once strongly reducing conditions are achieved, arsenic is released from the sediments. The mechanism for this release is poorly understood quantitatively but is believed to involve the desorption from, and dissolution of, arsenic from various oxides, especially iron oxides.

- This reaction is probably rapid and is essentially a digenetic response of the sediments to change from an oxidizing environment to a reducing environment following burial. Possible changes of significance are a reduction in surface area of the iron oxides following their partial recrystallisation and a change in their surface chemistry as a result of the formation of mixed-oxidation state surface. These changes, as well as the reduction of the strongly sorbed As(V) to the less strongly sorbed As(III), could lead to the release of arsenic from the sediments.

Geochemical modeling has confirmed that such changes could account for the high arsenic concentrations observed in Bangladesh groundwater. Phosphate is believed to be released by the same desorption and dissolution mechanisms.

☐ The release of arsenic has also frequently been observed in recently-buried and reducing freshwater and marine sediments, and in flooded soils from many parts of the world. This release is magnified by a number of factors in Bangladesh, especially the large size of the delta and the unusually large depth of recently deposited sediments, i.e. sediments deposited over the last few thousand years.

☐ The flow of water in the aquifer is also important since this is the normal natural mechanism for flushing away the arsenic so released. The large flat delta region of Bangladesh leads to extremely low hydraulic gradients and correspondingly low rates of flushing of the aquifer. This means that the arsenic released will accumulate, as observed. Where groundwater flushing is more active, as in parts of northern Bangladesh, or has existed for longer periods as in the deep aquifer, then arsenic concentrations are lower. It is likely that the high concentrations of arsenic found in Bangladesh groundwater will eventually disappear as fresh groundwater flushes through the aquifer, albeit very slowly. The rate of groundwater flow is poorly understood at present but this flushing will probably take thousands or tens of thousands of years. Significant falls in sea level have occurred in the recent past which will have greatly accelerated the flushing of the deeper aquifer. Such changes could occur again if the earth goes through another ice age.

☐ The concept that the present groundwater arsenic problem results from a relatively rapid change in response to recent burial, and that the desorption of arsenic from oxides is an important part of this process, is encouraging in the sense that once the initial release of arsenic has been flushed away, it should not continue to be released unless conditions once again change for the worse, e.g. become even more reducing. This is generally unlikely in the deep aquifer but could occur in those parts of the shallow aquifer that are not yet very strongly reducing. For example, certain changes at the land surface could lead to a reduced rate of diffusing of oxygen to the underlying aquifer. The establishment of more extensive flooding and the pudding of soils associated with paddy fields are the most obvious mechanisms for achieving this. However, the redox buffering by the large volume of sediments involved is large and so any such changes are likely to be slow.

☐ Therefore we believe that the deep aquifers which are currently predominantly arsenic-free in Bangladesh are likely to remain so, at least under natural flow conditions. However, we stress that this is only an initial observation based on limited evidence and that the precautionary principle suggests that this should not be relied on until more solid evidence is established in its favor. In particular, more detailed studies are required on the influence of pumping in both the shallow and deep aquifer to see how this might change the situation. There is conflicting anecdotal evidence on this at present. The connectivity of the shallow and deep aquifers is an important factor.

☐ The careful monitoring of water quality in the aquifers at different depths and over various timescales is essential. A better understanding of the ages of the sediments and groundwater and of the regional distribution of aquifers and aquicludes would also be very useful.

2.3.6 Sources of the arsenic

There is no doubt that the source of the As is natural, i.e. derived from 'ordinary sediments by natural geochemical processes. The quantity of As present in groundwater is simply too large to be derived from a discrete pollution source. There is also no need to postulate exceptional sources such as a particular mineralized area in the upstream catchments, as some workers have done for neighboring West Bengal, although of course such areas may exist. This is one of the lessons that need to be learned from the Bangladesh arsenic problem.

There is more than enough arsenic in most sediments to give rise to an As problem given the appropriate geochemical conditions for release and mobilization. If all of the arsenic in a sediment containing 1 mg As/kg sediment dissolves in the groundwater, then the arsenic concentration in the groundwater would be 6000 μg/l or more, way above all drinking-water standards. Both the average world and typical Bangladesh sediments contain several times this amount of arsenic. In other words, Bangladesh sediments do not appear to contain an exceptional amount of arsenic in total yet give rise to exceptionally large groundwater arsenic concentrations. The high solid/solution ratio in aquifers and the great toxicity of arsenic mean that the contamination of groundwater is sensitive to an imperceptible shift in the speciation of arsenic. A change between sediment and water is sufficient to give rise to a significant groundwater arsenic problem.

This is not to say that all sediments are equally likely to give rise to a groundwater As problem, or that Bangladesh sediments do not have some properties that make them particularly strong candidate for such problems. The Greatest concentrations of As, along with the fine-grained materials and these could therefore be a potential source of As. Fine grained materials are found not only in fine-grained horizons, particularly clay horizons, but also to a lesser degree in the coarser, sandy horizons. It may be that the concentration of fine-grained iron oxides in the coarse sediments is one of the important factors controlling the development of the groundwater As problem in Bangladesh and elsewhere.

There is also often a good correlation between the iron content of the sediment and its arsenic content. While iron is found in both iron oxides and iron sulphides, the low sulphur content of most Bangladesh sediments indicates that the dominant source of iron in these sediments is the oxides not sulphides. The structure of the iron oxides, the location of As on or within the oxides, and the binding strength for the surface-bound As are also important, i.e. the liability of the As.

Somewhat confusingly, there is not necessarily a direct relationship between the As content of various sediments and the As concentrations in groundwater in contact with such sediments – there may be other controlling factors. The mere presence of a good correlation between iron oxides and arsenic is also not by itself sufficient to indicate that the oxides are the dominant source of arsenic – the reverse could equality be argued, i.e. it could be that they are a sink. In practice, iron oxides buffer the arsenic concentration in the sediment pore waters and are both sources and sinks of As – they can both adsorb As and release it depending on the solution concentration and the surface loading with As as given by the sorption isotherm.

The concentration of iron in groundwater, and hence the extent of reductive dissolution, is also not necessarily directly related to the iron oxide content of the sediments.

Other facto such as the supply of reductants, the extent of microbial activity and the concentrations of other solutes are also important. The argument for oxides being a source term becomes stronger if diagenetic changes to the oxide structure are important since this provides a direct relationship between the amount of iron oxide in sediment and the amount of arsenic released into the sediment pore water. These factors are not well understood.

It is not yet clear whether the arsenic presently abstracted in groundwater has moved form an area of fine-grained high-As sediments or whether it has been derived directly from the screened sandy horizons. Insufficient is known about the movement of As between the various horizons in Bangladesh aquifers to answer this point. We suspect that in some cases there has been movement, particularly close to the surface, but that this is not necessarily generally so. The fine-grained horizons will tend to be naturally protected from rapid leaching by their low permeability. Diffusion processes will be important over the longer term.

The natural process of chromatograplhic separation during groundwater flow means that the various products of geochemical reactions will become spatially separated with time. This 'uncorrelated' the chemistry and obscures the nature of the release mechanisms involved, thereby greatly complicating simple interpretations of groundwater-quality variations.

Once released from the sediment, the arsenic will be slowly flushed away ultimately emerging in a river or to emerge from the sea-bed in the Bay of Bengal. The extremely low relief in Bangladesh leads to very slow rates of groundwater movement, especially at depth which means that this flushing will take thousands of years to take place – this is not long on the geological timescale, many aquifers in the world consist of sediments that are millions of years old. Limited evidence from groundwater 'dating' techniques confirms the relatively old age of the deeper groundwater, especially in south-east Bangladesh, and hydro geological calculations suggest that it could take several thousand years for the shallow aquifer to be flushed once. It will probably take many pore volumes of fresh water to pass through the aquifer before the as is completely flushed out – this depends on the nature of the As sorption isotherms which are presently largely unknown. The rate of flushing during the last glacial period would have been much faster than at present and may account in part for the very low As concentrations found in older sediments.

Minerals

Major arsenic minerals

Arsenic occurs as a maor constituents in more than 200 minerals, including elemental arsenic, arsenides, sulphides, oxides, arsenates and arsenites. A list of some of the most common As minierals is given in Table2.1. Most are ore minerals and their alteration products. The greatest concentrations of these minerals therefore occur I mineralized areas and are commonly found in close association with the transition metals as well as Cd, Pb, Ag, Au, Sb, P, W and Mo. The most widespread As ore mineral is arseopyrite, FeAsS. It is generally assumed that arsenopyrite, together with the other dominant As-sulphide minerals realgar and orpiment, are only formed under high temperature conditions in the earth's crust, although there is currently some debate about whether arsenopyrite can form at low temperatures as an authigenic mineral.

Rock-forming minerals

Though not a major component, arsenic is also often present in varying concentrations in other common rock forming minerals. As the chemistry of arsenic follows closely that of sulphur, the greatest concentrations of the element tend to occur in sulphide minerals, of which pyrite is the most abundant. Concentrations in pyrite, chalcopyrite and galena can be very variable, even within a given grain, but in some cases reach up to several weight percent. Arsenian pyrite is a relatively common mineral especially in ore bodies and As concentrations up to almost 80,000 mg kg-1 have been reported. Arsenic is also present in the crystal structure of many sulphide minerals as a substitute for sulphur.

Pyrite is not stable in aerobic systems and oxidizes to iron oxides with the release of large amounts of sulphate and acidity as well as many atrace elements. The presence of pyrite as a minor constituent in sulphide-rich coals is ultimately responsible for the production of 'acid rain' and acid mine drainage (AMD), and for the presence of arsenic and other trace metal problems around coal mines and areas of intensive coal burning.

High As concentrations are also found in many oxide minerals and hydrous metal oxides, either as part of the Fe oxides can also reach weight percent values, particularly where they form as the oxidation products of primary iron sulphide minerals which have an abundant supply of arsenic.

Rocks, sediments and soils

Igneous rocks:

Arsenic concentrations are generally low in most igneous rocks. Ure and Berrow quoted an average value of 1.5 mg kg-1 for all rock types.

Sedimentary rocks:

The concentration of As in sedimentary rocks is atypically in the range 5-10 mg kg-1 i.e. slightly above average terrestrial abundance. Average sediments are enriched in As relative to igneous rocks.

Unconsolidated sediments: Concentrations of As in unconsolidated sediments are not notably different from those in their indurated equivalents, with muds and clays having typically higher concentrations than sands and carbonates. Values are typically 3-10 mg kg-1, depending on texture and mineralogy.

Soils:

Baseline concentrations of As in soils are of the order of 5-10 mg kg-1.

2.3.7 *Changes with time*

There are very few reliable data for the changes of as concentration with time. Changes can be expected at various scales from hourly to decades and longer. Some of these can be expected to be fluctuating; others will show systematic trends reflecting the various geochemical and hydro geological processes involved. The extent of these changes is expected to vary with location, including the depth of the well, and the depth to the water table and redox boundary and the location of highly contaminated zones. In general, the deeper the well, the smaller the likely variation with time. There is an urgent need for a long-term monitoring program to be set up and maintained in Bangladesh. This should examine all the timescales of variation since them all have important implications – both for field testing and for long-term water resources planning.

2.4 Other health-related water quality problems

Of the inorganic constituents considered in Bangladesh groundwater, arsenic represents by far the most serious health risk. However, potential problems also arise from a number of other constituents. Many groundwaters also contained high concentration of phosphorus. This phosphorus was probably in part derived from the same source as the arsenic and while the phosphorus-arsenic correlation was not good enough to provide a reliable prediction of the concentration of arsenic in a particular on a regional scale. The majority of the groundwater show characteristics that are typical of reducing groundwater, notably high iron, high manganese and low sulphate, concentrations. High iron concentrations were widespread but were particularly common in the groundwater from the Brahmaputra valley in northern Bangladesh. There was a poor overall correlation between arsenic concentrations, although locally significant positive correlations existed. Excessive salinity in the coastal regions and particularly high iron concentrations in other areas including northern Bangladesh are important factors restricting the potability of groundwater in Bangladesh. From our national survey, 23% of tubewell waters contained greater than 5µg/l iron and nearby 10% contained more than 10µg/l. Boron exceeded the revised WHO guideline value of 0.5µg/l in 5.3% of samples and 9.1% exceeded the former guideline value of 0.3µg/l. These high-boron samples are mostly found in the southern coastal region and in the low-lying region around Netrokona-Kishorganj. Boron is a residual component from seawater and high concentrations are usually associated with relatively high salinities.

From the DPHE/BGS National Hydrochemical Survey, 35% of samples exceeded the WHO guideline value (0.5mg/l) for manganese in drinking water, and some significantly so. Of the DPHE/BGS National Hydrochemical Survey samples, 8% exceeded both 50 mg/l arsenic and 0.5 mg/l manganese, while 48% of samples were below both the Bangladesh arsenic standard and the WHO guideline value for manganese. Wells in parts of western Bangladesh are relatively high in manganese but low in arsenic. The reverse is true in much of southern Bangladesh. Altogether, 36% or about one third of samples that was below the Bangladesh standard for arsenic exceeded the WHO manganese guideline value. Groundwater from the older sediments, the deep aquifer in the southern coastal region, and from the coarse-grained sediments of north-western Bangladesh tended to comply with the WHO guideline values for both arsenic and manganese. Only 2% of the deep wells sampled in the National survey exceeded 0.5 mg Mn/l.

Groundwater Availability

Physically groundwater is generally clear, colorless with little or no suspended solids and has a relatively constant temperature. Groundwater is also free from disease-producing micro-organisms which are normally present in large numbers in surface waters. The slow filtering action of fine-grained soil through which the surface water percolates to join the groundwater removes almost all suspended impurities. Moreover, the lack of oxygen and nutrients in groundwater makes it an unfavorable environment for disease-producing micro-organisms to survive, grow or multiply. On the other hand, being a universal solvent, water dissolves many of the minerals present in earth's crust during its slow travel through the ground.

In the context of high prevalence of diarrhoeal diseases in Bangladesh, groundwater received priority as a source of water supply because it is generally free from pathogenic micro-organisms. Almost all rural water supplies and most of urban water supplies are groundwater based. Groundwater collected by tubewells is fit for consumption. Groundwater abstracted from shallow aquifers by hand tubewells has received acceptance in rural areas for drinking purposes, but due to its high iron content, hardness, etc. people do not want to use hand tubewells water for other domestic purposes like cooking, bathing and washing.

Aquifer Characteristics

The available geological information and related studies have shown that two types of aquifers exist in Bangladesh. A shallow aquifer lies within 100m from the surface with an overlaying clay/silt blanket which is less than 2m thick in the northwest and generally increases southward to more than 50m. Other deep aquifers whose water development potential is not known occur at depths between 300 and 2500m. In majority of alluvial basins, the thickness of top clay and silt layers varies between 5 and 15m. In the extreme northwest this layer does not exist and silty to fine sand occurs at the surface, while in the Mashupur and Barind Tracts as well as in chittagong District, the thickness of this layer is greater than 35m.

Groundwater Situation

Groundwater in Bangladesh, except in some places, is available at a shallow depth. Groundwater levels are at or near ground level during the period August-October and lowest in April-May. Groundwater rises as a result of recharge during May and usually reaches its highest in late July in each year. Between July and October groundwater levels are constant and maintain a balance between surface water levels and the fully recharged aquifers. Groundwater levels fall from October in response to rapid drainage of surface water and changes in base levels. The rate of fall is highest in October-November but equally large changes may take place after January when withdrawal of groundwater for irrigation starts. During the season most of the minor rivers are sustained by groundwater outflows.

Problems

Groundwater is the main source of water supply in urban rural areas of Bangladesh. Groundwater in Bangladesh is available in adequate quantity, but the availability of groundwater for drinking purposes has become a problem for the following reasons:

- ☐ Arsenic in groundwater;
- ☐ Excessive dissolved iron;
- ☐ Salinity in the sallow aquifers in the coastal areas;
- ☐ Lowering of groundwater level;
- ☐ Rock/stony layers in hilly areas.

Among these problems arsenic groundwater has become great concern for water supply in Bangladesh.

Water Supply

Schemes for the collection of groundwater through hand pump tubewells for community water supplies in rural Bangladesh were taken up as early as 1928. In the context of very high prevalence of diarrheal diseases in Bangladesh, groundwater, being usually free from disease producing micro-organisms, received priority as a source of water for water supply.

Chapter – 3

Methodology & Analysis

CHAPTER 3: METHODOLOGY AND ANALYSIS

3.1 Methodology

Although arsenic is the most recently identified water quality problem, it is recognized that there are other water quality issues in Bangladesh. This includes microbial quality of mitigation options, toxins from cyanobacteria and a number of other chemicals including manganese, boron and iron. The Government of Bangladesh is using the new WHO Guidelines for Drinking-Water Quality to improve risk assessment and risk management and has developed approaches for assessing the health risks associated with different mitigation options. It is expected that water safety plans will also be developed in Bangladesh. There needs to be further work in ensuring safe drinking water and in identifying appropriate responses to arsenic, including characterization of the deep aquifer.

3.2 Data Collection:

Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP) is the largest Government project on Arsenic Problem in Bangladesh. At January 2004 they have decided to do survey work on Water Quality Parameters along with Arsenic at selected Arsenic affected areas of Bangladesh and started their survey along with GPS on the basis of '**Protocol for Water Quality Testing & Monitoring of Drinking Water Supply Systems**'.

Collection and preservation of samples;

- ☐ The sample was colleted in glass or High Density Polyethylene (HDPE) bottle and store at low temperature (40-100 ^{o}C) in a dark place.
- ☐ The well was pumped minimum for five minutes and its pH with the help of pH meter and recorded it in the sampling form.
- ☐ pH, colour, Odour, Temperature, Turbidity, Oxidation-Reduction Potential (ORP), TDS, Dissolved Oxygen (DO), Electric Conductivity (EC), Alkalinity (HCO_3^-) and Salinity of the well water were tested immediately after sampling and measured by HACH portable meter, as the value of these parameters will change during storage and transport.

- ☐ Quantity of sample for;
    - ➢ Arsenic & Iron is = 100ml sample
    - ➢ Chloride and others = 1000ml sample
    - ➢ Coliform bacteria = 500ml sample
    - ➢ Other metals = 100ml sample.

Quality control and data storage;

- ☐ Quality control of the laboratory analysis was conducted by taking 5% of the total number of samples as duplicate samples for analysis in two different labs.
- ☐ Results were entered in the NAMIC database.

The data of Haziganj Upazila collected from NAMIC database of the BAMWSP Project.

Other data (Bakerganj Upzila and Faridganj Upazila) collected from ITN Bangladesh under the ------Project.

3.3 Data Analysis:

Correlation

Correlation is a measure of the relation between two or more variables. The measurement scales used should be at least interval scales, but other correlation coefficients are available to handle other types of data. Correlation coefficients can range from -1.00 to +1.00. The value of -1.00 represents a perfect negative correlation while a value of +1.00 represents a perfect positive correlation. A value of 0.00 represents a lack of correlation.

Positive Correlation:

The relationship between two variables is such that as one variable's values tend to increase, the other variable's values also tend to increase. This is represented by a positive correlation coefficient.

Negative Correlation:

The relationship between two variables is such that as one variable's values tend to increase, the other variable's values tend to decrease. This is represented by a negative correlation coefficient.

Pearson Correlation:

The most widely-used type of correlation coefficient is Pearson r (Pearson, 1896), also called linear or product-moment correlation (the term correlation was first used by Galton, 1888). Using non technical language, one can say that the correlation coefficient determines the extent to which values of two variables are "proportional" to each other. The value of the correlation (i.e., correlation coefficient) does not depend on the specific measurement units used; for example, the correlation between height and weight will be identical regardless of whether inches and pounds, or centimeters and kilograms are used as measurement units. Proportional means linearly related; that is, the correlation is high if it can be approximated by a straight line (sloped upwards or downwards). This line is called the regression line or least squares line, because it is determined such that the sum of the squared distances of all the data points from the line is the lowest possible. Pearson correlation assumes that the two variables are measured on at least interval scales. The Pearson product moment correlation coefficient is calculated as follows:

$r_{12} = [\Sigma(Y_{i1} - \text{Y-bar}_1)*(Y_{i2} - \text{Y-bar}_2)] / [\Sigma(Y_{i1} - \text{Y-bar}_1)^2 * \Sigma(Y_{i2} - \text{Y-bar}_2)^2]^{1/2}$

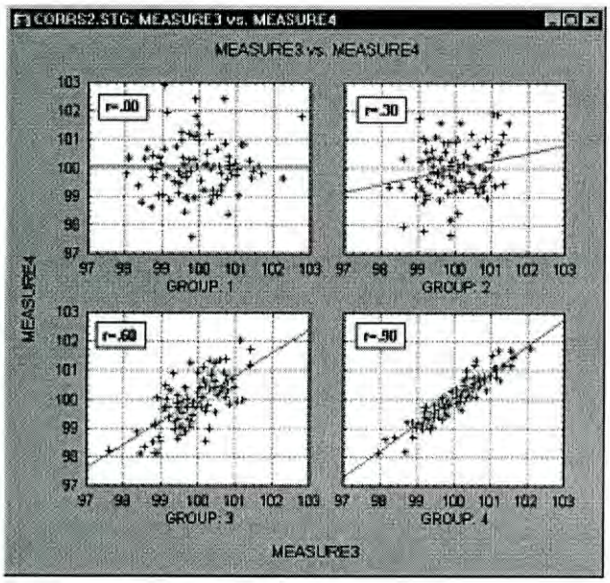
The correlation coefficient of a set of observations {(xi,yi): i=1,..,n} is given by the formula

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

Properties of the correlation coefficient, r:

- $-1 <= r <= +1$
- $|r| = 1$ if and only if the points lie exactly on a straight line.

- If the same constant is added to all of the Xs, the correlation coefficient is unchanged. Similarly for the Ys
- If all of the Xs are multiplied by a constant, the correlation coefficient is unchanged, except that the sign of the correlation coefficient is changed if the constant is negative. Similarly for the Ys.



r	**$1-\sqrt{(1-r2)}$**
0.5	0.13
0.7	0.29
0.8	0.40
0.9	0.56
0.99	0.86
0.999	0.96

Chapter – 4

Findings of the Study

CHAPTER 4: FINDINGS OF THE STUDY

4.1 Outcomes of the Study

Analysis of the data & subsequent summarization show that the values of the water quality parameters are different at different places. Moreover there are no variations of any water quality parameter with depth of the tubewell or aquifer. Also it seems that there are no significant Correlations among the Water Quality Parameters. Detail findings are as follows.

Haziganj Upazila:

Table 4.1:- Descriptive Statistics of Haziganj Upazila

	N	Minimum	Maximum	Mean	Std. Deviation
Depth (ft)	86	200	850	776.38	74.864
PH	85	6.35	7.40	6.8013	0.22264
Total Hardness as CaCO3 mg/l	86	90	900	350.15	207.272
Manganese mg/l	86	0.00	0.07	0.0192	0.01816
Iron mg/l	86	0.21	10.18	3.7873	2.89754
Chloride mg/l	86	16	1014	304.78	257.583
Phosphate mg/l	86	0.5	7.1	2.516	1.2134
Sulfate mg/l	86	10	103	19.58	21.793
Arsenic mg/l	86	0.01	0.47	0.0155	0.04960
Barium (mg/l)	86	0.1	2.1	0.769	0.4711
Nitrogen (Ammonia) mg/l	86	0.1	2.7	0.453	0.4920
Magnesium mg/l	86	14	171	65.41	39.580
Bi-Carbonate mg/l	86	95	840	186.50	83.597
TDS mg/l	86	2.0	1950.0	687.061	510.0504
Salinity %	86	0.1	2.3	0.727	0.5450
Conductivity	86	2.11	1944.00	666.2412	601.89490
Valid N (listwise)	85				

Table 4.2:- Correlations of Iron, Manganese and Arsenic with Depth (Haziganj):

		Depth (ft)	Iron mg/l	Manganese mg/l	Arsenic mg/l
Depth (ft)	Pearson Correlation	1	0.015	-0.086	0.028
	N	86	86	86	86
Iron mg/l	Pearson Correlation	0.015	1	0.658(**)	0.209
	N	86	86	86	86
Manganese mg/l	Pearson Correlation	-0.086	0.658(**)	1	-0.054
	N	86	86	86	86
Arsenic mg/l	Pearson Correlation	0.028	0.209	-0.054	1
	N	86	86	86	86

** Correlation is significant.

Table 4.3:- Nonparametric Correlations of Iron, Manganese and Arsenic with Depth (Haziganj):

			Depth (ft)	Iron mg/l	Manganese mg/l	Arsenic mg/l
Kendall's tau_b	**Depth (ft)**	Correlation Coefficient	1.000	0.055	-0.084	0.058
		N	86	86	86	86
	Iron mg/l	Correlation Coefficient	0.055	1.000	0.480(**)	0.134
		N	86	86	86	86
	Manganese mg/l	Correlation Coefficient	-0.084	0.480(**)	1.000	0.039
		N	86	86	86	86
	Arsenic mg/l	Correlation Coefficient	0.058	0.134	0.039	1.000
		N	86	86	86	86

** Correlation is significant.

Table 4.4:- Correlations of Salinity, pH, Iron and Sulfate with Depth (Haziganj):

		Depth (ft)	Salinity %	pH	Iron mg/l	Sulfate mg/l
Depth (ft)	Pearson Correlation	1	0.055	0.190	0.015	0.074
	N	86	86	85	86	86
Salinity %	Pearson Correlation	0.055	1	-0.401(**)	0.769(**)	0.657(**)
	N	86	86	85	86	86
pH	Pearson Correlation	0.190	-0.401(**)	1	-0.391(**)	-0.102
	N	85	85	85	85	85
Iron mg/l	Pearson Correlation	0.015	0.769(**)	-0.391(**)	1	0.483(**)
	N	86	86	85	86	86
Sulfate mg/l	Pearson Correlation	0.074	0.657(**)	-0.102	0.483(**)	1
	N	86	86	85	86	86

** Correlation is significant.

Table 4.5:- Correlations of Iron, Sulfate and Arsenic with Depth (Haziganj):

		Depth (ft)	Iron mg/l	Sulfate mg/l	Arsenic mg/l
Depth (ft)	Pearson Correlation	1	0.015	0.074	0.028
	N	86	86	86	86
Iron mg/l	Pearson Correlation	0.015	1	0.483(**)	0.209
	N	86	86	86	86
Sulfate mg/l	Pearson Correlation	0.074	0.483(**)	1	0.171
	N	86	86	86	86
Arsenic mg/l	Pearson Correlation	0.028	0.209	0.171	1
	N	86	86	86	86

** Correlation is significant.

Table 4.6:- Correlations between Chloride and Iron (Haziganj):

		Chloride mg/l	Iron mg/l
Chloride mg/l	Pearson Correlation	1	0.761(**)
	N	86	86
Iron mg/l	Pearson Correlation	0.761(**)	1
	N	86	86

** Correlation is significant.

Table 4.7:- Nonparametric Correlations between Chloride and Iron (Haziganj):

			Chloride mg/l	**Iron mg/l**
Kendall's tau_b	**Chloride mg/l**	Correlation Coefficient	1.000	0.547(**)
		N	86	86
	Iron mg/l	Correlation Coefficient	0.547(**)	1.000
		N	86	86

** Correlation is significant.

Table 4.8:- Correlations between different Water Quality Parameters (Haziganj):

		Chloride mg/l	**Iron mg/l**	**Manganese mg/l**	**Phosphate mg/l**	**Sulfate mg/l**	**Arsenic mg/l**	**Barium (mg/l)**
Chloride mg/l	Pearson Correlation	1	0.761(**)	0.671(**)	-0.061	0.646(**)	-0.043	0.389(**)
	N	86	86	86	86	86	86	86
Iron mg/l	Pearson Correlation	0.761(**)	1	0.658(**)	-0.009	0.483(**)	0.209(*)	0.449(**)
	N	86	86	86	86	86	86	86
Manganese mg/l	Pearson Correlation	0.671(**)	0.658(**)	1	0.181(*)	0.329(**)	-0.054	0.362(**)
	N	86	86	86	86	86	86	86
Phosphate mg/l	Pearson Correlation	-0.061	-0.009	0.181(*)	1	-0.076	-0.146	0.119
	N	86	86	86	86	86	86	86
Sulfate mg/l	Pearson Correlation	0.646(**)	0.483(**)	0.329(**)	-0.076	1	0.171	0.374(**)
	N	86	86	86	86	86	86	86
Arsenic mg/l	Pearson Correlation	-0.043	0.209(*)	-0.054	-0.146	0.171	1	0.132
	N	86	86	86	86	86	86	86
Barium (mg/l)	Pearson Correlation	0.389(**)	0.449(**)	0.362(**)	0.119	0.374(**)	0.132	1
	N	86	86	86	86	86	86	86

** Correlation is significant.

* Correlation is significant.

Table 4.9:- Correlations between Iron and Sulfate (Haziganj):

		Iron mg/l	Sulfate mg/l
Iron mg/l	Pearson Correlation	1	0.483(**)
	N	86	86
Sulfate mg/l	Pearson Correlation	0.483(**)	1
	N	86	86

** Correlation is significant.

Table 4.10:- Nonparametric Correlations between Iron and Sulfate (Haziganj):

			Iron mg/l	Sulfate mg/l
Kendall's tau_b	**Iron mg/l**	Correlation Coefficient	1.000	0.401(**)
		N	86	86
	Sulfate mg/l	Correlation Coefficient	0.401(**)	1.000
		N	86	86

** Correlation is significant.

Table 4.11:- Correlations between Iron and Phosphate (Haziganj):

		Iron mg/l	Phosphate mg/l
Iron mg/l	Pearson Correlation	1	-0.009
	N	86	86
Phosphate mg/l	Pearson Correlation	-0.009	1
	N	86	86

Table 4.12:- Nonparametric Correlations between Iron and Phosphate (Haziganj):

			Iron mg/l	**Phosphate mg/l**
Kendall's tau_b	**Iron mg/l**	Correlation Coefficient	1.000	0.042
		N	86	86
	Phosphate mg/l	Correlation Coefficient	0.042	1.000
		N	86	86

Table 4.13:- Correlations between Phosphate and Arsenic (Haziganj):

		Phosphate mg/l	**Arsenic mg/l**
Phosphate mg/l	Pearson Correlation	1	-0.146
	N	86	86
Arsenic mg/l	Pearson Correlation	-0.146	1
	N	86	86

Table 4.14:- Nonparametric Correlations between Phosphate and Arsenic (Haziganj):

			Phosphate mg/l	**Arsenic mg/l**
Kendall's tau_b	**Phosphate mg/l**	Correlation Coefficient	1.000	-0.099
		N	86	86
	Arsenic mg/l	Correlation Coefficient	-0.099	1.000
		N	86	86

Table 4.15:- Correlations between Arsenic and Sulfate (Haziganj):

		Arsenic mg/l	**Sulfate mg/l**
Arsenic mg/l	Pearson Correlation	1	0.171
	N	86	86
Sulfate mg/l	Pearson Correlation	0.171	1
	N	86	86

Table 4.16:- Nonparametric Correlations between Arsenic and Sulfate (Haziganj):

			Arsenic mg/l	**Sulfate mg/l**
Kendall's tau_b	**Arsenic mg/l**	Correlation Coefficient	1.000	0.095
		N	86	86
	Sulfate mg/l	Correlation Coefficient	0.095	1.000
		N	86	86

Table 4.17:- Correlations of Arsenic and Iron with Depth (Haziganj):

		Arsenic mg/l	**Iron mg/l**	**Depth (ft)**
Arsenic mg/l	Pearson Correlation	1	0.209	0.028
	N	86	86	86
Iron mg/l	Pearson Correlation	0.209	1	0.015
	N	86	86	86
Depth (ft)	Pearson Correlation	0.028	0.015	1
	N	86	86	86

Table 4.18:- Nonparametric Correlations of Arsenic and Iron with Depth (Haziganj):

			Arsenic mg/l	**Iron mg/l**	**Depth (ft)**
Kendall's tau_b	**Arsenic mg/l**	Correlation Coefficient	1.000	0.134	0.058
		N	86	86	86
	Iron mg/l	Correlation Coefficient	0.134	1.000	0.055
		N	86	86	86
	Depth (ft)	Correlation Coefficient	0.058	0.055	1.000
		N	86	86	86

Table 4.19:- Correlations between Barium and Iron (Haziganj):

		Barium (mg/l)	**Iron mg/l**
Barium (mg/l)	Pearson Correlation	1	0.449(**)
	N	86	86
Iron mg/l	Pearson Correlation	0.449(**)	1
	N	86	86

** Correlation is significant.

Table 4.20:- Nonparametric Correlations between Barium and Iron (Haziganj):

			Barium (mg/l)	**Iron mg/l**
Kendall's tau_b	**Barium (mg/l)**	Correlation Coefficient	1.000	0.272(**)
		N	86	86
	Iron mg/l	Correlation Coefficient	0.272(**)	1.000
		N	86	86

** Correlation is significant.

Vandaria Upazila:

Table 4.21:- Descriptive Statistics of the Data of Vandaria Upazila (Vandaria):

	N	Minimum	Maximum	Mean	Std. Deviation
Chloride mg/l	32	402.00	1636.00	904.0000	277.28150
Total Hardness as CaCO3 mg/l	32	83	413	173.88	68.439
Iron mg/l	32	0.14	2.25	.5888	0.55355
Calcium mg/l	32	16.00	57.00	32.1250	8.62760
Phosphate mg/l	32	0.39	1.85	0.7134	0.28122
Nitrogen (Ammonia) mg/l	32	0.03	0.81	0.5531	0.16824
Sulfate mg/l	32	0.00	33.30	3.1031	5.85912
Arsenic mg/l	32	0.000	0.004	0.00050	0.000950
Barium mg/l	32	0.30	1.60	0.7584	0.28947
Aluminium mg/l	32	0.008	1.100	0.09306	0.189983
Valid N (list wise)	32				

Table 4.22:- Correlations between Iron, Arsenic and Phosphate (Vandaria):

		Iron mg/l	Arsenic mg/l	Phosphate mg/l
Iron mg/l	Pearson Correlation	1	0.322	0.024
	N	32	32	32
Arsenic mg/l	Pearson Correlation	0.322	1	0.053
	N	32	32	32
Phosphate mg/l	Pearson Correlation	0.024	0.053	1
	N	32	32	32

Table 4.23:- Nonparametric Correlations between Iron, Arsenic and Phosphate (Vandaria):

			Iron mg/l	Arsenic mg/l	Phosphate mg/l
Kendall's tau_b	**Iron mg/l**	Correlation Coefficient	1.000	0.265	-0.168
		N	32	32	32
	Arsenic mg/l	Correlation Coefficient	0.265	1.000	0.138
		N	32	32	32
	Phosphate mg/l	Correlation Coefficient	-0.168	0.138	1.000
		N	32	32	32

Table 4.24:- Correlations between Arsenic, Total Hardness, Aluminium and Barium (Vandaria):

		Arsenic mg/l	Total Hardness as CaCO3 mg/l	Aluminium mg/l	Barium (mg/l)
Arsenic mg/l	Pearson Correlation	1	-0.037	0.709(**)	0.168
	N	32	32	32	32
Total Hardness as CaCO3 mg/l	Pearson Correlation	-0.037	1	-0.191	0.560(**)
	N	32	32	32	32
Aluminium mg/l	Pearson Correlation	0.709(**)	-0.191	1	-0.203
	N	32	32	32	32
Barium (mg/l)	Pearson Correlation	0.168	0.560(**)	-0.203	1
	N	32	32	32	32

** Correlation is significant.

Table 4.25:- Nonparametric Correlations between Arsenic, Total Hardness, Aluminium and Barium (Vandaria):

			Arsenic mg/l	**Total Hardness as CaCO3 mg/l**	**Aluminium mg/l**	**Barium (mg/l)**
Kendall's tau_b	**Arsenic mg/l**	Correlation Coefficient	1.000	0.157	0.192	0.096
		N	32	32	32	32
	Total Hardness as CaCO3 mg/l	Correlation Coefficient	0.157	1.000	-0.342(*)	0.472(**)
		N	32	32	32	32
	Aluminium mg/l	Correlation Coefficient	0.192	-0.342(*)	1.000	-0.223
		N	32	32	32	32
	Barium (mg/l)	Correlation Coefficient	0.096	0.472(**)	-0.223	1.000
		N	32	32	32	32

* Correlation is significant.

** Correlation is significant.

ChapaiNawabganj Upazila:

Table 4.26:- Descriptive Statistics of the Data of ChapaiNawabganj Upazila (Chapai):

	N	Minimum	Maximum	Mean	Std. Deviation
Iron mg/l	25	0.19	21.70	3.4900	4.87400
Manganese mg/l	25	0.05	1.93	0.7664	0.34084
Phosphate mg/l	25	0.89	3.70	1.3756	0.59043
Nitrogen (Ammonia) mg/l	24	0.23	0.79	0.4258	0.17644
Arsenic mg/l	25	0.01	0.58	0.0808	0.14163
Total Hardness as CaCO3 mg/l	25	146	530	363.32	98.812
Chloride mg/l	25	2.10	82.90	25.6076	22.66670
Sulfate mg/l	25	0.45	36.40	6.7356	9.77024
Barium (mg/l)	25	0.35	1.56	0.8564	0.37171
Valid N (listwise)	24				

Table 4.27:- Correlations between Arsenic, Calcium, Potassium and Sodium (Chapai):

		Arsenic mg/l	Calcium mg/l	Potassium mg/l	Sodium mg/l
Arsenic mg/l	Pearson Correlation	1	0.147	-0.048	-0.328
	N	25	25	25	25
Calcium mg/l	Pearson Correlation	0.147	1	0.267	0.195
	N	25	25	25	25
Potassium mg/l	Pearson Correlation	-0.048	0.267	1	-0.024
	N	25	25	25	25
Sodium mg/l	Pearson Correlation	-0.328	0.195	-0.024	1
	N	25	25	25	25

Table 4.28:- Nonparametric Correlations between Arsenic, Calcium, Potassium and Sodium (Chapai):

			Arsenic mg/l	Calcium mg/l	Potassium mg/l	Sodium mg/l
Kendall's tau_b	Arsenic mg/l	Correlation Coefficient	1.000	0.125	0.374(*)	-0.537(**)
		N	25	25	25	25
	Calcium mg/l	Correlation Coefficient	0.125	1.000	0.272	0.013
		N	25	25	25	25
	Potassium mg/l	Correlation Coefficient	0.374(*)	0.272	1.000	-0.455(**)
		N	25	25	25	25
	Sodium mg/l	Correlation Coefficient	-0.537(**)	0.013	-0.455(**)	1.000
		N	25	25	25	25

* Correlation is significant

** Correlation is significant

Table 4.29:- Correlations between Iron, Arsenic, Phosphate and Nitrogen (Ammonia) (Chapai):

		Iron mg/l	**Arsenic mg/l**	**Phosphate mg/l**	**Nitrogen (Ammonia) mg/l**
Iron mg/l	Pearson Correlation	1	0.688(**)	0.103	0.141
	N	25	25	25	24
Arsenic mg/l	Pearson Correlation	0.688(**)	1	0.228	0.319
	N	25	25	25	24
Phosphate mg/l	Pearson Correlation	0.103	0.228	1	-0.084
	N	25	25	25	24
Nitrogen (Ammonia) mg/l	Pearson Correlation	0.141	0.319	-0.084	1
	N	24	24	24	24

** Correlation is significant.

Table 4.30:- Correlations between Iron, Arsenic, Phosphate and Nitrogen (Ammonia) (Chapai):

			Iron mg/l	Arsenic mg/l	Phosphate mg/l	Nitrogen (Ammonia) mg/l
Kendall's tau_b	**Iron mg/l**	Correlation Coefficient	1.000	0.589(**)	0.278	0.180
		N	25	25	25	24
	Arsenic mg/l	Correlation Coefficient	0.589(**)	1.000	0.453(**)	0.139
		N	25	25	25	24
	Phosphate mg/l	Correlation Coefficient	0.278	0.453(**)	1.000	0.007
		N	25	25	25	24
	Nitrogen (Ammonia) mg/l	Correlation Coefficient	0.180	0.139	0.007	1.000
		N	24	24	24	24

** Correlation is significant.

Table 4.31:- Correlations between Iron, Sulfate and Arsenic (Chapai):

		Iron mg/l	Sulfate mg/l	Arsenic mg/l
Iron mg/l	Pearson Correlation	1	-0.264	0.688(**)
	N	25	25	25
Sulfate mg/l	Pearson Correlation	-0.264	1	-0.266
	N	25	25	25
Arsenic mg/l	Pearson Correlation	0.688(**)	-0.266	1
	N	25	25	25

** Correlation is significant.

Table 4.32:- Nonparametric Correlations between Iron, Sulfate and Arsenic (Chapai):

			Iron mg/l	Sulfate mg/l	Arsenic mg/l
Kendall's tau_b	**Iron mg/l**	Correlation Coefficient	1.000	-0.341(*)	0.589(**)
		N	25	25	25
	Sulfate mg/l	Correlation Coefficient	-0.341(*)	1.000	-0.452(**)
		N	25	25	25
	Arsenic mg/l	Correlation Coefficient	0.589(**)	-0.452(**)	1.000
		N	25	25	25

* Correlation is significant.

** Correlation is significant.

Table 4.33:- Correlations between Iron and Chloride (Chapai):

		Iron mg/l	Chloride mg/l
Iron mg/l	Pearson Correlation	1	0.025
	N	25	25
Chloride mg/l	Pearson Correlation	0.025	1
	N	25	25

Table 4.34:- Nonparametric Correlations between Iron and Chloride (Chapai):

			Iron mg/l	Chloride mg/l
Kendall's tau_b	**Iron mg/l**	Correlation Coefficient	1.000	0.107
		N	25	25
	Chloride mg/l	Correlation Coefficient	0.107	1.000
		N	25	25

Table 4.35:- Correlations between Arsenic and Barium (Chapai):

		Arsenic mg/l	Barium (mg/l)
Arsenic mg/l	Pearson Correlation	1	0.316
	N	25	25
Barium (mg/l)	Pearson Correlation	0.316	1
	N	25	25

Table 4.36:- Nonparametric Correlations between Arsenic and Barium (Chapai):

			Arsenic mg/l	Barium (mg/l)
Kendall's tau_b	**Arsenic mg/l**	Correlation Coefficient	1.000	0.409(**)
		N	25	25
	Barium (mg/l)	Correlation Coefficient	0.409(**)	1.000
		N	25	25

** Correlation is significant.

Bakerganj Upazila:

Table 4.37:- Descriptive Statistics of the Data of Bakerganj Upazila

	N	Minimum	Maximum	Mean	Std. Deviation
Iron mg/l	6	0.05	0.15	0.0985	0.03569
Manganese mg/l	6	0.01	0.02	0.0162	0.00422
Phosphate mg/l	6	0.44	1.22	0.8917	0.33796
Nitrogen (Ammonia) mg/l	6	0.576	0.870	0.71600	0.131269
Arsenic mg/l	6	0.08	1.68	1.3150	0.61249
Valid N (list wise)	6				

Table 4.38:- Correlations between different Water Quality Parameters (Bakerganj):

		PH	Iron mg/l	Manganese mg/l	Phosphate mg/l	Nitrogen (Ammonia) mg/l	Arsenic mg/l	Barium mg/l
PH	Pearson Correlation	1	-0.077	0.523	-0.669	-0.642	-0.279	-0.516
	N	6	6	6	6	6	6	6
Iron mg/l	Pearson Correlation	-0.077	1	-0.254	-0.273	-0.081	-0.208	0.709
	N	6	6	6	6	6	6	6
Manganese mg/l	Pearson Correlation	0.523	-0.254	1	-0.589	-0.306	-0.413	-0.300
	N	6	6	6	6	6	6	6
Phosphate mg/l	Pearson Correlation	-0.669	-0.273	-0.589	1	0.886(*)	0.738	-0.112
	N	6	6	6	6	6	6	6
Nitrogen (Ammonia) mg/l	Pearson Correlation	-0.642	-0.081	-0.306	0.886(*)	1	0.601	-0.048
	N	6	6	6	6	6	6	6
Arsenic mg/l	Pearson Correlation	-0.279	-0.208	-0.413	0.738	0.601	1	-0.036
	N	6	6	6	6	6	6	6
Barium mg/l	Pearson Correlation	-0.516	0.709	-0.300	-0.112	-0.048	-0.036	1
	N	6	6	6	6	6	6	6

* Correlation is significant.

Faridganj Upazila:

Table 4.39:- Descriptive Statistics of the Data of Faridganj Upazila:

	N	Minimum	Maximum	Mean	Std. Deviation
Conductivity	6	360	480	405.00	41.833
TDS mg/l	6	240	320	270.00	27.892
Turbidity	6	0	1	0.33	0.516
PH	6	6.6	7.3	7.033	0.2582
Iron mg/l	6	0.5	1.5	1.000	0.4331
Manganese mg/l	6	0.005	0.033	0.01867	0.010967
Phosphate mg/l	6	0.15	0.49	0.2733	0.11877
Nitrogen (Ammonia) mg/l	6	0.07	0.41	0.2650	0.13853
Arsenic mg/l	6	0	0	0.06	0.151
Valid N (listwise)	6				

Table 4.40 :- Correlations between different Water Quality Parameters (Faridganj):

		PH	Iron mg/l	Manganese mg/l	Phosphate mg/l	Nitrogen (Ammonia) mg/l	Arsenic mg/l	Barium mg/l
PH	Pearson Correlation	1	-0.077	0.523	-0.669	-0.642	-0.279	-0.516
	N	6	6	6	6	6	6	6
Iron mg/l	Pearson Correlation	-0.077	1	-0.254	-0.273	-0.081	-0.208	0.709
	N	6	6	6	6	6	6	6
Manganese mg/l	Pearson Correlation	0.523	-0.254	1	-0.589	-0.306	-0.413	-0.300
	N	6	6	6	6	6	6	6
Phosphate mg/l	Pearson Correlation	-0.669	-0.273	-0.589	1	0.886(*)	0.738	-0.112
	N	6	6	6	6	6	6	6
Nitrogen (Ammonia) mg/l	Pearson Correlation	-0.642	-0.081	-0.306	0.886(*)	1	0.601	-0.048
	N	6	6	6	6	6	6	6
Arsenic mg/l	Pearson Correlation	-0.279	-0.208	-0.413	0.738	0.601	1	-0.036
	N	6	6	6	6	6	6	6
Barium mg/l	Pearson Correlation	-0.516	0.709	-0.300	-0.112	-0.048	-0.036	1
	N	6	6	6	6	6	6	6

* Correlation is significant.

The above correlations have been developed by analyzing in Pearson Method between different Water Quality Parameters like, Chloride, Iron, Manganese, Phosphate, Sulfate, Arsenic, Barium, pH, Nitrogen (Ammonia), etc. from the collected data of Arsenic affected area Haziganj, Vandaria, ChapaiNawabganj, Bakerganj and Faridganj. It is now seen from those that the correlations have been developed within the range of 0.3 to 0.8 between Phosphate-Ammonia, Chloride-Iron, Chloride-Manganese, Chloride-Sulfate, Chloride-Barium, Iron-Manganese, Iron-Sulfate, Iron-Barium, Sulfate-Manganese, Sulfate-Barium, Manganese-Barium, etc. Among those correlations, only Chloride with Iron, Manganese & Sulfate and Iron with Manganese and Ammonia with Phosphate have been developed within the range of 0.6-0.8. According to the definition of the correlation, if the value of the coefficient ranges from +1 to -1, it can be said that the correlation has been developed. But practically the correlation is not significant if the value is not within the range of +0.5 to -0.5. That is why in most of the cases the correlation is not significant where the value of the coefficient is with in the range of 0.3 and 0.5. We can have a clearer picture by analyzing the following graphs. Moreover there is no consistency of coefficient value between the same parameters of different places. On the contrary we can say that there is no significant correlation between the water quality parameters in the Arsenic affected area.

The above Co-relations among different water quality parameter have been developed by analyzing the Data in Pearson Method.

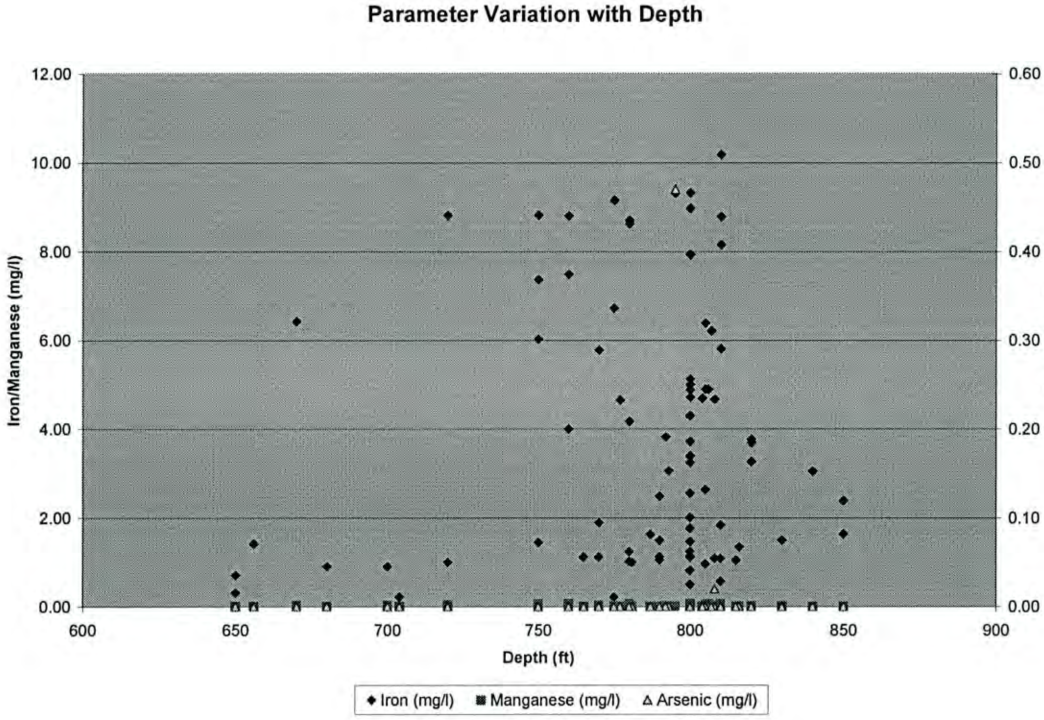


Figure 4.1 :- Parameter variation with Depth (Haziganj).

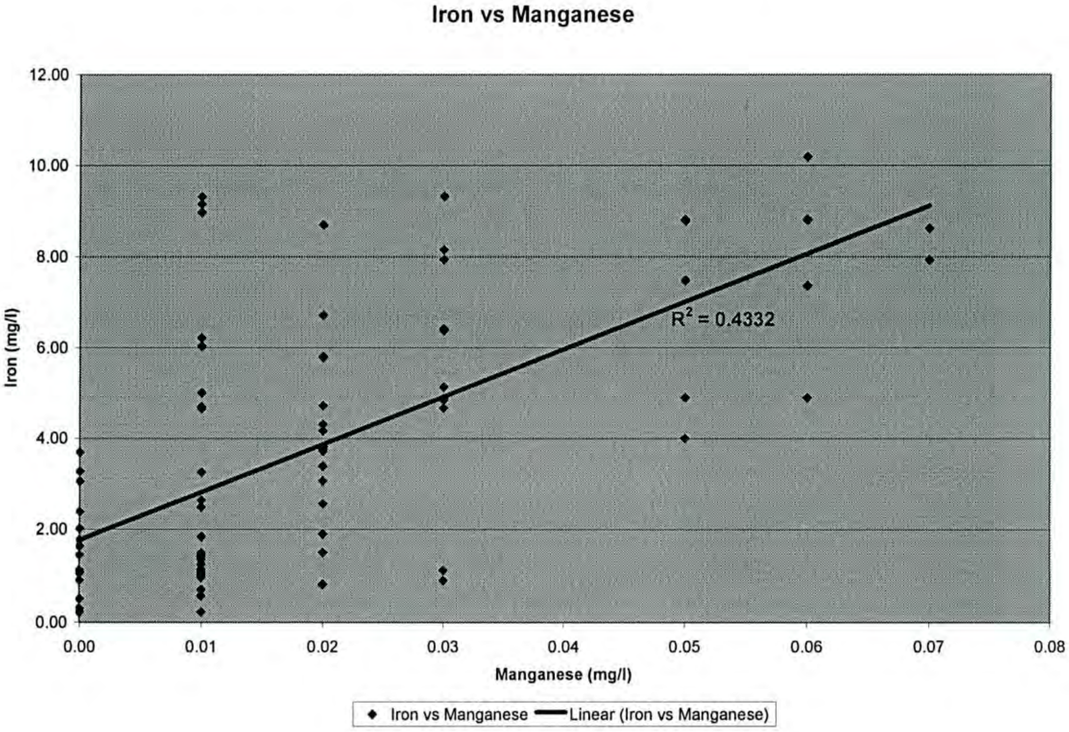


Figure 4.2 :- Iron Vs Manganese Curve (Haziganj).

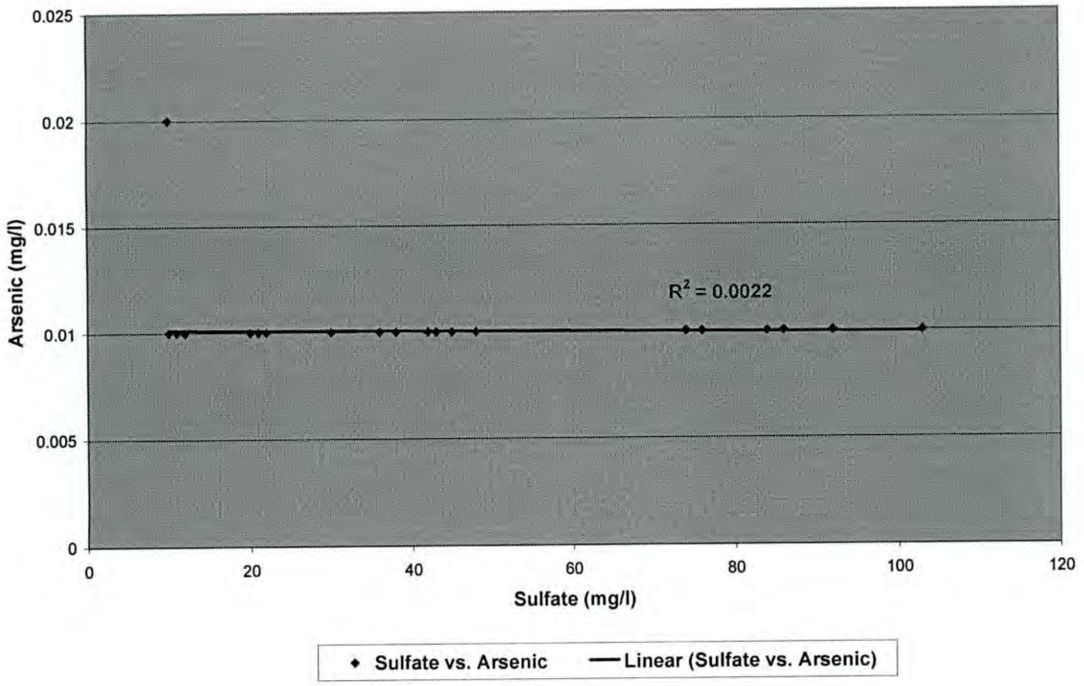


Figure 4.3 :- Sulfate Vs Arsenic Curve (Haziganj).

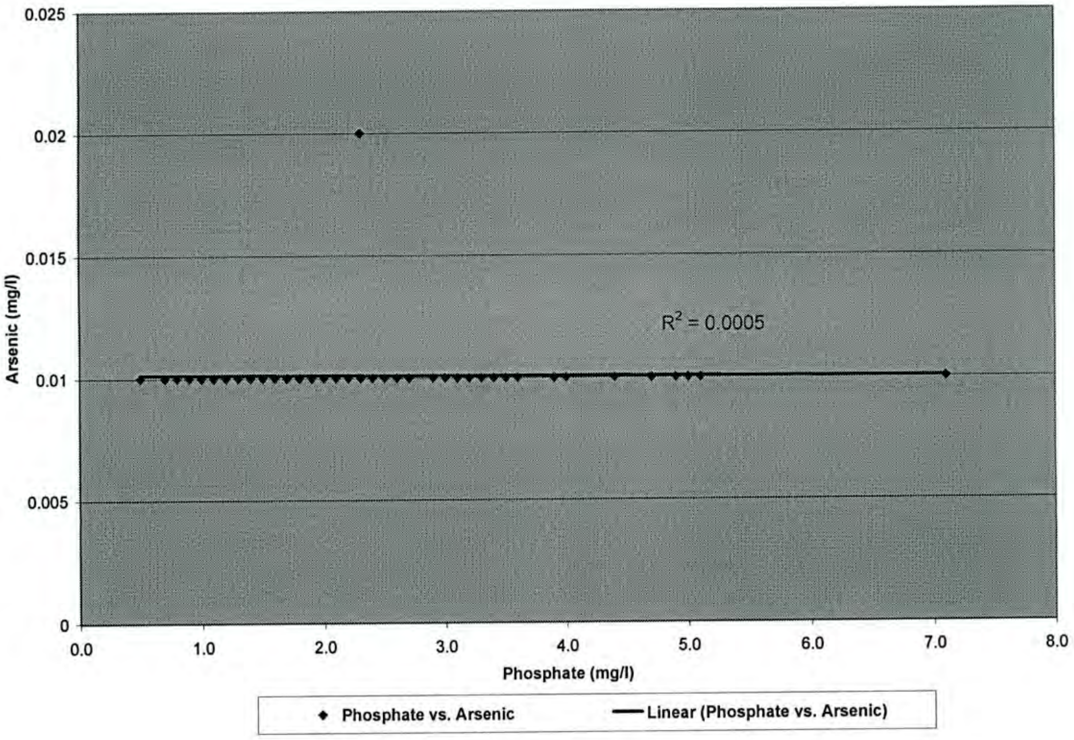


Figure 4.4 :- Phosphate Vs Arsenic Curve (Haziganj).

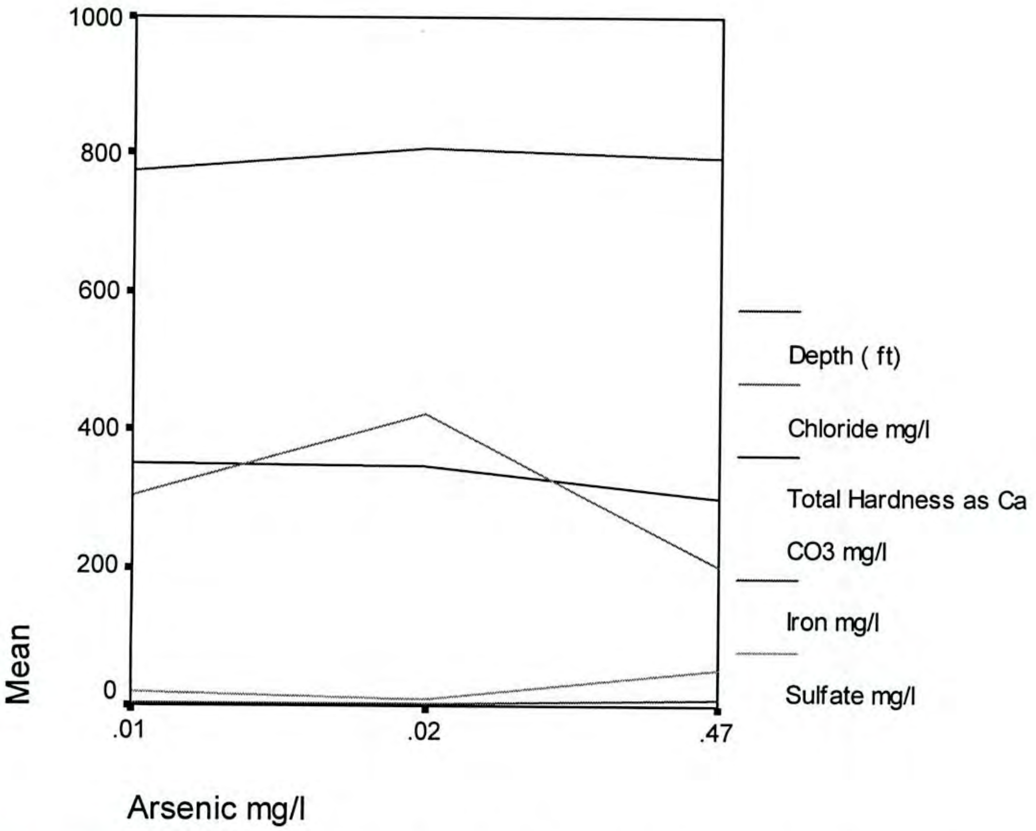


Figure 4.5 :- Relationship among different parameters with respect to arsenic (Haziganj).

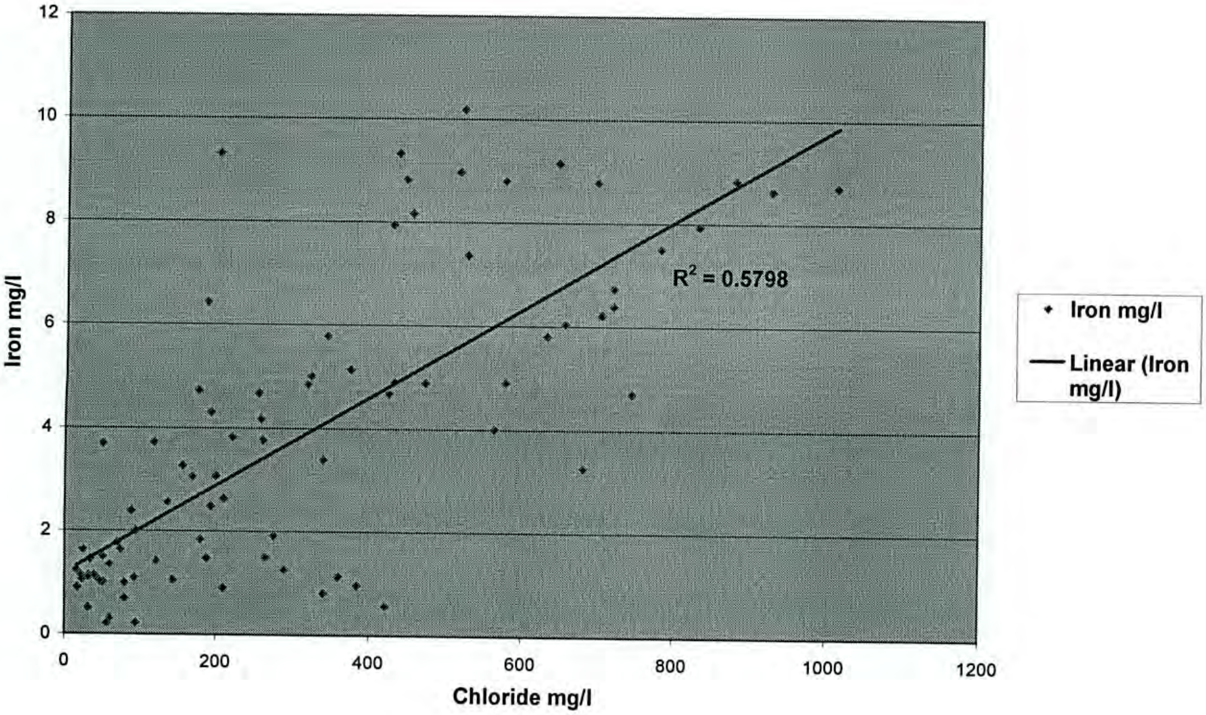


Figure 4.6 :- Iron Vs Chloride Curve (Haziganj).

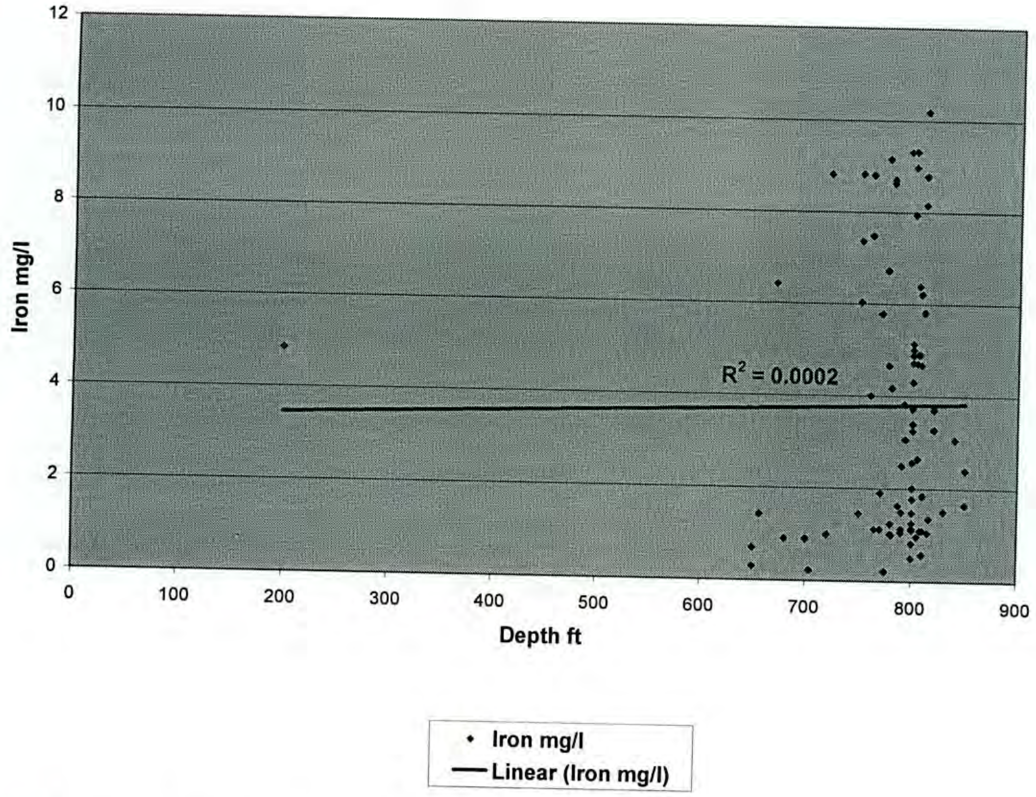


Figure 4.7 :- Iron Vs Depth Curve (Haziganj).

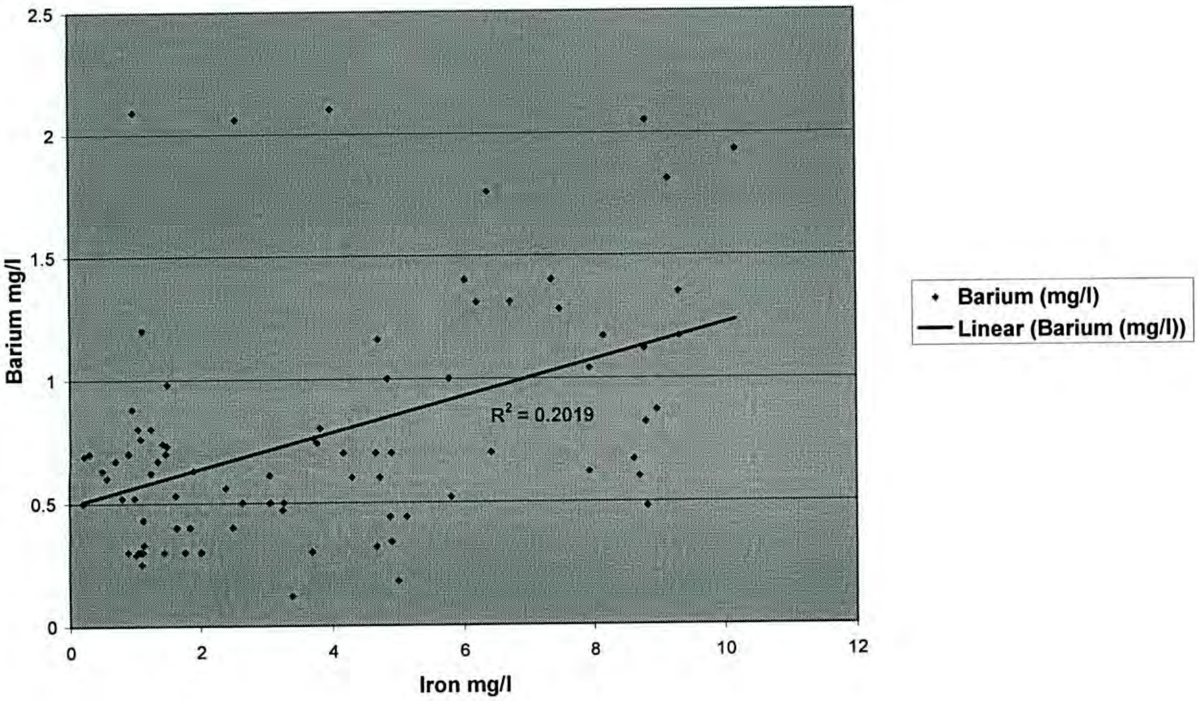


Figure 4.8 :- Iron Vs Barium Curve (Haziganj).

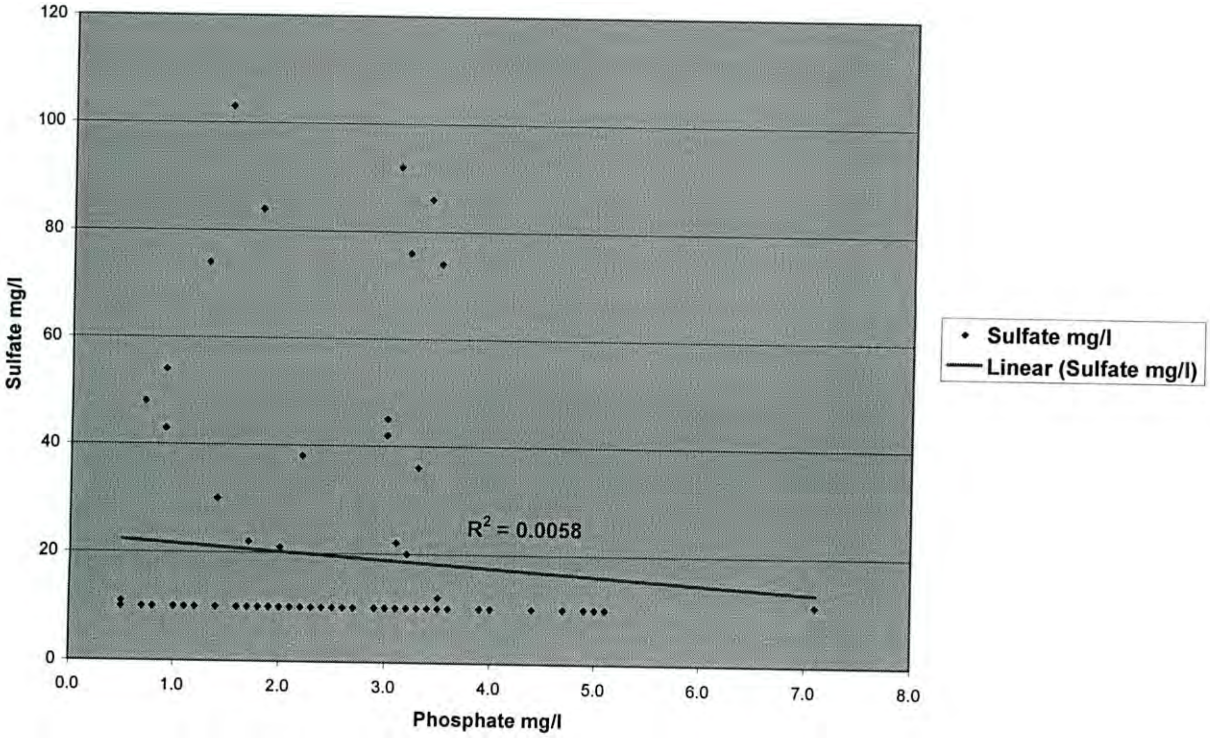


Figure 4.9 :- Sulfate Vs Phosphate Curve (Haziganj).

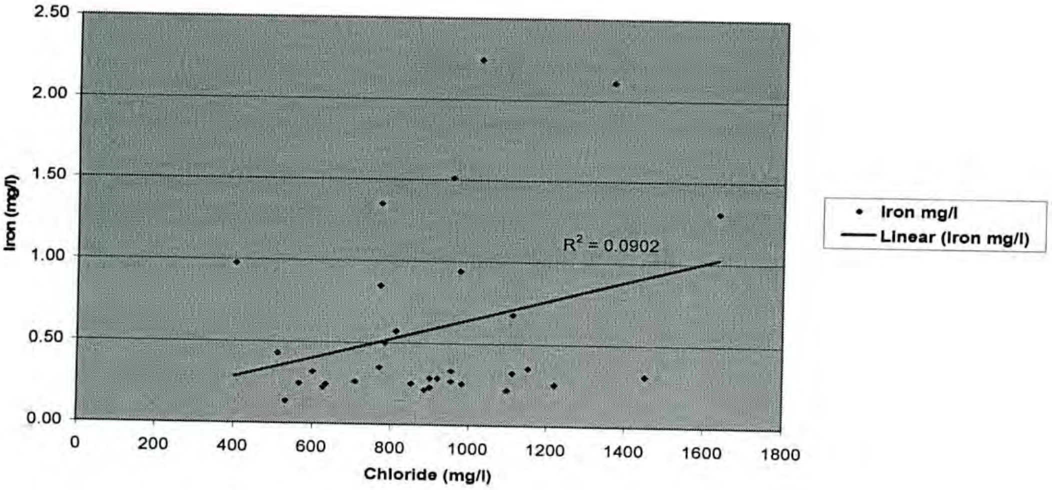


Figure 4.10 :- Iron Vs Chloride Curve (Vandaria).

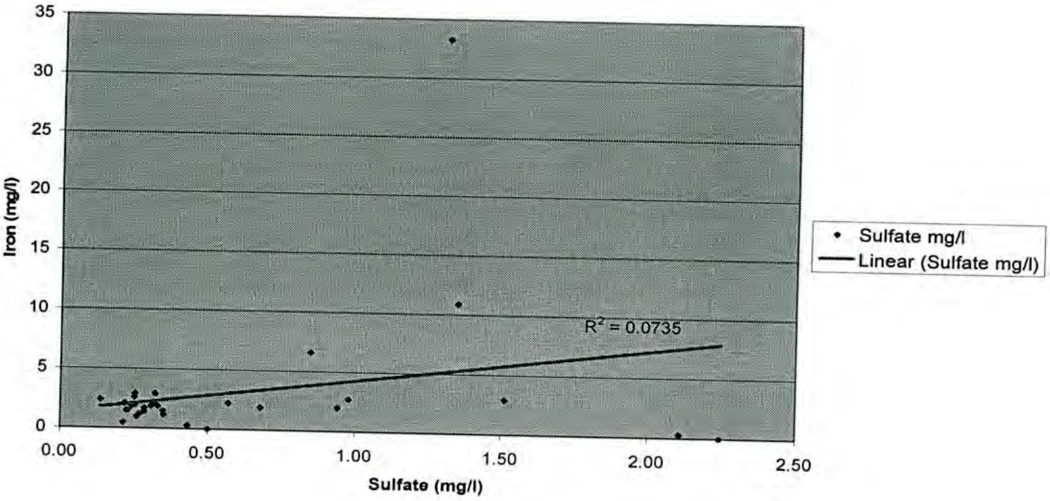


Figure 4.11 :- Iron Vs Sulfate Curve (Vandaria).

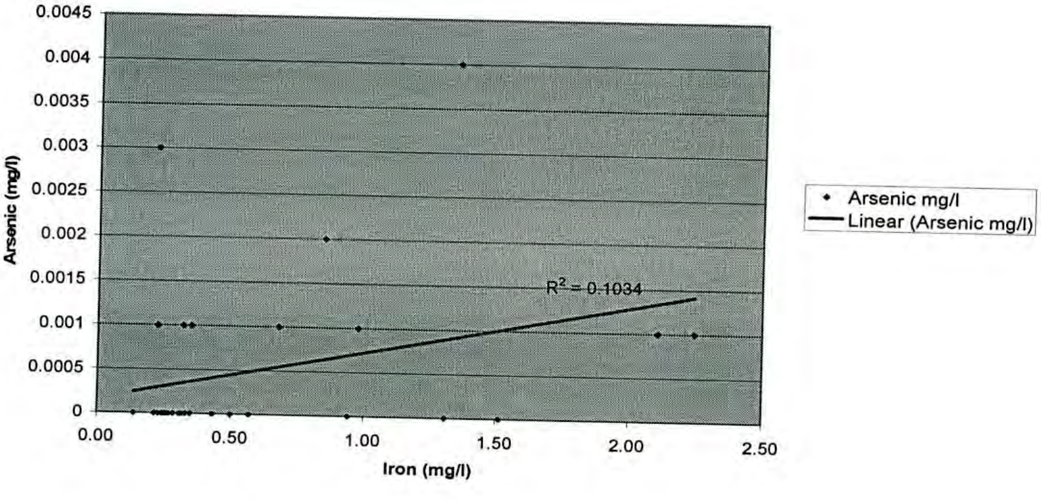


Figure 4.12 :- Arsenic Vs Iron Curve (Vandaria).

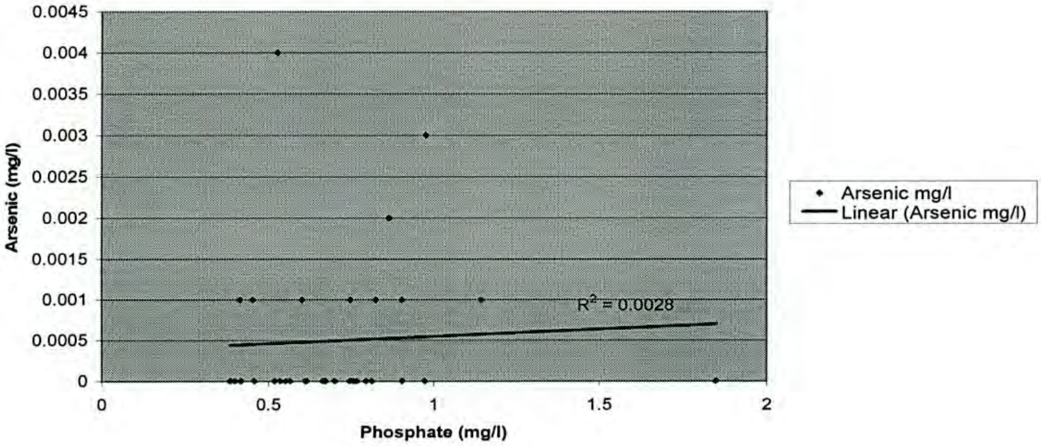


Figure 4.13 :- Arsenic Vs Phosphate Curve (Vandaria).

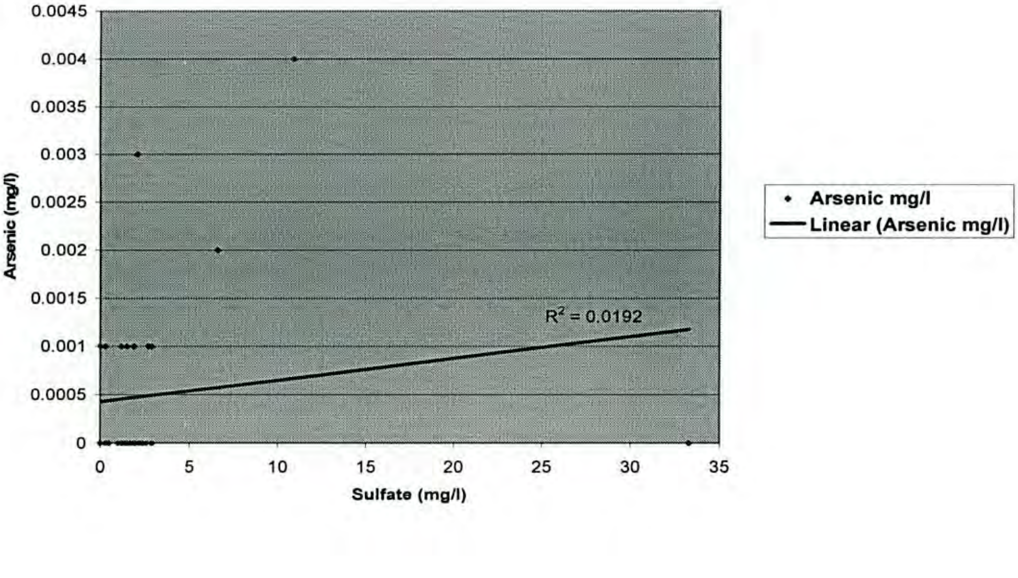


Figure 4.14 :- Arsenic Vs Sulfate Curve (Vandaria).

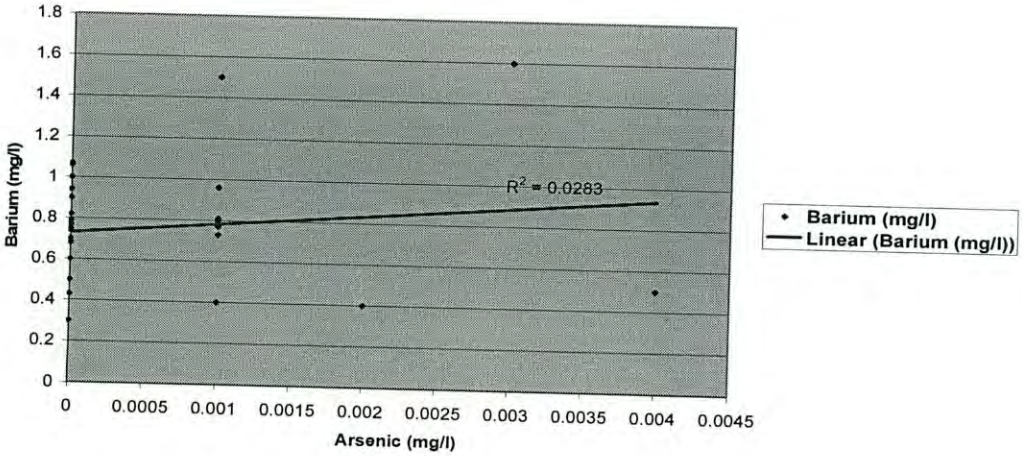


Figure 4.15 :- Arsenic Vs Barium Curve (Vandaria).

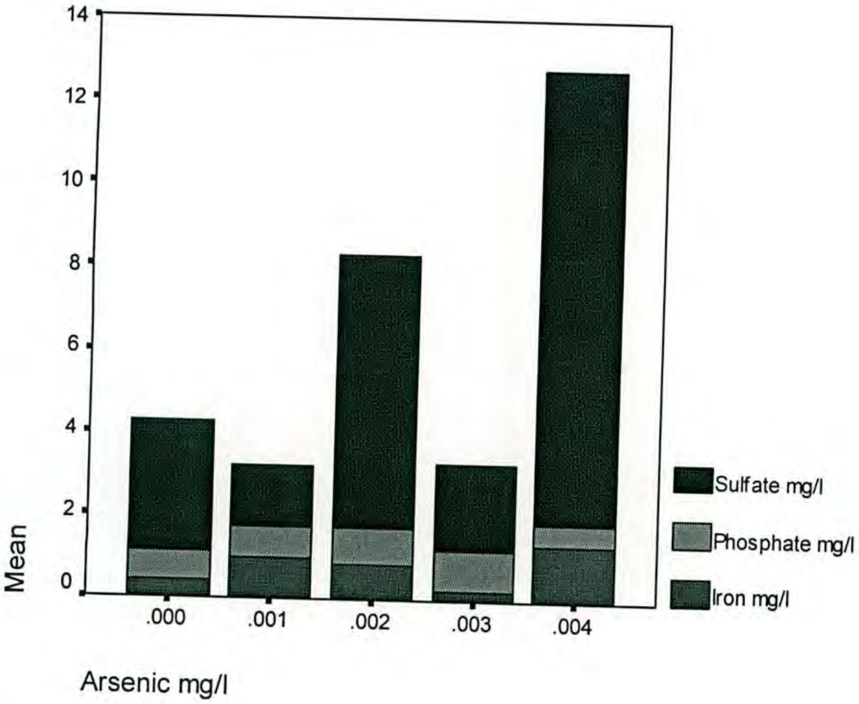


Figure 4.16 :- Arsenic Vs Mean Sulfate, Phosphate, Iron Curve (Vandaria).

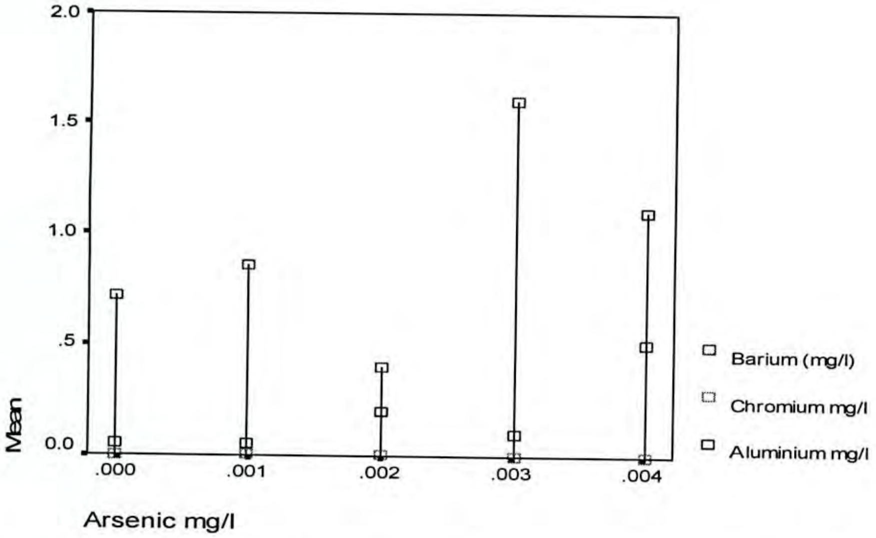


Figure 4.17 :- Arsenic Vs Mean Barium, Chromium, Aluminium Curve (Vandaria).

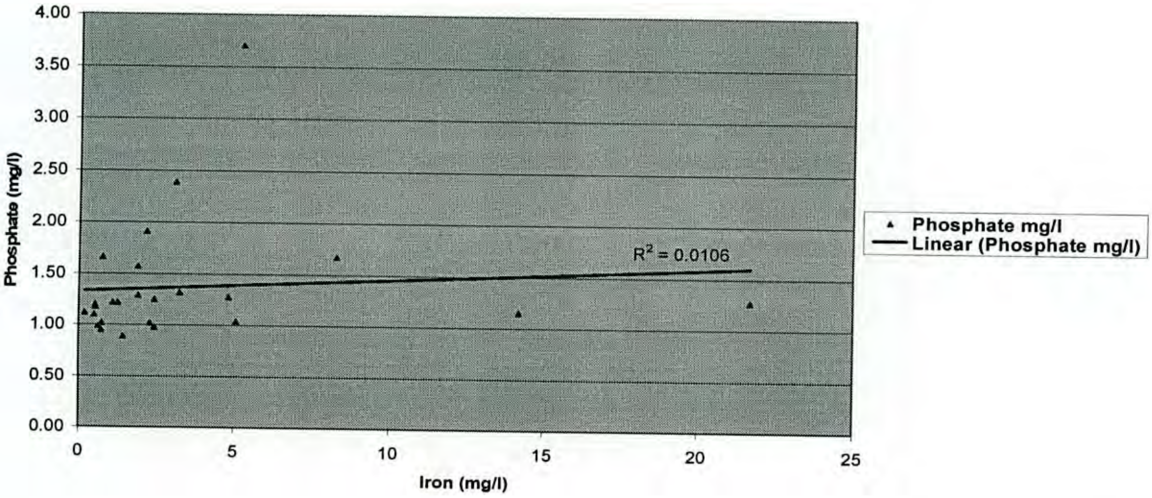


Figure 4.18 :- Iron Vs Phosphate Curve (Chapai).

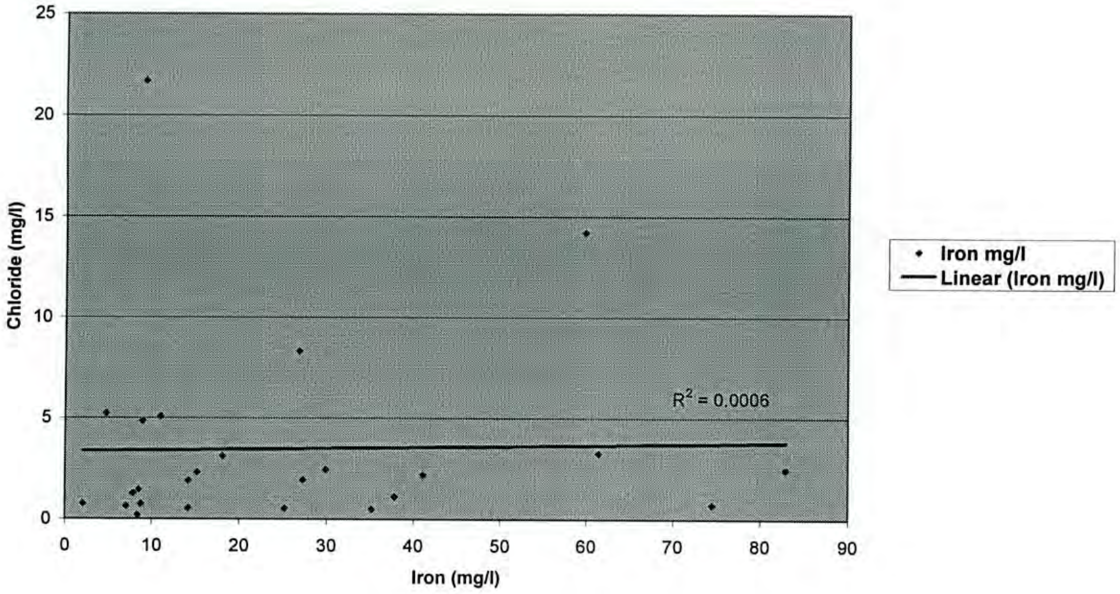


Figure 4.19 :- Iron Vs Chloride Curve (Chapai).

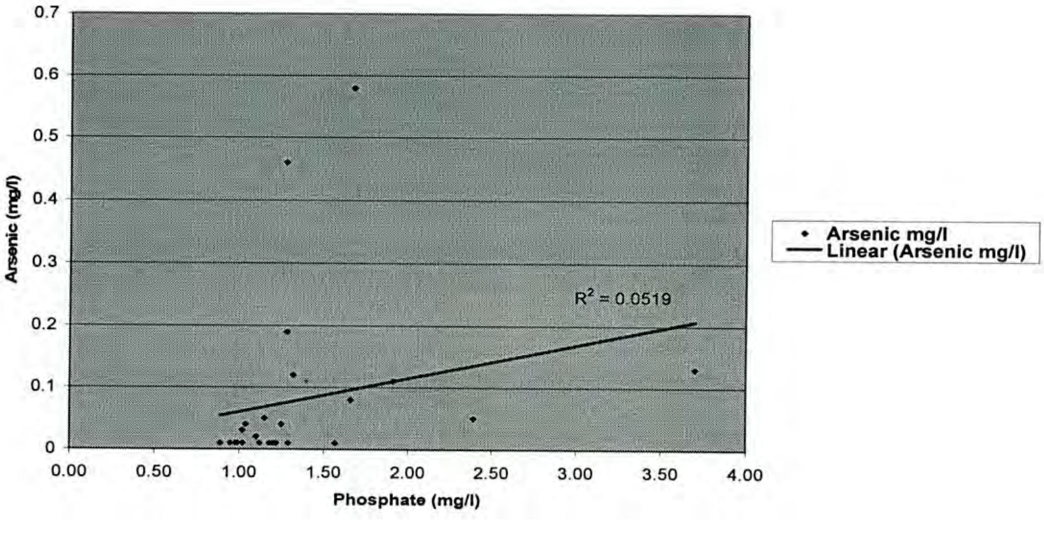


Figure 4.20 :- Arsenic Vs Phosphate Curve (Chapai).

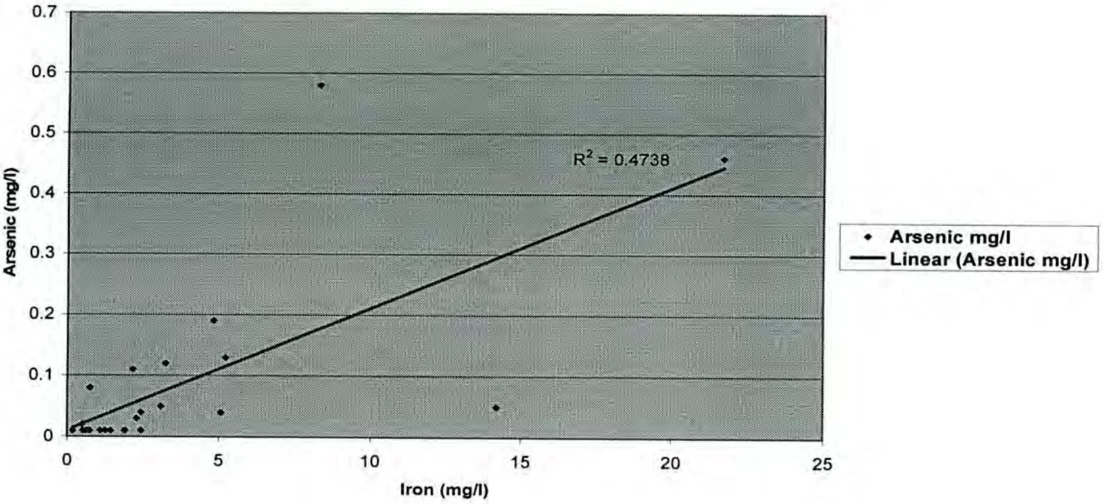


Figure 4.21 :- Arsenic Vs Iron Curve (Chapai).

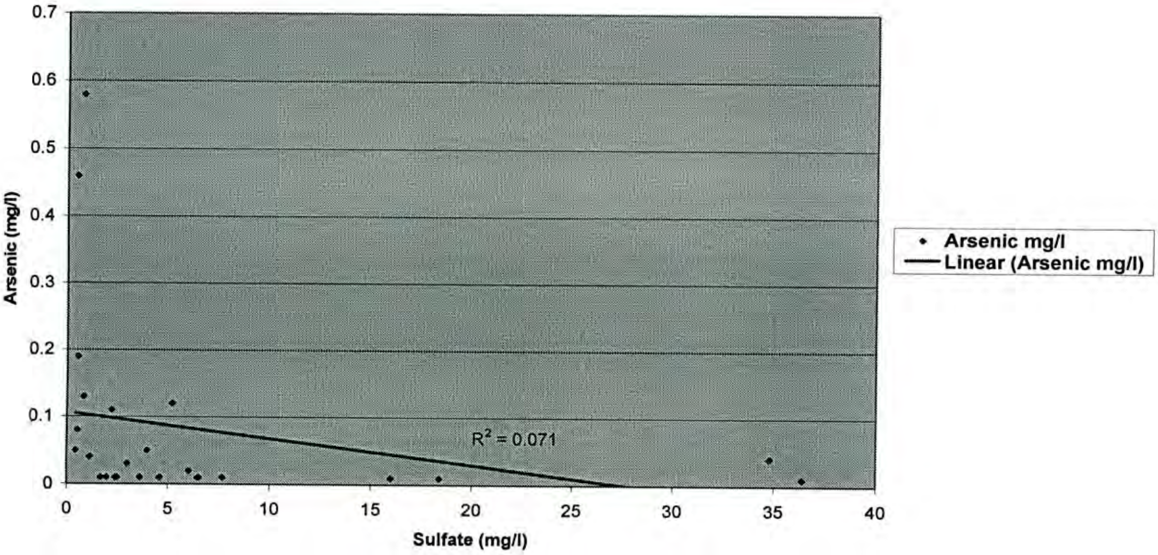


Figure 4.22 :- Arsenic Vs Sulfate Curve (Chapai).

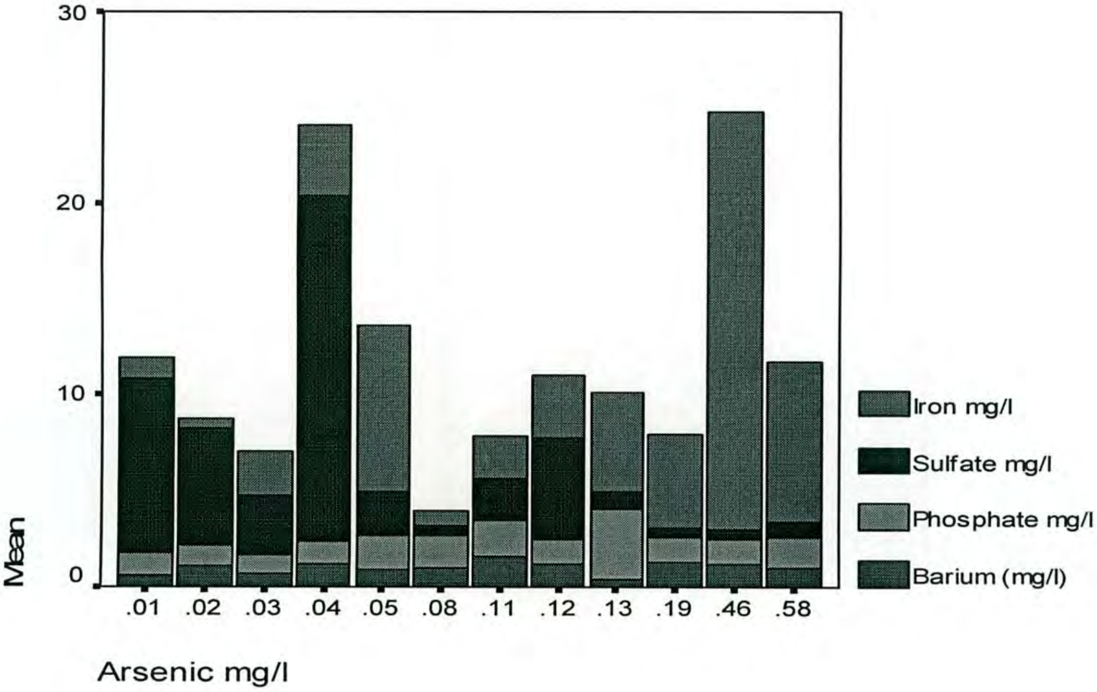


Figure 4.23 :- Arsenic Vs Mean Iron, Sulfate, Phosphate, Barium Curve (Chapai).

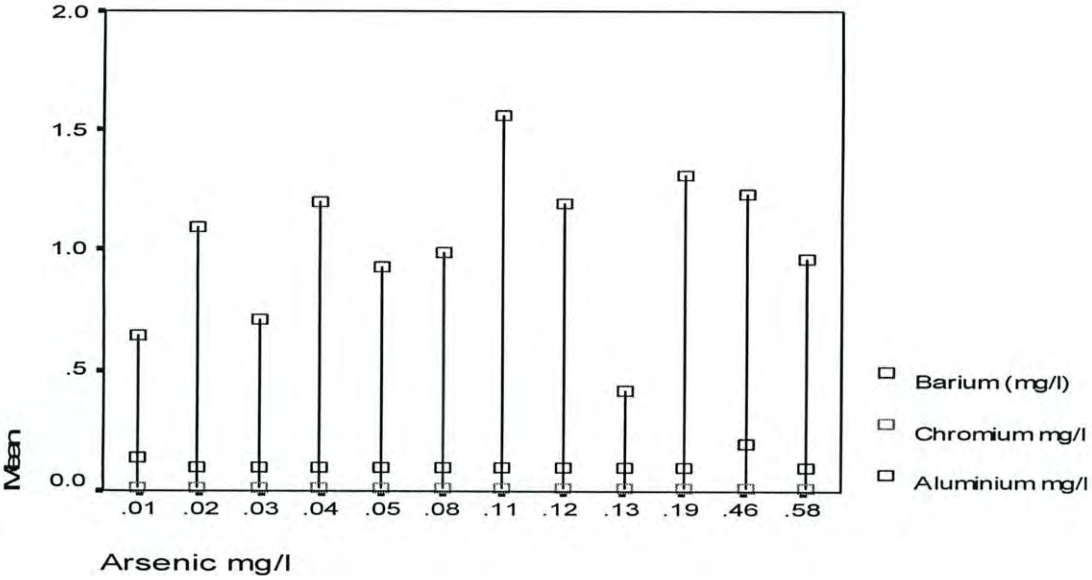


Figure 4.24 :- Arsenic Vs Mean Barium, Chromium, Aluminium Curve (Chapai).

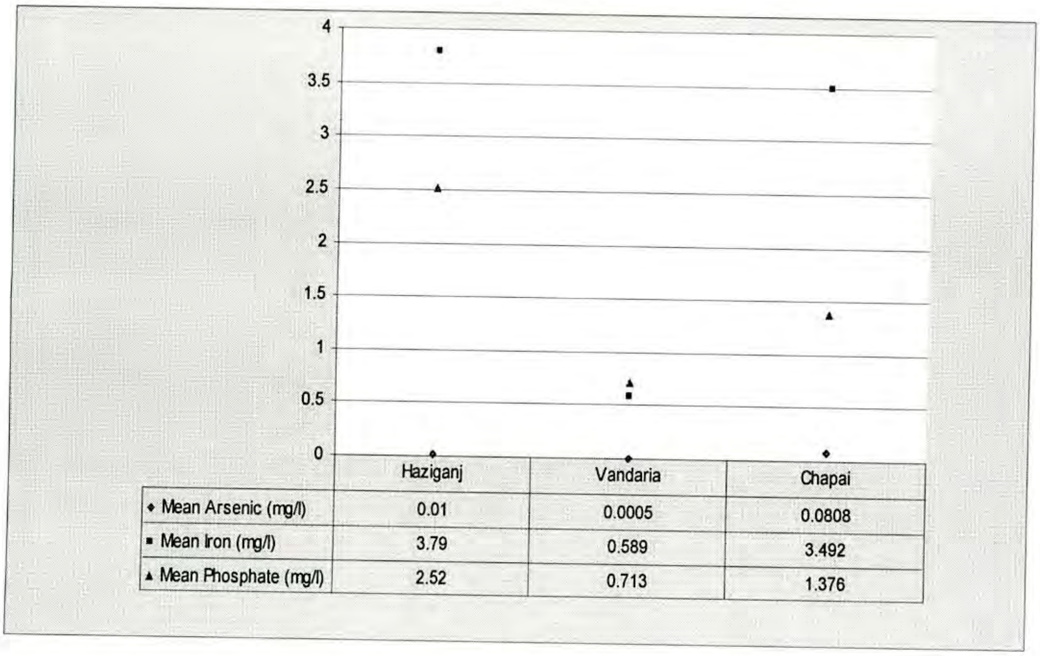


Figure 4.25 :- **Variation of the mean value of different Water Quality Parameters in three Upazilas.**

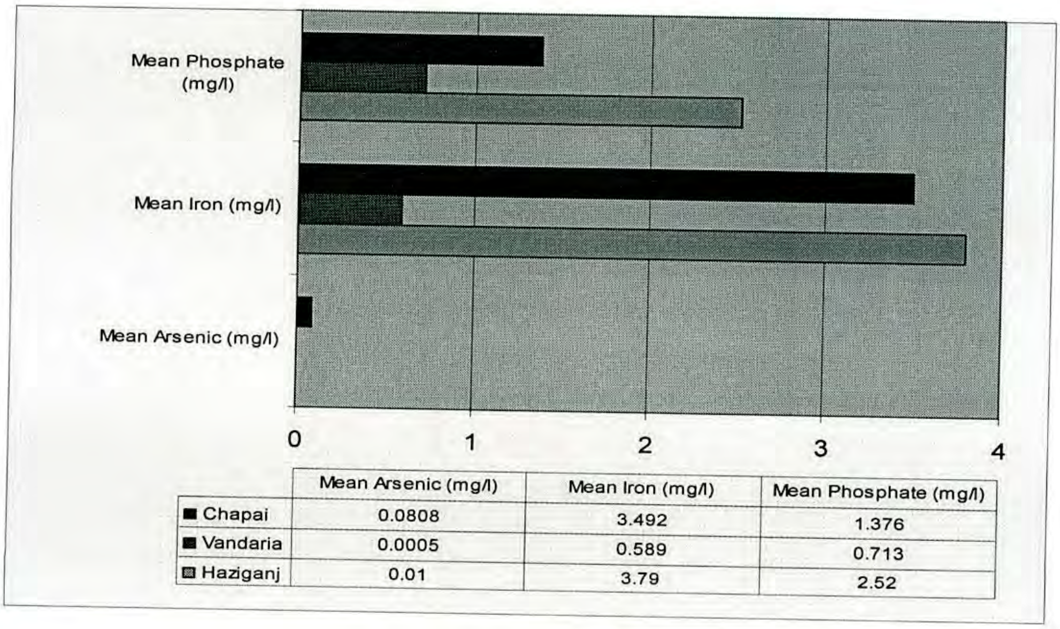
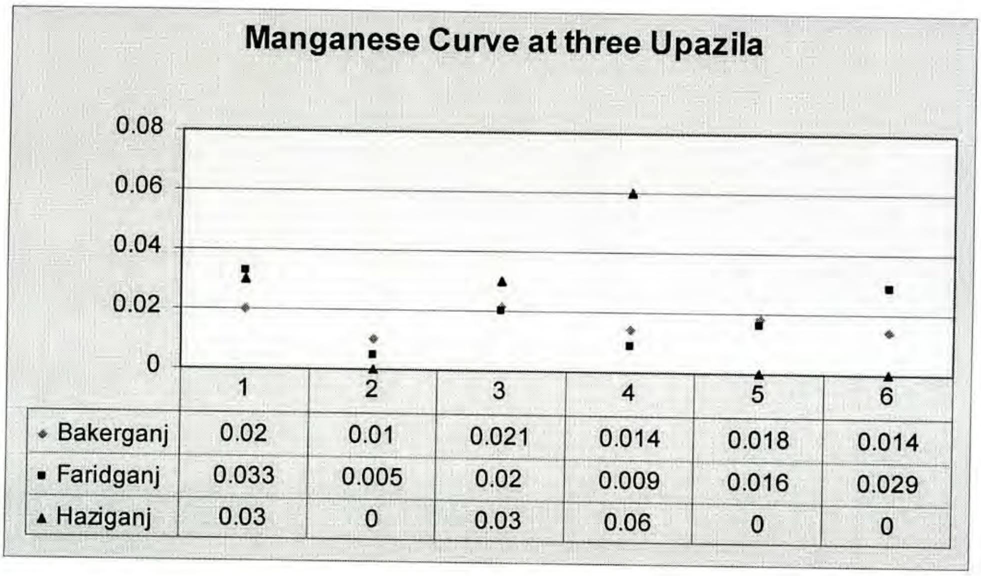


Figure 4.26 :- **Variation of the mean value of different Water Quality Parameters in three Upazilas.**



	1	2	3	4	5	6
◆ Bakerganj	0.02	0.01	0.021	0.014	0.018	0.014
■ Faridganj	0.033	0.005	0.02	0.009	0.016	0.029
▲ Haziganj	0.03	0	0.03	0.06	0	0

Figure 4.27 :- Manganese Curve at three Upazilas.

The afore Presented graphs show the relationship among different Water Quality Parameters. From graph no. 4.2 to 4.27 there is the variation of arsenic, manganese, iron, sulfate, phosphate, chloride, Barium, Aluminium, Chromium and total hardness as $CaCo_3$ with one another. From these graphs and their trend lines it is clear that the Regression values (r^2) are between 0.3 and 0.8. Among these correlations, Chloride with Iron, Manganese & Sulfate and Iron with Manganese and Ammonia with Phosphate show co-relations within the range of 0.6-0.8. According to the definition of the correlation, if the value of the coefficient ranges from +1 to -1, it can be said that the correlation has been developed. But practically the correlation is not significant if the value is not within the range of + 0.5 to - 0.5. That's why in most of the cases the correlation is not significant where the value of the coefficient is with in the range of 0.3 and 0.5.

The graphs 4.1 and 4.7 are also showing the variation of parameters (Iron, Manganese and Arsenic) with depth between 600 ft and 900 ft. It is clear from the above graph that there is no rational relationship among the parameters with depth. In some cases, parameter concentrations are of different ranges even at the same depth.

Figure 4.16, 4.17, 4.23, 4.24, 4.25, 4.26 and 4.27 are showing the variation of the Water Quality Parameters in Haziganj, Vandaria, Chapai, Faridganj and Bakerganj upazila. But it is evident that, at the same place the mean value of any of the parameter is different and same value of any parameter is showing at different places that means at different upazilas. Arsenic is very low at deeper depth.

In conclusion, it can be said that there is no significant relation of water quality parameters with depth and even among themselves also. At the same time it also clears that there is no clear variation of water quality parameters with the change of place.

Chapter – 5

Conclusions & Recommendations

CHAPTER 5: CONCLISIONS AND RECOMMENDATIONS

5.1 Introduction

The severity of the Prevailing As Contamination is causing concern around the country and among the Global communities. From the perspective of treatment of groundwater with objective to provide arsenic free water to the people it is necessary to determine whether or not there exists any correlation ship among the different water quality parameters. In addition, from management perspective any definite information on the correlation between the arsenic concentration in water and the depth of the well is of much importance. This study therefore, is an attempt to investigate whether or not there exists any co-relation among the water quality parameters. However, the absence of any such relationship may also provide valuable information regarding the approach towards treatment as well as management of the groundwater resources. The objective of the research work is to determine the correlation among ground water quality parameters of drinking water sources and the temporal variation of ground water quality parameters. Data Collected from field analyzed with the help of statistical soft wares like MS Excel, SPSS etc. and subsequent co-relation tables, charts, graphs etc. prepared. Secondary data collected from 'Office of The Project Director, Bangladesh Arsenic Mitigation Water Supply Project', 'ITN- Bangladesh', NGOs and other Government organizations.

5.2 Conclusions

This study, based on the available data, reveals that there exists no significant correlation among the water quality parameters with depth or location of the wells. In general, there is lack of correlation among the water quality parameters themselves.

The tables, graphs and the trend lines show that the regression values (r^2) ranged between 0.3 and 0.8. Among all the parameters, only Chloride with Iron, Manganese and Sulfate, Iron with Manganese, and Ammonia with Phosphate have moderate correlation where the correlation coefficients ranged between 0.6-0.8.

The data on iron, manganese and arsenic with depth between 600 ft and 900 ft show that there is no rational relationship with depth. The lack of correlation is evident among the data from different location. Therefore, spatial variation of water quality parameters does not follow any statistical trend.

Thus, following conclusions may be drawn from the findings of this study:

i) There exists is no significant correlation among the water quality parameters with depth or location of the well or even among the parameters themselves.

ii) Mild positive correlation exists between iron and manganese and iron and chloride.

iii) Mild negative correlation exists between arsenic and phosphate.

iv) Since very few temporal water quality data were available, no correlation analysis could be performed.

5.3 Recommendations

This study has been done upon a limited data. Data from only five upazilas were available for analysis. Moreover at Faridganj and Bakerganj upazila data on only six tube wells were available. Therefore, extensive data acquisition and subsequent statistical analysis may reveal further information on the relationships among various water quality parameters as well as the location and depth of the water sources.

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Annex – A

Questionnaires & Survey Form

Annex- A

Government of the People's Republic of Bangladesh
Department of Public Health Engineering (DPHE)
Office of the Senior Chemist of Zonal Laboratory
Mymensing /Comilla / Rajshahi / Khulna / Rangpur/ Barisal / Sylhet

Sample Collection Form for Laboratory test

(1) Information of Area:

DPHE Circle: -	District: -
Upazila: - Mouza:-	Union: - Ward No: -
Village: -	Name of the Household Chief/Caretaker: -

(2) Information of about Water Source:

Source Identification# Type of Source= Ground/Surface water	Date of Installation = Installed by: -
Geographical Location (GPS): - (a) Latitude= (b) Longitude=	Subsurface Litho Information= Depth=
Number of users= Number of patient nearby= Max. Distance of users=	Type of use = Drinking /Cooking /Irrigation /Others………………….

Platform condition = Good /Bad /No platform	Distance of Latrine= Distance of Domestic garbage =
Sealing done = Yes / No At what depth= Its thickness=	Borehole logging done= yes/no At depth saline water detected=
Number of connection (if present)=	Type of Maintenance= Maintenance by =

(3) Sample Information:

Sample Identification number =	Sample Collection date=
Sample mailing date to the Laboratory=	Type of Sample= Water / Others
Source of sample= Deep Tube well / Tube well / Production Well / Dug well / PSF/ Rain water / Irrigation well / Bottled water/Surface water/ others…………..	Type of preservative used= HCl / H_2SO_4 / HNO_3 / Others ………..
Is sample preserved in the cool box during transportation= Yes / No	Types of test requested= Physical/ Chemical/ Bacteriological

(4) Type of Parameter requested for Laboratory Test:

A: Full set of Water quality parameters:

(1)Colour/Taste/Odor, (2) Temperature, (3) pH, (4) Electric conductivity, (5) Suspended solids, (6) Eh/ORP (groundwater), (7) Alkalinity (HCO_3), (8) Total Dissolved Solids (TDS), (9) Turbidity, (10) Aluminium (Al), (11) Ammonium (NH_4), (12) Calcium (Ca), (13) Chloride (Cl), (14) Sulphide (H_2S), (15) Iron (Fe), (16) Magnesium (Mg), (17) Potassium (K), (18) Sodium (Na), (19) Sulphate (SO_4), (20) Zinc (Zn), (21) Arsenic (As), (22) Barium (Ba), (23) Cadmium (Cd), (24) Chromium (Cr), (25) Copper (Cu), (26) Fluoride (F), (27) Iodine (I), (28) Lead (Pb), (29) Manganese (Mn), (30) Mercury (Hg), (31) Nickel (Ni), (32) Nitrate (NO_3), (33) Selenium (Se), (34) Phosphate (P), (35) Faecal coliform (surface water), (36) Total coliform (surface water), (37) Nitrite (NO_2), (38) Hardness.

B: Reduced set of Water quality parameters:

(1) Colour/ Taste/Odor, (2) Temperature, (3) pH, (4) Electric conductivity (EC), (5) Suspended solids, (6) Alkalinity (HCO_3), (7) Eh/ORP (groundwater), (8) TDS, (9) Ammonium (NH_4), (10) Calcium (Ca), (11) Chloride (Cl), (12) Iron (Fe), (13) Magnesium (Mg), (14) Potassium (K), (16) Sodium (Na), (17) Sulphate (SO_4), (18) Arsenic (As), (19) Manganese (Mn), (20) Nitrate (NO_3), (21) Faecal coliform (surface water).

(5) Total number of parameters requested =

(6) Comments of users and observations of the sampling collector concerning water quality

(7)

Test requested by:	**Sample collected by:**
Name:	Name:
Organization:	Designation:
Address:	Signature:
Date:	Date:

(8)

Sample Receiving Date from Field:	**Countersigned by:**
Name:	Name:
Designation:	Designation: Senior/Junior Chemist
Signature:	Signature:
Date:	Date:

Annex – B

Sample Identification Form

Annex-B

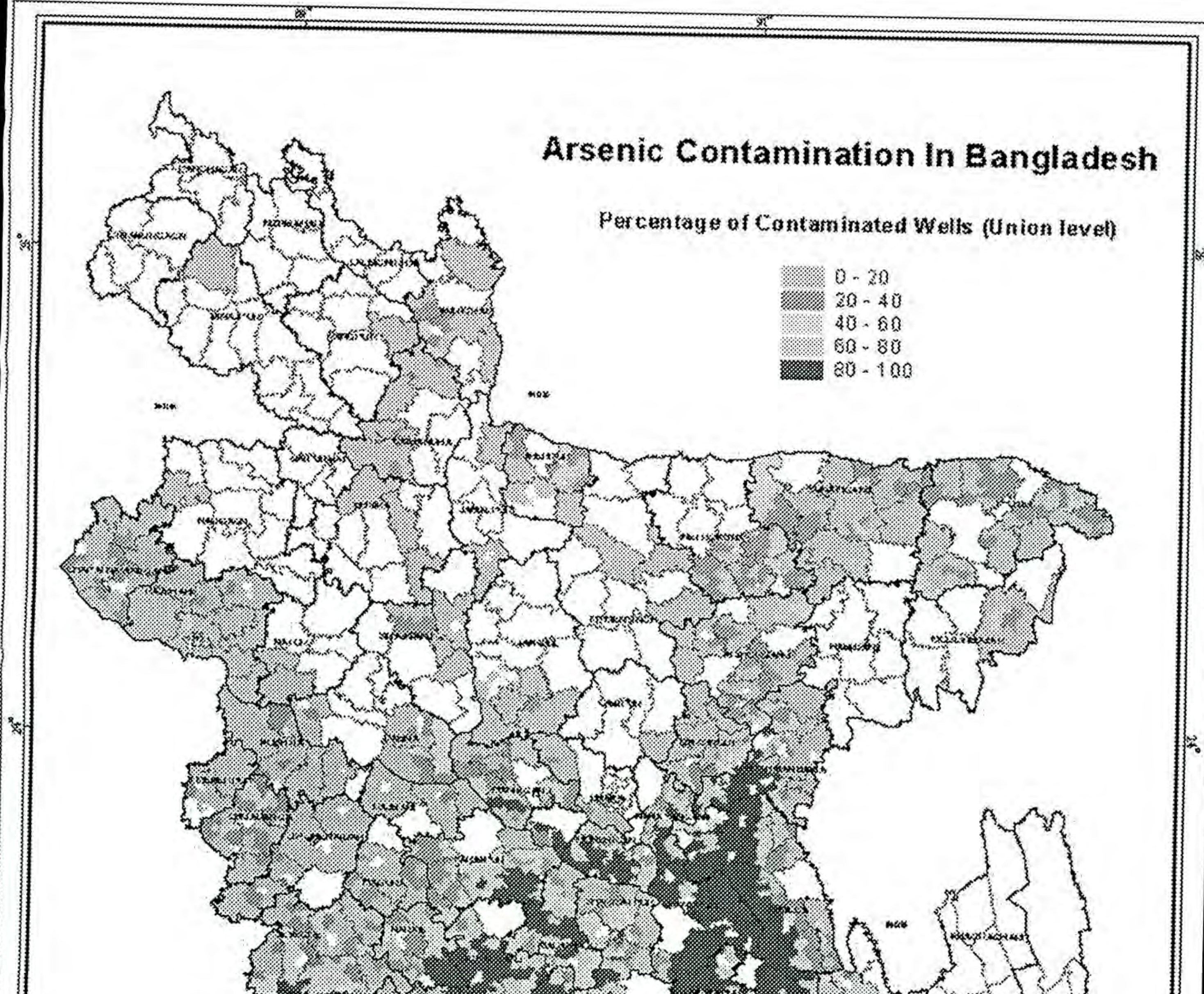
Government of the People's Republic of Bangladesh
Department of Public Health Engineering (DPHE)
Office of the Senior Chemist of Zonal Laboratory
Mymensing /Comilla / Rajshahi / Khulna / Rangpur/ Barisal / Sylhet

Physical /Chemical/ Bacteriological Analysis of Water Sample

Sample Identification#	**Sample Collection date:**
Laboratory No:	Sample receiving date:
Sent By: Sample location:	Your Reference:
Sample Source Other Information about source:	
Date of Testing:	

Annex – C

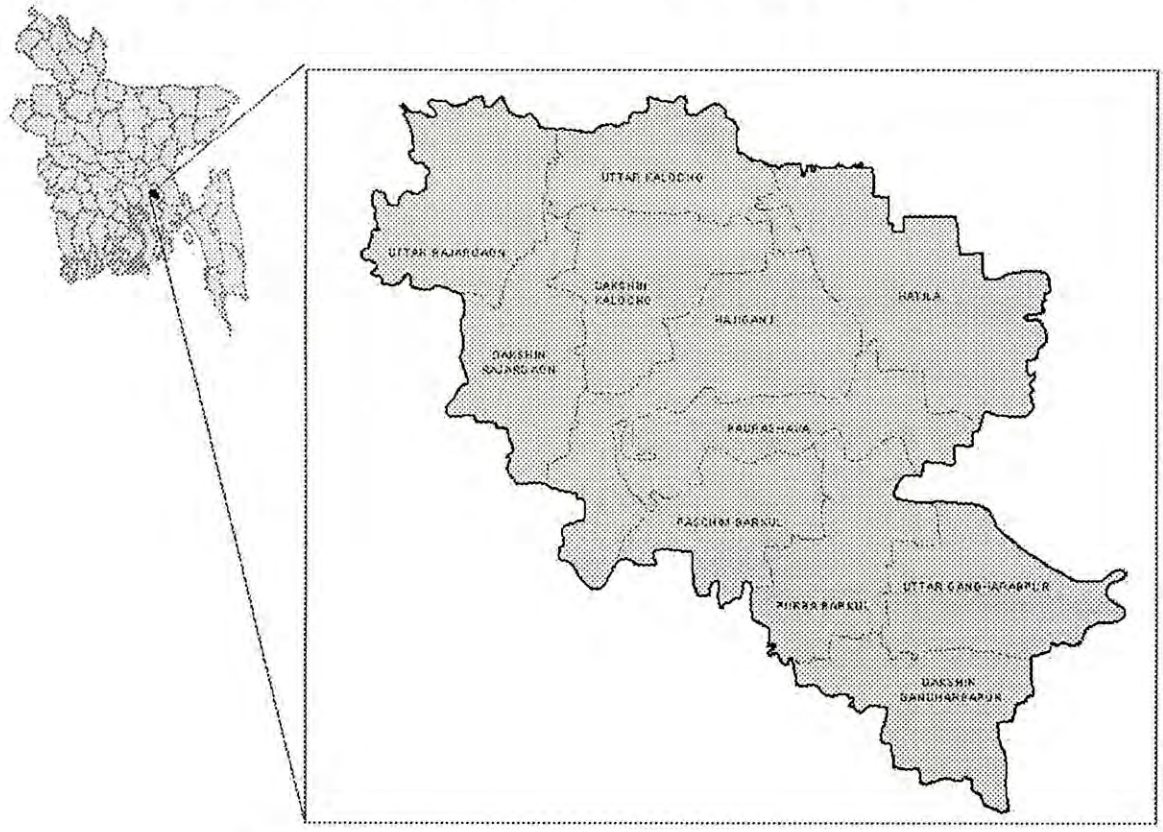
Map of the Location



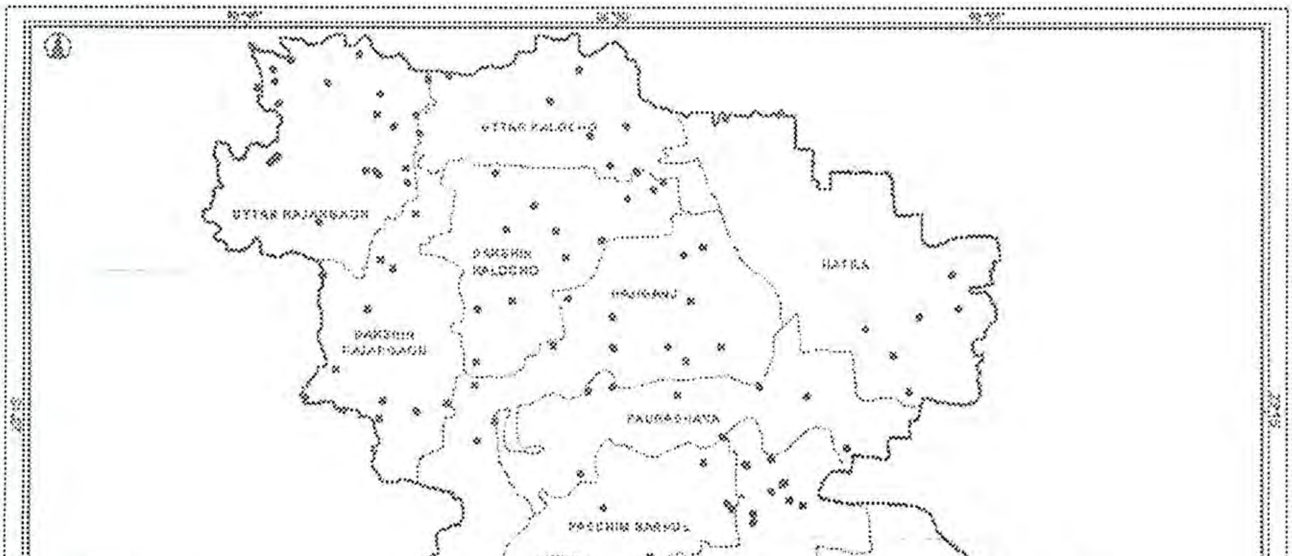
Arsenic Contamination In Bangladesh

Percentage of Contaminated Wells (Union level)

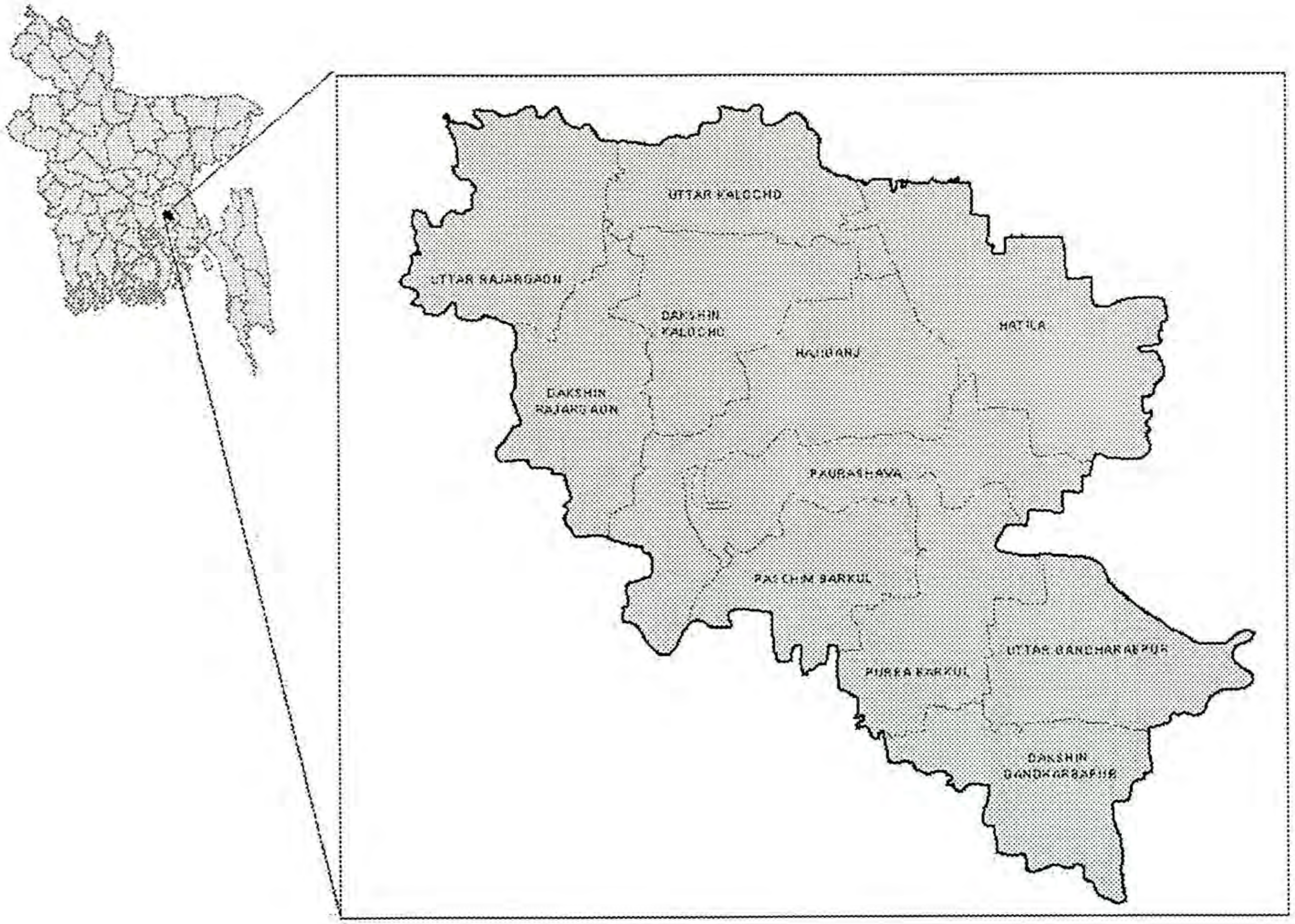
LOCATION MAP OF HAZIGANJ UPAZILA



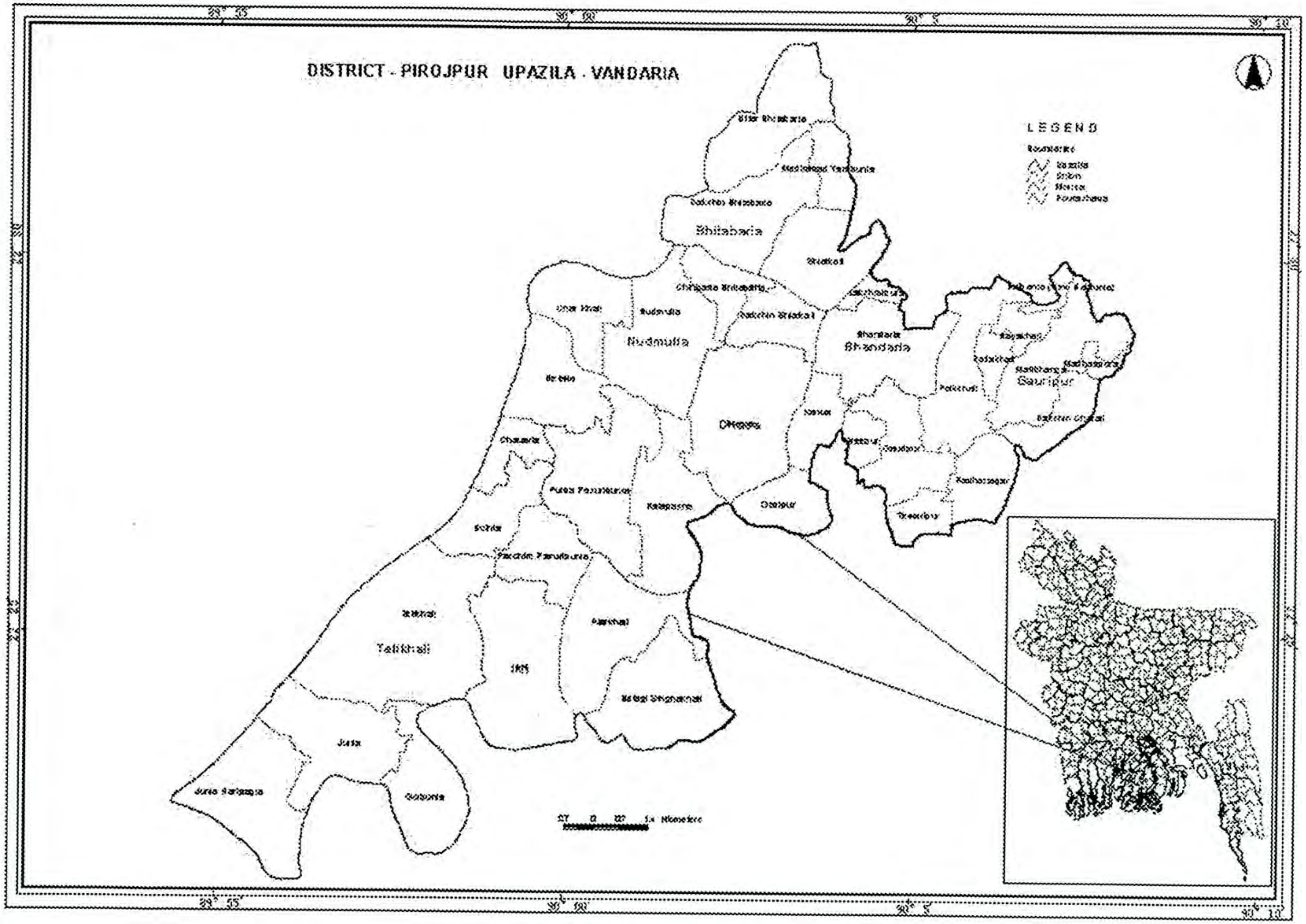
Location of DTWs at Haziganj Upazila



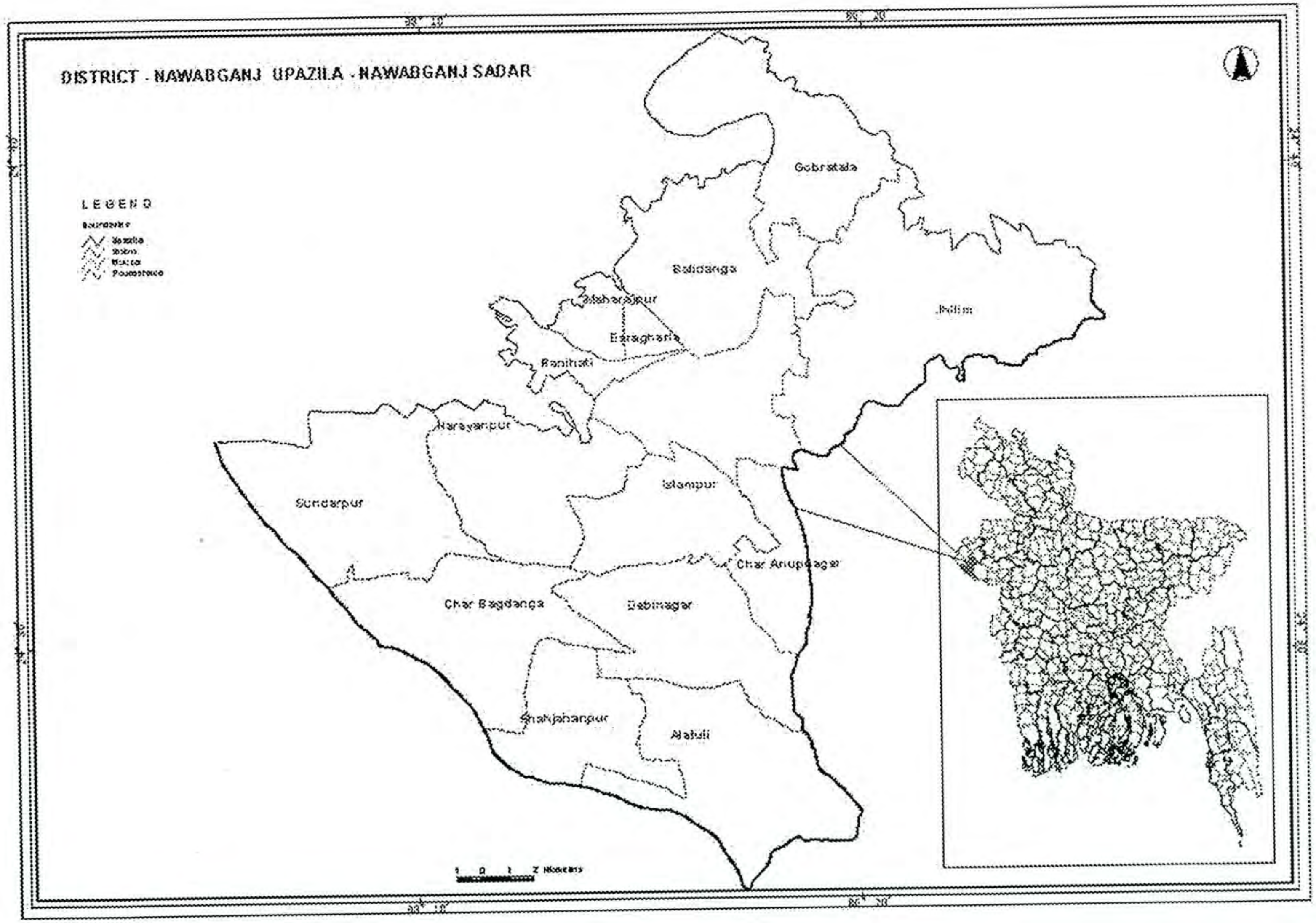
Location Map of Haziganj Upazila



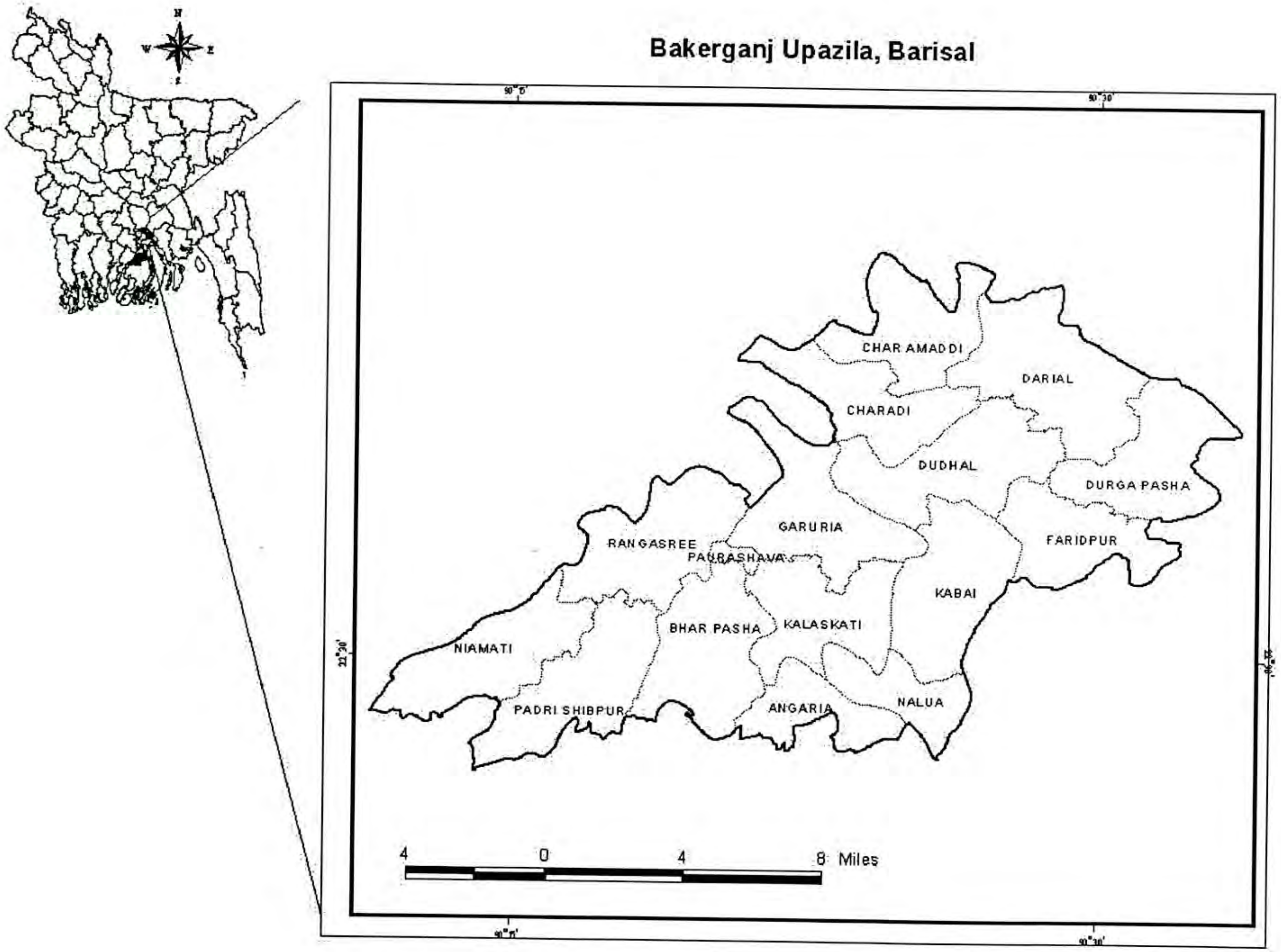
Location Map of Vandaria Upazila



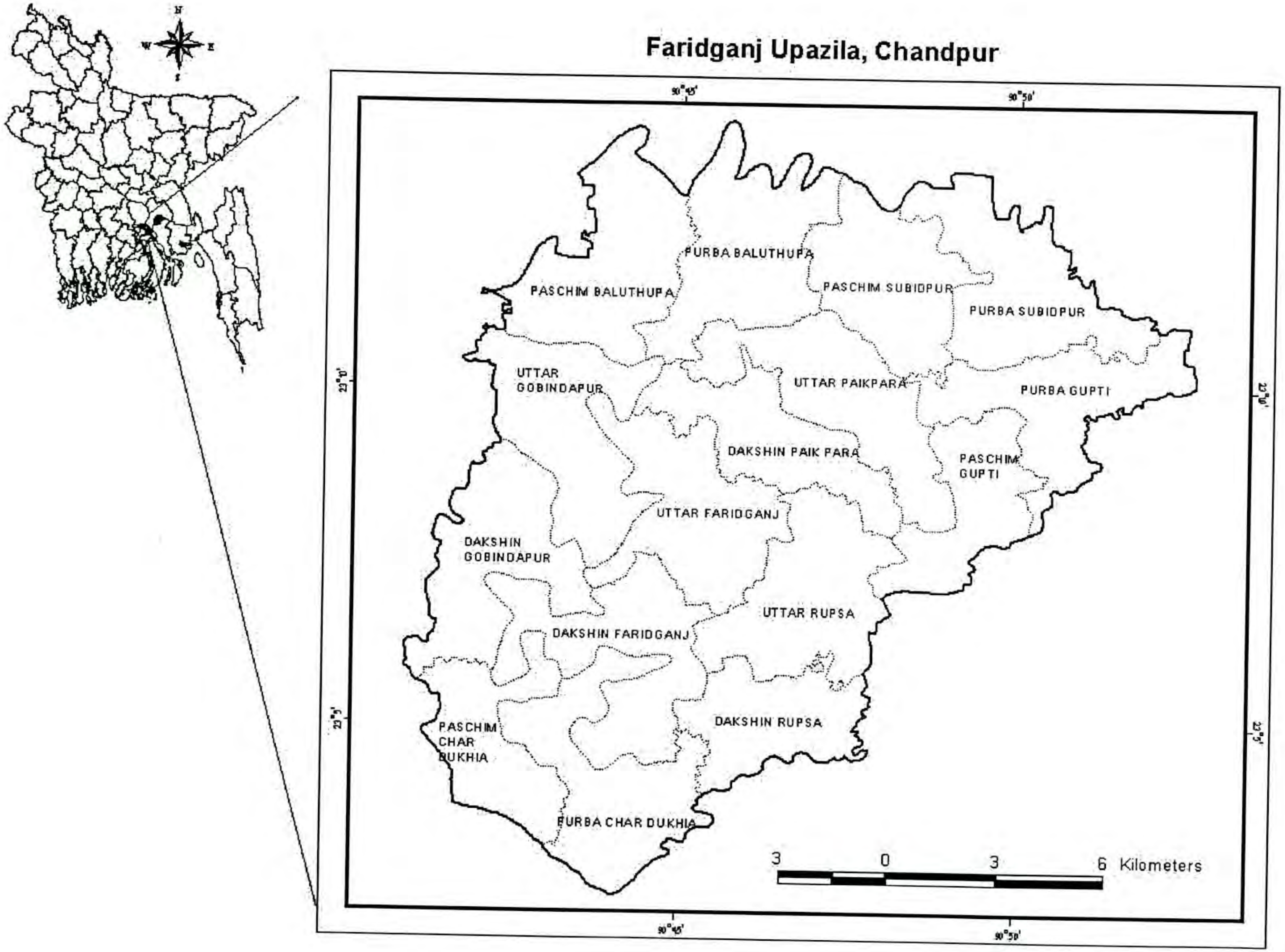
Location Map of ChapaiNawabganj Sadar Upazila



Location Map of Bakerganj Upazila



Location Map of Faridganj Upazila



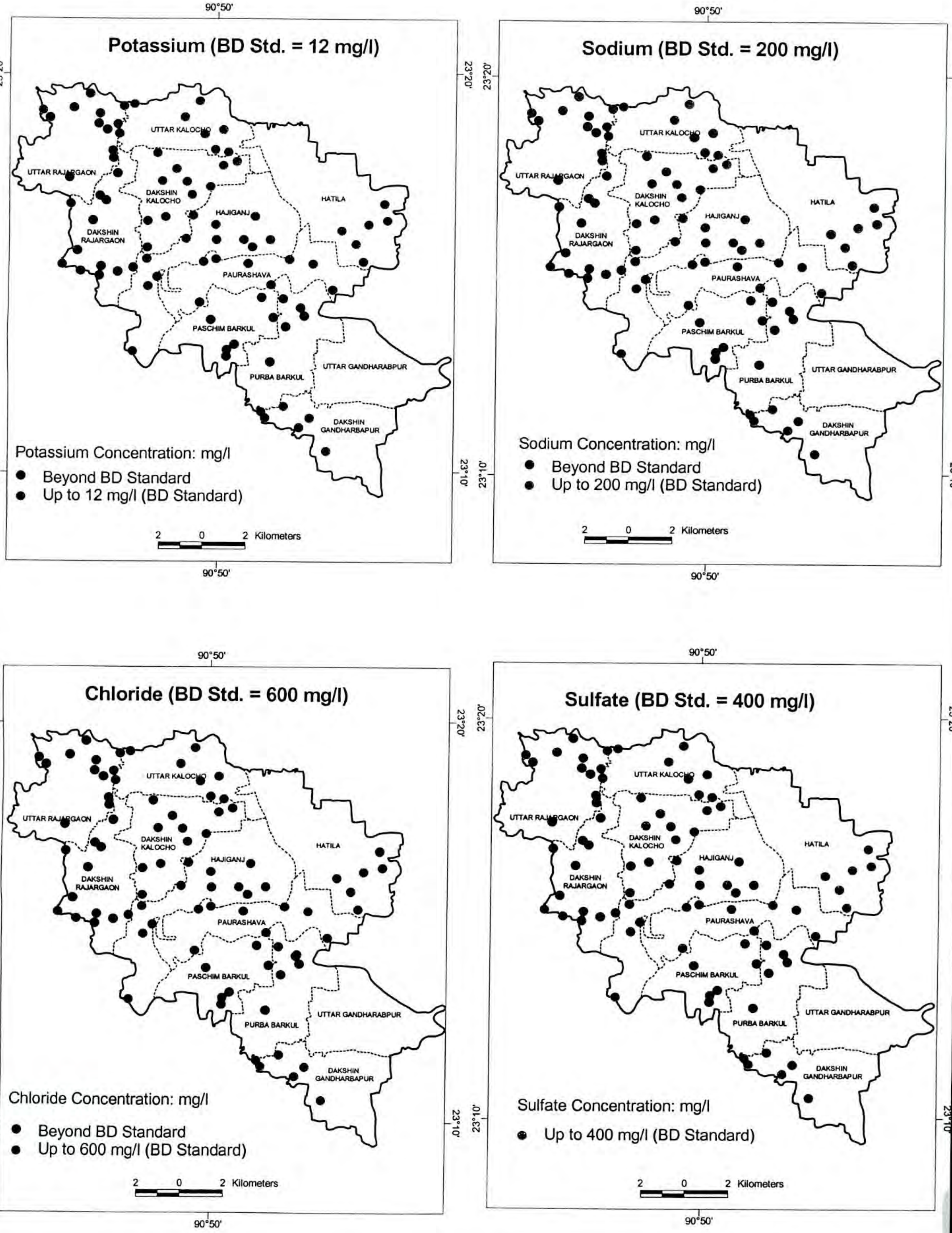
Annex – D

Concentrations of the Water Quality Parameters

Concentration of Potassium, Sodium, Sulfate and Chloride of DHTw Water
at
Haziganj Upazila

Surface Geology (Alam et al,1990)

☐ Alluvial Sand
☐ Chandina Alluvium



Concentration of Phosphate, Arsenic, Manganese & Iron of DHTw Water

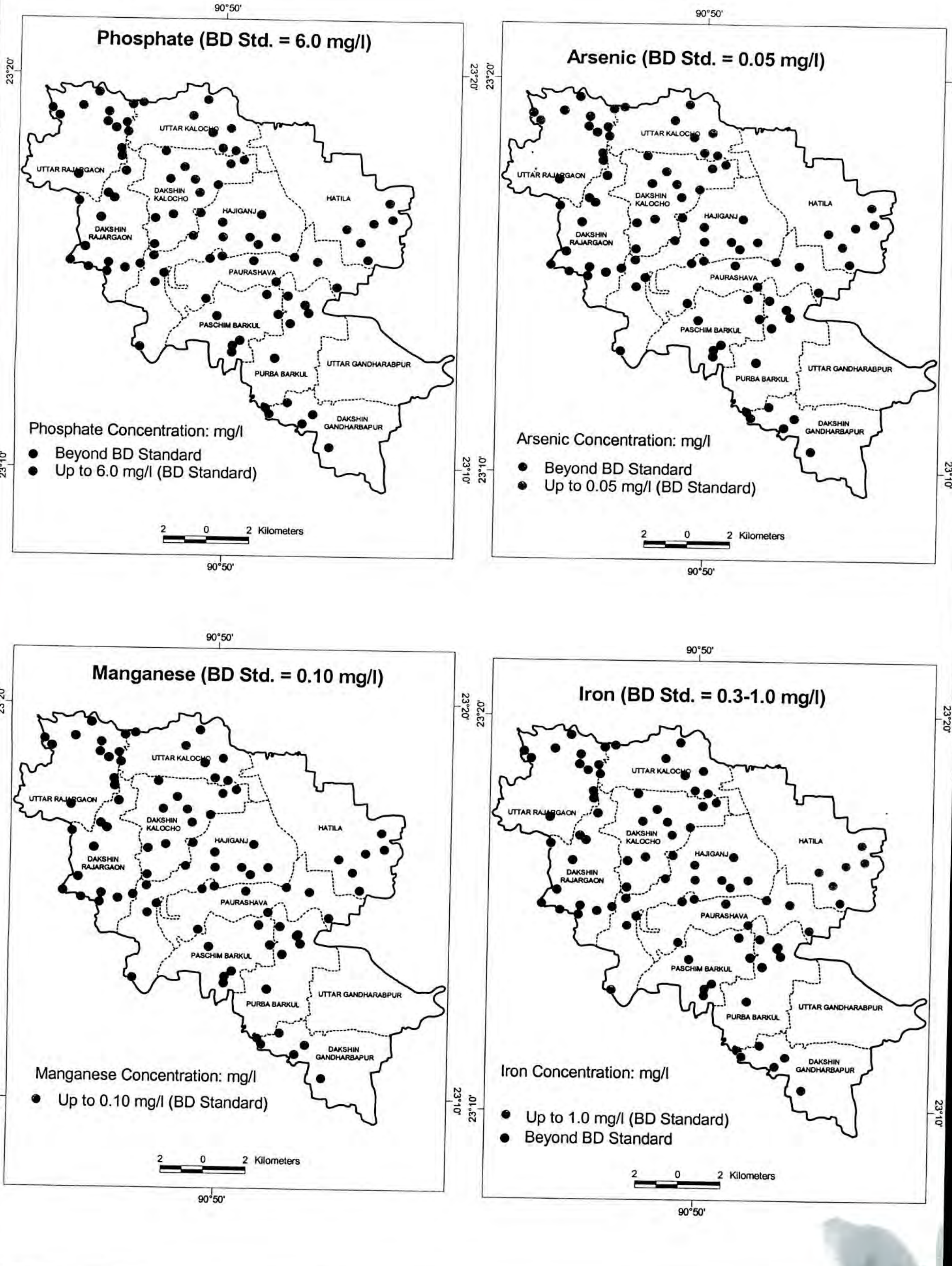
at

Haziganj Upazila

Surface Geology (Alam et al,1990)

☐ Alluvial Sand

☐ Chandina Alluvium

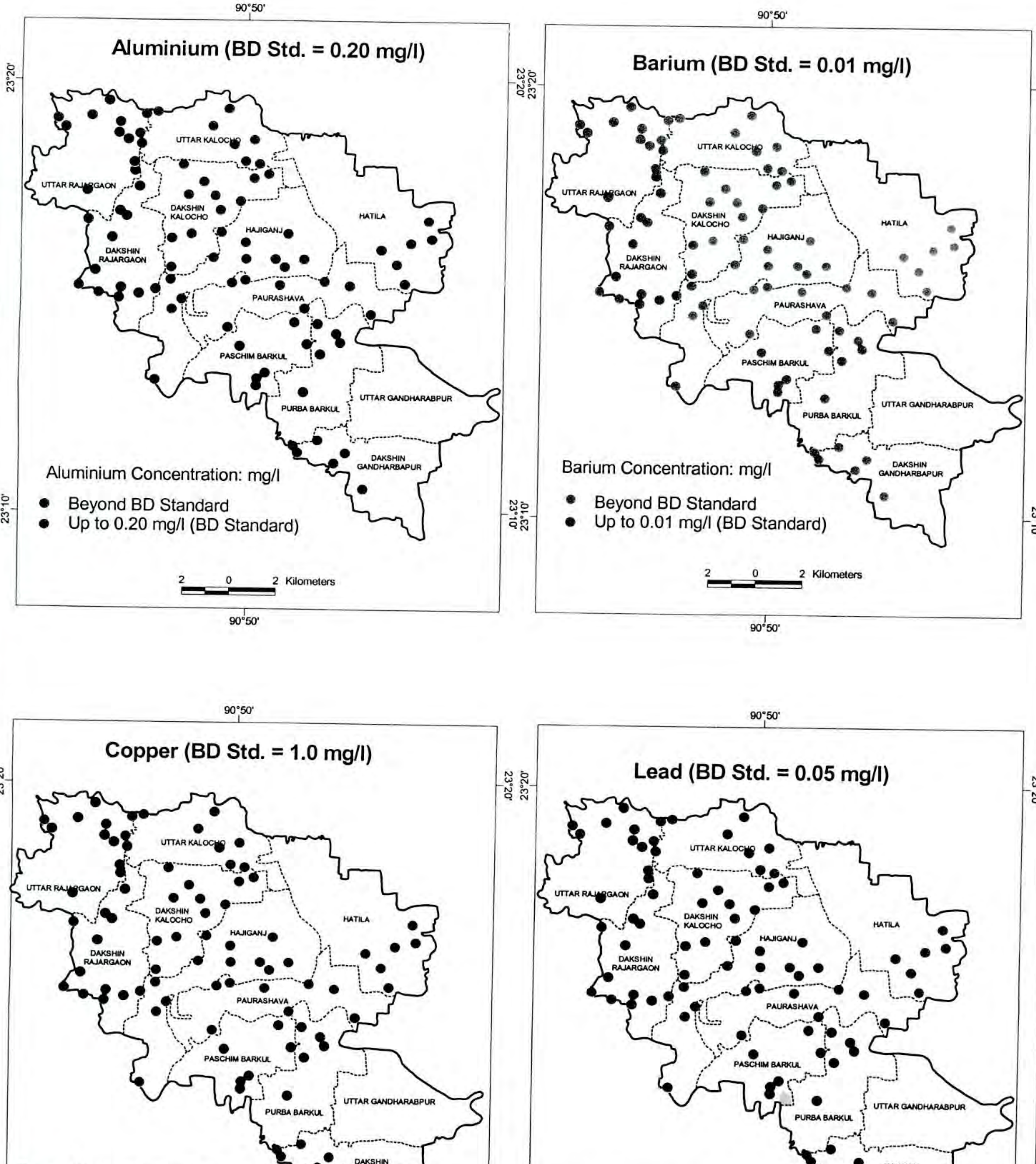


Concentration of Aluminium, Barium, Copper & Lead of DHTw Water

at
Haziganj Upazila

Surface Geology (Alam et al,1990)

- ☐ Alluvial Sand
- ☐ Chandina Alluvium



Annex – E

Data of Haziganj Upazila

Data on Water Quality Parameters in Haziganj Upazila

ID	Type of Source	Source of	District	Upazila	UNION	Village	Depth (ft)	LATITUDE	LONGITUDE	TDS mg/l	pH	Chloride mg/l	Total Hardness as CaCO3 mg/l	Iron mg/l
1	Ground	Deep TW	Chandpur	Hajiganj	Paurashava	Mukinabad	700	23.25416667	90.84694444	480	6.48	210	332	0.9
2	Ground	Deep TW	Chandpur	Hajiganj	Paurashava	Taragor(Uttar Para)	650	23.25583333	90.86555556	205	6.73	61	144	0.3
3	Ground	Deep TW	Chandpur	Hajiganj	Paurashava	Kongaish	200	23.25388889	90.87611111	693	6.49	319	444	4.84
4	Ground	Deep TW	Chandpur	Hajiganj	Paurashava	Enayetpur	750	23.24305556	90.885	1100	6.46	527	624	7.36
5	Ground	Deep TW	Chandpur	Hajiganj	Paurashava	Khattra Biluai	750	23.25611111	90.8325	174	6.97	34	140	1.45
6	Ground	Deep TW	Chandpur	Hajiganj	Paurashava	Dherra	680	23.255	90.82694444	148.8	6.62	17	110	0.9
7	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Sree Narayanpur	820	23.24888889	90.80611111	406	6.53	156	284	3.27
8	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Satbaria	800	23.25277778	90.79527778	435	6.53	176	310	4.72
9	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Uchanga	850	23.245	90.80194444	256	6.61	74	284	1.64
10	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Ulipur	775	23.21777778	90.79527778	240	6.67	57	228	0.21
11	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Betiapara	793	23.25638889	90.80138889	475	6.6	200	332	3.06
12	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Matain	800	23.26416667	90.845	448	6.77	193	292	4.3
13	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Sudhia	790	23.26416667	90.83277778	152	6.62	23	128	1.05
14	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Duahia	792	23.27055556	90.8325	505	6.35	221	324	3.82
15	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Moishait	670	23.27444444	90.8225	458	6.56	187	304	6.42
16	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Subitpur	765	23.26472222	90.81916667	167.5	6.59	23	90	1.12
17	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (South)	Maramura	770	23.28305556	90.82194444	725	6.57	343	400	5.78
18	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Perapur	770	23.28638889	90.83027778	798	6.9	360	580	1.12
19	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Pashim kazirgaon	800	23.26111111	90.84888889	633	6.78	289	452	1.25
20	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Purba Kazirgaon	780	23.26416667	90.85694444	586	6.68	258	372	4.17
21	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Badda	777	23.27388889	90.85027778	550	6.62	255	392	4.66
22	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Kholapara	800	23.25111111	90.78833333	279	6.95	95	208	2.011
23	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Bakila	820	23.24944444	90.78	199	7.02	51	152	3.69
24	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Sanna	800	23.25333333	90.78083333	254	6.95	71	176	1.77
25	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Gogra	810	23.25138889	90.77166667	452	6.83	180	304	1.84
26	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Chatontor	805	23.25416667	90.76333333	508	6.85	210	360	2.64
27	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Dashkhin sreepur	790	23.26	90.77027778	468	6.86	193	312	2.49
28	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Uttar sreepur	810	23.27944444	90.76722222	958	7.06	421	180	0.57
29	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Radhasa	800	23.2725	90.77722222	825	6.95	374	460	5.13
30	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Bakher Para	805	23.31277778	90.78833333	1230	6.66	578	660	4.9
31	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Chhaychial	800	23.28083333	90.78305556	756	6.62	340	476	0.81

Data on Water Quality Parameters in Haziganj Upazila

ID	Type of Source	Source of	District	Upazila	UNION	Village	Depth (ft)	LATITUDE	LONGITUDE	TDS mg/l	pH	Chloride mg/l	Total Hardness as CaCO3 mg/l	Iron mg/l
32	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Digol	800	23.28277778	90.78027778	1028	6.7	472	520	4.88
33	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Lodhpara	808	23.29222222	90.78833333	977	6.93	425	348	4.67
34	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Salbaribhanga	806	23.29861111	90.78638889	857	6.88	431	472	4.9
35	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Kirtonkhola	800	23.30166667	90.78611111	788	7.1	323	312	5
36	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (North)	Rabidaspara	810	23.31055556	90.78361111	1373	6.7	632	628	5.81
37	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (North)	Kapaikap	800	23.30888889	90.78916667	792	6.91	340	360	3.39
38	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (North)	Doudron	760	23.32027778	90.79111111	1658	6.73	782	828	7.48
39	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (North)	Charpara	810	23.32111111	90.79583333	1456	6.64	697	900	8.78
40	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(North)	Nasirkot	805	23.31722222	90.78027778	1577	6.73	720	700	6.38
41	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (South)	Sidla	820	23.26111111	90.80166667	590	6.93	261	368	3.77
42	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (South)	Rampur	656	23.27388889	90.81	340	6.92	122	220	1.42
43	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (South)	Noahata	770	23.27222222	90.80194444	637	6.83	275	320	1.9
44	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (South)	Kalacho (Moddhop	704	23.29527778	90.83583333	276	6.82	95	164	0.22
45	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (South)	Mohammadpur	808	23.29694444	90.84194444	282	6.92	93	140	1.09
46	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (South)	Noapara	720	23.28861111	90.81972222	943	6.91	445	660	8.81
47	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (South)	Orrpur	810	23.29388889	90.815	1119		520	752	10.18
48	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (South)	Bhatora	775	23.30055556	90.80638889	1559	6.76	720	416	6.72
49	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (South)	Soidpur	760	23.28888889	90.80861111	1215	6.79	564	744	4
50	Ground	Deep TW	Chandpur	Hajiganj	Purba Barkul	Uttar Barkul	800	23.23555556	90.87055556	350	6.83	136	224	2.56
51	Ground	Deep TW	Chandpur	Hajiganj	Purba Barkul	Dakshin Barkul (Mc	720	23.22777778	90.86388889	254	6.94	80	150	1
52	Ground	Deep TW	Chandpur	Hajiganj	Purba Barkul	Dhakin Raicho	781	23.23166667	90.85833333	204	7.01	51	136	1
53	Ground	Deep TW	Chandpur	Hajiganj	Purba Barkul	Madhya Barkul	840	23.23222222	90.87222222	418	6.91	169	236	3.05
54	Ground	Deep TW	Chandpur	Hajiganj	Purba Barkul	Uttar Raicho	850	23.23944444	90.86277778	273	6.84	89	176	2.39
55	Ground	Deep TW	Chandpur	Hajiganj	Paschim Barkul	Randhanimura	650	23.24	90.85305556	257	7.04	80	144	0.7
56	Ground	Deep TW	Chandpur	Hajiganj	Gondovpur	Nischintapur	800	23.18861111	90.84888889	1775	7.17	32	116	0.5
57	Ground	Deep TW	Chandpur	Hajiganj	Gondovpur	Joyshora	787	23.18972222	90.85472222	158.9	7.15	25	116	1.63
58	Ground	Deep TW	Chandpur	Hajiganj	South Gondovpur	Vaurpara	790	23.19444444	90.86305556	172.6	7.06	32	114	1.13
59	Ground	Deep TW	Chandpur	Hajiganj	Gondovpur	Pachai	810	23.18555556	90.87	176.8	7.11	32	112	1.09
60	Ground	Deep TW	Chandpur	Hajiganj	South Gondovpur	Hotani	800	23.18944444	90.87472222	177.6	7.15	40	118	1.14
61	Ground	Deep TW	Chandpur	Hajiganj	South Gondovpur	Deshgaon	800	23.17555556	90.88222222	481	6.94	188	248	1.47
62	Ground	Deep TW	Chandpur	Hajiganj	Puba Hatile	Ganganagar	760	23.25472222	90.89888889	1307	6.36	576	288	8.8

Data on Water Quality Parameters in Haziganj Upazila

ID	Type of Source	Source of	District	Upazila	UNION	Village	Depth (ft)	LATITUDE	LONGITUDE	TDS mg/l	pH	Chloride mg/l	Total Hardness as CaCO3 mg/l	Iron mg/l
63	Ground	Deep TW	Chandpur	Hajiganj	Puba Hatile	Purbo Hatia	750	23.26222222	90.89555556	1950	6.41	880	540	8.82
64	Ground	Deep TW	Chandpur	Hajiganj	Puba Hatile	Harian	800	23.26777778	90.88916667	1767	6.38	832	604	7.93
65	Ground	Deep TW	Chandpur	Hajiganj	Puba Hatile	Tongipur	780	23.27027778	90.90138889	2.01	6.45	928	632	8.62
66	Ground	Deep TW	Chandpur	Hajiganj	Puba Hatile	Purba Noapara	800	23.27194444	90.91	1597	6.51	681	316	3.25
67	Ground	Deep TW	Chandpur	Hajiganj	Puba Hatile	Laokara	780	23.27888889	90.90861111	2.25	6.49	1014	636	8.7
68	Ground	Deep TW	Chandpur	Hajiganj	Paschim Barkul	Debipur	800	23.21555556	90.83722222	168.1	7.1	41	118	1.11
69	Ground	Deep TW	Chandpur	Hajiganj	Paschim Barkul	Kuruli	780	23.21833333	90.8375	149.8	7.08	48	99	1.02
70	Ground	Deep TW	Chandpur	Hajiganj	Paschim Barkul	Gopalkhur	770	23.22055556	90.84083333	146.4	7.08	22	92	1.12
71	Ground	Deep TW	Chandpur	Hajiganj	Paschim Barkul	Brahmanichoo	780	23.23083333	90.83027778	143.9	7.08	16	97	1.24
72	Ground	Deep TW	Chandpur	Hajiganj	Paschim Barkul	Nathchora	830	23.23805556	90.82527778	625	6.86	265	354	1.5
73	Ground	Deep TW	Chandpur	Hajiganj	Puba Barkul	Kondra	816	23.21305556	90.85694444	225	7.09	60	144	1.35
74	Ground	Deep TW	Chandpur	Hajiganj	Puba Barkul	Dakatia Char (Noad	790	23.24527778	90.85722222	181.6	6.95	51	112	1.49
75	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (North)	Mohabbatpur	815	23.30194444	90.83222222	388	6.77	144	187	1.05
76	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (North)	Shihircho	800	23.30083333	90.83805556	346	6.91	118	201	3.72
77	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (North)	Marki	810	23.31027778	90.83583333	1050	6.62	454	439	8.15
78	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (North)	Pirojpur	800	23.30833333	90.8275	965	6.59	428	374	7.94
79	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (North)	Tarapuka	805	23.32222222	90.82527778	907	6.78	384	306	0.96
80	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (North)	Baniacho	800	23.31555556	90.81861111	955	6.46	435	579	9.32
81	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon (North)	Purba Rajargaon	800	23.29055556	90.76666667	1251	6.92	515	367	8.97
82	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon (North)	Ahmadabad	775	23.31305556	90.77972222	1505	6.89	646	604	9.15
83	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon (North)	Menapur	795	23.31555556	90.75777778	939	7.4	201	302	9.31
84	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon (North)	Nairain	804	23.31861111	90.75277778	1724	7.05	745	597	4.7
85	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon (North)	Char Riani	750	23.32555556	90.77583333	1489	6.83	656	766	6.03
86	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon (North)	Malapara	807	23.31972222	90.76861111	1574	6.82	704	763	6.21

Data on Water Quality Parameters in Haziganj Upazila

ID	Type of Source	Source of sample	District	Upazila	UNION	Village	Manganese mg/l	Phosphate mg/l	Nitrogen (Ammonia) mg/l	Sulfate mg/l	Arsenic mg/l	Copper mg/l	Lead mg/l	Nickel mg/l	Zinc mg/l	Barium (mg/l)
1	Ground	Deep TW	Chandpur	Hajiganj	Paurashava	Mukinabad	0.03	2.0	0.3	<10	<0.01	0.01	<0.01	<0.01	0.03	0.7
2	Ground	Deep TW	Chandpur	Hajiganj	Paurashava	Taragor(Uttar Para	0	1.9	0.2	<10	<0.01	0.01	<0.01	<0.01	0.06	0.7
3	Ground	Deep TW	Chandpur	Hajiganj	Paurashava	Kongaish	0.03	7.1	0.4	11	<0.01	0.01	<0.01	<0.01	0.20	1
4	Ground	Deep TW	Chandpur	Hajiganj	Paurashava	Enayetpur	0.06	4.7	0.3	<10	<0.01	0.01	0.01	<0.01	0.08	1.4
5	Ground	Deep TW	Chandpur	Hajiganj	Paurashava	Khattra Biluai	0	3.1	0.1	<10	<0.01	0.03	<0.01	<0.01	0.04	0.3
6	Ground	Deep TW	Chandpur	Hajiganj	Paurashava	Dherra	0	2.6	0.1	<10	<0.01	0.01	0.01	<0.01	0.03	0.3
7	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Sree Narayanpur	0	2.9	0.3	<10	<0.01	0.01	0.01	<0.01	0.05	0.5
8	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Satbaria	0.02	2.3	0.2	<10	<0.01	0.01	<0.01	<0.01	0.06	0.6
9	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Uchanga	0	2.9	0.2	<10	<0.01	0.01	<0.01	<0.01	0.03	0.4
10	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Ulipur	0	2.4	0.2	<10	<0.01	0.02	<0.01	<0.01	<0.01	0.5
11	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Betiapara	0.02	2.3	0.3	<10	<0.01	0.01	0.01	<0.01	0.05	0.5
12	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Matain	0.02	3.0	0.5	<10	<0.01	0.03	0.03	<0.01	0.10	0.6
13	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Sudhia	0	4.4	0.2	<10	<0.01	0.02	0.02	<0.01	0.30	0.3
14	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Duahia	0.02	2.6	0.3	<10	<0.01	0.01	0.02	<0.01	0.04	0.8
15	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Moishait	0.03	5.0	2.0	<10	<0.01	0.01	0.03	<0.01	0.53	0.7
16	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Subitpur	0	2.1	0.1	<10	<0.01	0.02	<0.01	<0.01	0.01	0.3
17	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (South)	Maramura	0.02	2.2	0.4	<10	<0.01	0.02	0.01	<0.01	0.25	1
18	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Perapur	0.03	2.6	1	<10	<0.01	0.01	0.01	<0.01	0.30	1.2
19	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Pashim kazirgaon	0.01	2.7	0.5	<10	<0.01	0.01	<0.01	<0.01	0.11	0.8
20	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Purba Kazirgaon	0.02	1.9	0.4	<10	<0.01	<0.01	0.01	<0.01	0.04	0.7
21	Ground	Deep TW	Chandpur	Hajiganj	Hajiganj Sadar	Badda	0.01	2.6	0.3	<10	<0.01	<0.01	0.02	<0.01	1.22	0.7
22	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Kholapara	0	2.0	0.1	<10	<0.01	0.01	0.02	<0.01	0.03	0.3
23	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Bakila	0	2.5	0.2	<10	<0.01	0.01	0.01	<0.01	0.31	0.3
24	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Sanna	0	2.0	0.1	<10	<0.01	0.01	0.01	<0.01	0.03	0.3
25	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Gogra	0.01	1.9	0.3	<10	<0.01	0.02	0.02	<0.01	0.02	0.4
26	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Chatontor	0.01	2.3	0.3	<10	<0.01	0.01	0.02	<0.01	0.02	0.5
27	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Dashkhin sreepur	0.01	2.2	0.3	10	<0.01	0.02	0.01	<0.01	0.05	0.4
28	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Uttar sreepur	0.01	2.0	0.1	21	<0.01	0.01	0.01	<0.01	0.06	0.6
29	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Radhasa	0.03	3.5	0.4	12	<0.01	0.01	0.02	<0.01	0.17	0.44
30	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Bakher Para	0.05	3.0	0.5	42	<0.01	0.01	0.03	<0.01	0.19	0.7
31	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Chhaychial	0.02	3.6	<0.2	<10	<0.01	0.02	0.02	<0.01	0.18	0.52

Data on Water Quality Parameters in Haziganj Upazila

ID	Type of Source	Source of sample	District	Upazila	UNION	Village	Manganese mg/l	Phosphate mg/l	Nitrogen (Ammonia) mg/l	Sulfate mg/l	Arsenic mg/l	Copper mg/l	Lead mg/l	Nickel mg/l	Zinc mg/l	Barium (mg/l)
32	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Digol	0.03	3.2	0.4	20	<0.01	0.01	0.02	<0.01	0.11	0.44
33	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Lodhpara	0.03	2.3	<0.2	<10	0.02	0.01	0.03	<0.01	0.25	0.32
34	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Salbaribhanga	0.06	4.0	0.2	<10	<0.01	0.02	0.52	<0.01	0.64	0.34
35	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(south)	Kirtonkhola	0.01	3.2	<0.2	<10	<0.01	0.01	0.13	<0.01	1.67	0.18
36	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (North)	Rabidaspara	0.02	3.5	<0.2	74	<0.01	0.01	0.01	<0.01	0.05	0.52
37	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (North)	Kapaikap	0.02	3.1	0.2	22	<0.01	0.02	0.01	<0.01	0.07	0.12
38	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (North)	Doudron	0.05	3.1	0.4	92	<0.01	0.01	0.01	<0.01	0.07	1.28
39	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (North)	Charpara	0.05	3.2	0.6	76	<0.01	0.01	0.03	<0.01	0.24	1.12
40	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon(North)	Nasirkot	0.03	3.4	1.3	86	<0.01	0.01	0.03	<0.01	0.19	1.76
41	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (South)	Sidla	0.02	3.2	0.5	<10	<0.01	0.01	0.01	<0.01	0.06	0.74
42	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (South)	Rampur	0.01	3.3	<0.2	<10	<0.01	0.02	0.02	<0.01	0.13	0.74
43	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (South)	Noahata	0.02	3.0	<0.2	<10	<0.01	0.01	0.03	<0.01	0.2	0.63
44	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (South)	Kalacho (Moddhop	0.01	3.6	<0.2	<10	<0.01	0.01	0.01	<0.01	0.07	0.69
45	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (South)	Mohammadpur	0.01	3.6	<0.2	<10	<0.01	0.02	0.01	<0.01	0.05	0.76
46	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (South)	Noapara	0.05	3.3	0.2	<10	<0.01	0.01	0.04	<0.01	0.24	2.05
47	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (South)	Orrpur	0.06	3.3	0.2	36	<0.01	0.02	0.02	<0.01	0.1	1.93
48	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (South)	Bhatora	0.02	3.9	<0.2	<10	<0.01	0.01	0.13	<0.01	0.18	1.31
49	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (South)	Soidpur	0.05	3.0	1.3	45	<0.01	0.02	0.03	<0.01	0.22	2.1
50	Ground	Deep TW	Chandpur	Hajiganj	Purba Barkul	Uttar Barkul	0.02	3.5	<0.2	<10	<0.01	0.01	0.01	<0.01	0.05	2.06
51	Ground	Deep TW	Chandpur	Hajiganj	Purba Barkul	Dakshin Barkul (M	0.01	3.6	<0.2	<10	<0.01	0.01	0.02	<0.01	0.08	2.09
52	Ground	Deep TW	Chandpur	Hajiganj	Purba Barkul	Dhakin Raicho	0.01	3.4	<0.2	<10	<0.01	0.01	0.02	<0.01	0.08	0.52
53	Ground	Deep TW	Chandpur	Hajiganj	Purba Barkul	Madhya Barkul	0	3.3	<0.2	<10	<0.01	0.02	0.02	<0.01	0.09	0.61
54	Ground	Deep TW	Chandpur	Hajiganj	Purba Barkul	Uttar Raicho	0	3.6	<0.2	<10	<0.01	0.01	<0.01	<0.01	0.01	0.56
55	Ground	Deep TW	Chandpur	Hajiganj	Paschim Barkul	Randhanimura	0.01	0.7	0.7	<10	<0.01	0.01	0.01	<0.01	0.02	0.67
56	Ground	Deep TW	Chandpur	Hajiganj	Gondovpur	Nischintapur	0	0.8	0.3	<10	<0.01	0.01	0.01	<0.01	0.03	0.63
57	Ground	Deep TW	Chandpur	Hajiganj	Gondovpur	Joyshora	0	1.4	2.7	<10	<0.01	0.01	0.04	<0.01	0.58	0.53
58	Ground	Deep TW	Chandpur	Hajiganj	South Gondovpur	Vaurpara	0.01	1.7	0.4	<10	<0.01	0.03	0.02	<0.01	0.08	0.43
59	Ground	Deep TW	Chandpur	Hajiganj	Gondovpur	Pachai	0	1.4	1.5	<10	<0.01	0.01	<0.01	<0.01	0.02	0.3
60	Ground	Deep TW	Chandpur	Hajiganj	South Gondovpur	Hotani	0.01	1.0	<0.2	<10	<0.01	0.01	<0.01	<0.01	0.02	0.33
61	Ground	Deep TW	Chandpur	Hajiganj	South Gondovpur	Deshgaon	0.01	4.9	<0.2	<10	<0.01	0.01	0.02	<0.01	0.13	0.7
62	Ground	Deep TW	Chandpur	Hajiganj	Puba Hatile	Ganganagar	0.06	4.4	0.6	<10	<0.01	0.01	0.03	<0.01	0.21	0.82

Data on Water Quality Parameters in Haziganj Upazila

ID	Type of Source	Source of sample	District	Upazila	UNION	Village	Manganese mg/l	Phosphate mg/l	Nitrogen (Ammonia) mg/l	Sulfate mg/l	Arsenic mg/l	Copper mg/l	Lead mg/l	Nickel mg/l	Zinc mg/l	Barium (mg/l)
63	Ground	Deep TW	Chandpur	Hajiganj	Puba Hatile	Purbo Hatia	0.06	0.8	0.7	<10	<0.01	<0.01	0.03	<0.01	0.15	0.48
64	Ground	Deep TW	Chandpur	Hajiganj	Puba Hatile	Harian	0.07	<0.5	1	11	<0.01	0.02	0.02	<0.01	0.14	0.62
65	Ground	Deep TW	Chandpur	Hajiganj	Puba Hatile	Tongipur	0.07	1.5	1	103	<0.01	0.01	0.02	<0.01	0.17	0.67
66	Ground	Deep TW	Chandpur	Hajiganj	Puba Hatile	Purba Noapara	0.01	1.4	1.2	30	<0.01	0.01	0.01	<0.01	0.07	0.47
67	Ground	Deep TW	Chandpur	Hajiganj	Puba Hatile	Laokara	0.02	0.9	1.3	43	<0.01	0.02	0.01	<0.01	0.12	0.6
68	Ground	Deep TW	Chandpur	Hajiganj	Paschim Barkul	Debipur	0.01	1.4	<0.2	<10	<0.01	0.01	0.01	<0.01	0.02	0.25
69	Ground	Deep TW	Chandpur	Hajiganj	Paschim Barkul	Kuruli	0.01	1.1	2.5	<10	<0.01	0.01	<0.01	<0.01	0.03	0.29
70	Ground	Deep TW	Chandpur	Hajiganj	Paschim Barkul	Gopalkhur	0.01	1.9	0.8	<10	<0.01	0.01	0.01	<0.01	0.04	0.3
71	Ground	Deep TW	Chandpur	Hajiganj	Paschim Barkul	Brahmanichoo	0.01	1.6	<0.2	<10	<0.01	0.01	0.01	<0.01	0.07	0.62
72	Ground	Deep TW	Chandpur	Hajiganj	Paschim Barkul	Nathchora	0.02	1.1	<0.2	<10	<0.01	0.01	0.02	<0.01	0.08	0.98
73	Ground	Deep TW	Chandpur	Hajiganj	Puba Barkul	Kondra	0.01	1.8	<0.2	<10	<0.01	0.01	0.01	<0.01	0.06	0.67
74	Ground	Deep TW	Chandpur	Hajiganj	Puba Barkul	Dakatia Char (Noa	0.01	1.2	<0.2	<10	<0.01	0.01	<0.01	<0.01	0.01	0.73
75	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (North)	Mohabbatpur	0.01	1.6	<0.2	<10	<0.01	0.01	0.04	<0.01	0.34	0.8
76	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (North)	Shihircho	0.02	5.1	<0.2	<10	<0.01	0.01	0.2	<0.01	0.45	0.76
77	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (North)	Marki	0.03	1.7	1.1	22	<0.01	0.02	0.01	<0.01	0.09	1.17
78	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (North)	Pirojpur	0.03	1.2	0.6	<10	<0.01	0.01	0.02	<0.01	0.14	1.04
79	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (North)	Tarapuka	0.01	1.8	<0.2	<10	<0.01	0.01	0.01	<0.01	0.26	0.88
80	Ground	Deep TW	Chandpur	Hajiganj	Kalacho (North)	Baniacho	0.03	1.2	<0.2	<10	<0.01	0.01	0.03	<0.01	0.28	1.17
81	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon (North)	Purba Rajargaon	0.01	<0.5	<0.2	<10	<0.01	0.02	<0.01	<0.01	0.06	0.87
82	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon (North)	Ahmadabad	0.01	0.7	<0.2	48	<0.01	0.01	0.02	<0.01	0.1	1.81
83	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon (North)	Menapur	0.01	0.9	<0.2	54	0.47	0.08	0.07	0.05	0.92	1.35
84	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon (North)	Nairain	0.01	2.2	0.4	38	<0.01	0.02	0.03	<0.01	0.29	1.16
85	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon (North)	Char Riani	0.01	1.3	0.5	74	<0.01	0.01	0.01	<0.01	0.06	1.4
86	Ground	Deep TW	Chandpur	Hajiganj	Rajargaon (North)	Malapara	0.01	1.8	<0.2	84	<0.01	0.01	0.02	<0.01	0.08	1.31

Annex – F

Data of Vandaria Upazila

Data on Water Quality Parameters in Vandaria Upazila

ID	TYPE	Type of Source	Type of sample	Source of sample	DPHE_ Circle	District	Upazila	Chloride mg/l	Total Hardness as CaCO3 mg/l	Iron mg/l	Calcium mg/l	Magnesium mg/l	Sulfate mg/l	Potassium mg/l	Sodium mg/l	Phosphate mg/l
1	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	770	165	0.848	33	20	6.6	4.73	732	0.865
2	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	634	132	0.243	25	17	1.9	3.86	657	0.7
3	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	600	124	0.318	33	10	2.2	3.75	620	0.673
4	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	1098	126	0.22	28	13	2.1	4.74	884	0.976
5	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	532	83	0.138	25	5	2.4	3.33	497	0.795
6	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	709	124	0.261	30	12	1	4.92	732	0.973
7	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	1363	339	2.11	57	48	0.3	10.02	1042	1.145
8	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	784	120	0.501	31	10	0	4.33	769	0.905
9	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	627	83	0.226	23	6	1.5	3.82	531	0.904
10	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	770	132	1.349	23	18	10.9	4.76	879	0.527
11	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	511	83	0.433	16	10	0.3	3.28	531	0.536
12	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	770	165	0.35	33	20	1.5	4.49	779	0.552
13	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	566	124	0.245	16	20	1.9	3.6	457	0.519
14	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	402	190	0.978	33	26	2.7	5.47	865	0.601
15	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	1220	207	0.254	36	28	2.9	4.71	1138	0.671
16	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	975	198	0.941	33	28	2	5.93	671	0.757
17	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	920	165	0.286	33	20	1.4	5	1500	0.566
18	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	954	165	1.513	33	20	2.9	6	950	0.615
19	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	954	145	0.332	33	15	1.9	6	900	0.418
20	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	886	145	0.216	33	15	0.5	5	900	0.813
21	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	811	124	0.57	25	15	2.2	5	800	0.385
22	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	900	165	0.286	33	20	1.7	6	800	0.768
23	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	1452	248	0.309	49	30	1.9	8	1300	0.665
24	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	1636	413	1.307	41	76	33.3	14	1300	0.399
25	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	900	186	0.23	36	23	1.5	5	750	0.458
26	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	982	186	0.255	33	25	2	6	950	0.612
27	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	852	186	0.253	25	30	2.6	7	1050	0.746
28	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	1111	198	0.322	25	33	2.9	8	1100	0.747
29	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	1022	207	2.246	38	27	0	7	900	0.824
30	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	1111	227	0.679	49	25	1.9	7	1000	0.414
31	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	1152	227	0.352	34	34	1.2	7	1050	0.452
32	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	954	182	0.269	33	24	1.2	6	1000	1.849

Data on Water Quality Parameters in Vandaria Upazila

ID	TYPE	Type of Source	Type of sample	Source of sample	DPHE_ Circle	District	Upazila	Nitrogen (Ammonia) mg/l	Nitrogen (Nitrate) mg/l	Nitrogen (Nitrite) mg/l	Arsenic mg/l	Chromium mg/l	Aluminium mg/l	Zinc mg/l	Barium mg/l
1	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.51	8	0.0054	0.002	0.004	0.2	0.05	0.4
2	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.42	6	1.1264	0	0.019	0.1	0	0.6
3	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.4	6	1.206	0	0.017	0.1	0	0.6
4	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.03	11	2.0452	0.003	0.003	0.1	0.045	1.6
5	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.35	5	0.0097	0	0	0.1	0.111	0.3
6	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.47	7	0.0116	0	0.016	0.1	0.03	0.7
7	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.7	7	0.0054	0.001	0.036	0.1	0	1.5
8	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.52	8	0.0078	0	0.012	0.1	0	0.5
9	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.42	6	0.0223	0.001	0	0.1	0	0.4
10	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.51	8	0.0145	0.004	0	1.1	0.091	0.5
11	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.34	5	1.1737	0	0	0.1	0.301	0.3
12	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.51	8	0.0116	0	0	0.1	0.633	0.9
13	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.38	6	0.0728	0	0	0.1	0	0.7
14	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.27	4	3.1402	0.001	0	0.1	0.318	0.8
15	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.81	10	0.008	0	0	0.1	0.028	1
16	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.65	10	2.399	0	0	0.1	0	0.7
17	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.61	9	2.2726	0	0	0.012	0	0.7
18	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.64	10	0.0228	0	0	0.032	0	0.82
19	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.64	10	1.7707	0	0	0.023	0	0.94
20	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.59	9	0.0131	0	0	0.008	0	0.75
21	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.54	8	0.0078	0	0	0.042	0	0.75
22	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.6	9	2.0794	0	0	0.015	0.022	0.77
23	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.6	11	2.8424	0	0	0.012	0.207	1.07
24	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.8	9	0.0107	0	0	0.016	0.497	1.06
25	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.6	9	0.1261	0	0	0.01	0	0.43
26	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.65	10	2.0536	0	0	0.017	0	0.74
27	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.57	8	0.0109	0	0	0.015	0.211	0.68
28	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.74	11	0.451	0.001	0	0.012	0.01	0.96
29	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.68	10	0.0065	0.001	0	0.01	0.1	0.81
30	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.74	11	0.0068	0.001	0	0.013	0	0.73
31	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.77	12	2.9784	0.001	0	0.024	0	0.77
32	TDW	Ground	Water	Deep TW	Barisal	Pirojpur	Vandaria	0.64	10	0.0063	0	0	0.017	0.098	0.79

Annex – G

Data of ChapaiNawabganj Upazila

Data on Water Quality Parameters in ChapaiNawabganj Sadar Upazila

ID	TYPE	Type of Source	Type of sample	Source of sample	DPHE_ Circle	District	Upazila	Alkalinity (HCO3) mg/l	Chloride mg/l	Total Hardness as CaCO3 mg/l	Iron mg/l	Manganese mg/l	Calcium mg/l	Magnesium mg/l	Sulfate mg/l	Potassium mg/l	Sodium mg/l
1	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	505	14.2	263	0.54	0.62	70.9	20.6	1.97	0.76	66.7
2	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	440	8.78	259	0.74	0.6	77.1	15.9	1.69	0.76	69.4
3	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	521	8.54	361	1.44	0.94	103	25.1	7.69	0.86	38
4	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	497	61.4	467	3.25	0.91	135	31.1	5.24	1.19	31.5
5	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	509	14.2	287	1.9	0.65	86.6	17	2.4	0.75	63
6	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	509	29.9	374	2.44	0.54	94.8	32.8	18.4	0.86	60
7	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	557	26.8	442	8.29	1.07	125	30.9	0.78	2.84	28.5
8	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	485	9.18	406	21.7	0.88	102	36.2	0.49	2.84	31.5
9	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	485	2.1	353	0.76	0.95	104	22.2	0.52	3.44	25.6
10	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	581	41.1	514	2.18	0.8	155	30.7	2.24	4.2	22.5
11	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	412	35.2	380	0.5	0.84	113	23.7	6.04	7.55	17.5
12	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	557	74.5	484	0.73	0.78	133	36.4	36.4	28.9	55.5
13	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	617	8.92	456	4.82	1.1	128	32.5	0.52	4.85	17.6
14	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	353	11	306	5.07	0.39	76.4	27.6	1.16	2.78	22.5
15	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	424	27.3	363	1.92	0.6	104	24.6	2.5	1.64	38.9
16	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	460	7.87	349	1.26	0.05	101	23.1	3.62	1.12	44
17	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	303	15.2	196	2.3	0.86	56.7	13	3.02	2.51	19
18	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	442	7.08	303	0.63	0.32	82	23.4	16	1.19	45.8
19	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	509	59.8	411	14.2	1.93	126	23.2	0.45	7.91	40
20	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	485	37.8	396	1.1	0.74	124	20.9	6.53	4.58	40
21	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	545	25.2	530	0.53	0.52	175	22	6.49	0.81	83.7
22	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	509	82.9	482	2.44	0.9	140	31.7	34.8	3.64	34.5
23	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	327	18.1	269	3.1	0.88	77.3	18.2	4	3.69	18.2
24	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	448	8.4	286	0.19	0.66	77.8	22	4.6	1.25	37.6
25	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sa	267	4.72	146	5.22	0.63	50.2	4.91	0.84	3.46	7.3

Data on Water Quality Parameters in ChapaiNawabganj Sadar Upazila

ID	TYPE	Type of Source	Type of sample	Source of sample	DPHE_ Circle	District	Upazila	Phosphate mg/l	Nitrogen (Ammonia) mg/l	Nitrogen (Nitrate) mg/l	Nitrogen (Nitrite) mg/l	Arsenic mg/l	Chromium mg/l	Aluminium mg/l	Zinc mg/l	Barium mg/l
1	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	1.18	0.43	3.82	0.01	0.01	0.01	0.1	0.03	0.52
2	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	1.02	0.37	4.95	0.01	0.01	0.01	0.1	0.25	0.67
3	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	0.89	0.77	2.7	0.01	0.01	0.01	0.1	0.05	0.53
4	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	1.32	0.58	8.05	0.01	0.12	0.01	0.1	0.09	1.19
5	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	1.57	0.37	5.44	0.01	0.01	0.01	0.2	0.1	0.45
6	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	0.98	0.32	3.48	0.02	0.01	0.01	0.3	0.32	0.65
7	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	1.67	0.63	23.3	0.01	0.58	0.01	0.1	0.1	0.96
8	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	1.27	0.44	38.4	0.06	0.46	0.01	0.2	0.25	1.23
9	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	1.66	0.26	6.93	0.01	0.08	0.01	0.1	0.01	0.99
10	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	1.91	0.72	10.5	0.01	0.11	0.01	0.1	0.12	1.56
11	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	1.10	0.32	6.72	0.01	0.02	0.01	0.1	0.03	1.09
12	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	0.95	0.56	48.8	0.02	0.01	0.01	0.1	0.08	1.42
13	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	1.28	0.68	12.6	0.01	0.19	0.01	0.1	0.08	1.31
14	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	1.04	0.27	12.3	0.01	0.04	0.01	0.1	0.09	0.95
15	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	1.29	0.31	8.98	0.03	0.01	0.01	0.1	0.05	0.57
16	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	1.22	0.26	11.3	0.01	0.01	0.01	0.1	0.05	0.56
17	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	1.02	0.31	11.5	0.01	0.03	0.01	0.1	0.09	0.71
18	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	0.99	0.33	12.2	0.01	0.01	0.01	0.3	0.21	0.35
19	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	1.15	N.D	25	0.01	0.05	0.01	0.1	0.13	1.22
20	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	1.22	0.34	11.4	0.02	0.01	0.01	0.1	0.05	1
21	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	1.20	0.31	5.95	0.01	0.01	0.01	0.1	0.03	0.6
22	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	1.25	0.79	13.4	0.01	0.04	0.01	0.1	0.08	1.45
23	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	2.39	0.32	6.17	0.03	0.05	0.01	0.1	0.11	0.64
24	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	1.12	0.23	3.18	0.01	0.01	0.01	0.1	0.06	0.37
25	TDW	Ground	Water	Deep TW	Rajshah	ChapaiNaw	Chapai Sad	3.70	0.3	13.7	0.04	0.13	0.01	0.1	0.04	0.42

Annex – H

Data of Bakerganj Upazila

Data on Water Quality Parameters in Bakerganj Upazila

ID	TYPE	Type of Source	Type of sample	Source of sample	District	Upazila	TDS mg/l	pH	Iron mg/l	Manganese mg/l	Phosphate mg/l	Nitrogen (Ammonia) mg/l	Nitrogen (Nitrate) mg/l	Arsenic mg/l	Silica mg/l	Barium mg/l
1	TDW	Ground	Water	Deep TW	Barisal	Bakergonj	646.7	8	0.11	0.02	0.44	0.587	0.5	0.08	20.3	0.1
2	TDW	Ground	Water	Deep TW	Barisal	Bakergonj	560	8	0.12	0.01	0.91	0.643	0.5	1.43	22.4	0.1
3	TDW	Ground	Water	Deep TW	Barisal	Bakergonj	566.7	8.1	0.09	0.021	0.52	0.576	0.4	1.47	20.7	0.1
4	TDW	Ground	Water	Deep TW	Barisal	Bakergonj	706.7	7.8	0.15	0.014	1.07	0.85	0.4	1.61	22.4	0.2
5	TDW	Ground	Water	Deep TW	Barisal	Bakergonj	553.3	8	0.07	0.018	1.19	0.87	0.5	1.68	21.9	0
6	TDW	Ground	Water	Deep TW	Barisal	Bakergonj	506.7	7.8	0.05	0.014	1.22	0.77	0.5	1.62	22.7	0.1

Annex – I

Data of Faridganj Upazila

Data on Water Quality Parameters in Faridganj Upazila

ID	TYPE	Type of Source	Type of sample	Source of sample	District	Upazila	TDS mg/l	pH	Iron mg/l	Manganese mg/l	Phosphate mg/l	Nitrogen (Ammonia) mg/l	Nitrogen (Nitrate) mg/l	Arsenic mg/l	Silica mg/l
1	TDW	Ground	Water	Deep TW	Chandpur	Faridganj	280	6.6	0.6	0.033	0.15	0.32	0.4	0	63.2
2	TDW	Ground	Water	Deep TW	Chandpur	Faridganj	266.7	7	1.21	0.005	0.26	0.07	0.5	0	58.4
3	TDW	Ground	Water	Deep TW	Chandpur	Faridganj	240	7	1.43	0.02	0.30	0.41	0.6	0	63.9
4	TDW	Ground	Water	Deep TW	Chandpur	Faridganj	253.3	7.3	0.45	0.009	0.19	0.13	0.5	0	50.5
5	TDW	Ground	Water	Deep TW	Chandpur	Faridganj	260	7.3	0.84	0.016	0.49	0.39	0.7	0.37	56.8
6	TDW	Ground	Water	Deep TW	Chandpur	Faridganj	320	7	1.47	0.029	0.25	0.27	0.7	0	61.5