2002

Arsenic Contamination of Groundwater in Chapainawabganj, Bangladesh: A Sustainable Mitigation Option

Islam, Md. Shariful

University of Rajshahi

http://rulrepository.ru.ac.bd/handle/123456789/982

ARSENIC CONTAMINATION OF GROUNDWATER IN CHAPAINAWABGANJ, BANGLADESH: A SUSTAINABLE MITIGATION OPTION

M. Phil. Thesis

SUBMITTED BY

MD. SHARIFUL ISLAM
Roll No. 62
Batch: JULY 1999

August, 2002

Department of Geology and Mining
University of Rajshahi
Rajshahi, Bangladesh

ARSENIC CONTAMINATION OF GROUNDWATER IN CHAPAINAWABGANJ, BANGLADESH: A SUSTAINABLE MITIGATION OPTION

A Thesis Submitted to the Department of Geology and Mining, University of Rajshahi, in Fulfillment of the Requirements for the Degree of Master of Philosophy in Geology and Mining.

SUBMITTED BY

MD. SHARIFUL ISLAM
Roll No. 62
Batch: JULY 1999

RESEARCH SUPERVISORS

Professor Mushfique Ahmed

Professor Quamrul Hasan Mazumdar

DEPARTMENT OF GEOLOGY AND MINING
UNIVERSITY OF RAJSHAHI, RAJSHAHI, BANGLADESH
AUGUST, 2002

CERTIFICATE

The thesis submitted by the candidate embodies the results of investigation carried out by him under our direct

We certify that this work has

other Degree or Diploma.

Hasan 23.7.2002

Dr. Quamrul Hasan Mazumdar
Professor
Department of Geology and Mining
University of Rajshahi, Rajshahi.

CERTIFICATE

The thesis submitted by the candidate embodies the results of investigation carried out by him under our direct supervision and guidance. We certify that this work has not been presented for any other Degree or Diploma.

23.7.'02

Dr. Mushfique Ahmed
Professor
Department of Geology and Mining
University of Rajshahi, Rajshahi.

Hasan 23.7.2002

Dr. Quamrul Hasan Mazumdar
Professor
Department of Geology and Mining
University of Rajshahi, Rajshahi.

Dedicated to the
memory of My Father

ABSTRACT

About 97% Bangladeshi people use tube well water for drinking purposes. In recent time, this water has been found to contain arsenic concentration above the permissible limit. Arsenic contaminated groundwater has already become a health hazard for a large part of the population. People with long-term exposure to arsenic polluted groundwater have been affected by arsenicosis as well as related complications; and some people are reported to have died.

To mitigate the arsenic contaminated groundwater problem, a sustainable mitigation is needed in the country immediately. From this point of view, an attempt has been taken to develop a sustainable mitigation technique in the present research. The developed mitigation system has been implemented in Rajarampur, a severely arsenic affected village of Chapainawabganj district.

Rajarampur was selected as the site for field implementation as it has now been established as a hotspot of arsenic contaminated groundwater. It is a semi-urban locality of Nawabganj Municipality situated in northwestern Bangladesh.

Physiographically, the study area lies within Ganges-Mahananda flood plain characterized by gentle topography with a mean elevation ranges from 20 meter to 25 meter. Geologically, it lies in the Rangpur Platform, which is a stable part of the Bengal Basin. Stratigraphically, the study area is characterized by a thick sequence of Cretaceous to Recent sediments overlying the Archean basement thickness of the Quaternary sediment of the area is 60 meter to 111 meter.

In the early 1990s, high concentrations of arsenic were first reported in the groundwater of Chapainawabganj of Bangladesh. It is estimated that about 25 million people are exposed to arsenic contamination, 59 districts out of 64 have arsenic contaminated groundwater, 249 *upazilas* out of 467 affected, and over 7000 patients have been identified. About 27% of shallow tube wells exceed the Bangladesh standard limit (0.05 ppm) and 42% exceed the WHO guideline value (0.01) for arsenic in drinking water. In the Rajarampur village, the arsenic concentration ranges from 0.035 to 1.08 ppm.

On basis of regional groundwater development potentiality, the study area is characterized by simple geology comprising younger alluvium. According to the UNDP

Classification (1982), the area belongs to zone F, which covers the flood plain of Rajshahi district. National Water Plan of WARPO (former MPO), however, puts the area in the catchment area no 31 of planing area no 12 of the NW region in the Catchment Planing and Regions Map of Bangladesh.

According to the geological cross sections constructed on the basis bore log data, it is inferred that the aquifer of study area is more of less confined. The aquifer mostly overlies the Barind Clay layer, and sometimes the Trap Wash. According to the BGS & MML, there are three known water-bearing layers in the area. The thickness of these layers are 10 to 50 meter, 20 meter and 10 to 60 meter respectively The horizontal/vertical permeability of these layers is 1/0.1to 10/1 m/d, to 20/2 m/d and 1/0.1 to 50/5 m/d respectively. The confined/unconfined storage of these layers is 0.001/0.1 to 0.1, 0.001/0.15 and 0.001/0.2 respectively. The porosity of these the layers is 0.1, 0.4 and .04.

From the chemical analyses of groundwater of the study area it shows that the pH of groundwater ranges from 7.5 to 9.8; EC concentration ranges from 550 μS/cm to 745 μS/cm; TDS concentration ranges from 357.5 ppm 484.25 ppm; Ca^{2+} concentration ranges from 67.13 ppm to 150 ppm; Mg^{2+} from 2 ppm to 41.63 ppm; Na^{+} from 1.25 ppm to 15 ppm; K^{+} from 0.3 to 7.2 ppm; Fe^{total} from 0.11 ppm to 6.4 ppm; HCO_3^- from 273 ppm to 483 ppm; Cl^- from 12.00 ppm to 23.37 ppm; SO_4^{2-} from 0.00 ppm to 1.00 ppm; NO_3^- from 0.00 ppm to 1.00 ppm; As from 0.035 ppm to 1.8 ppm; and the total hardness from 239.46 ppm to 367.68 ppm.

By the genetic classification, the groundwater of the study area is of “Normal Chloride”, “Normal Sulphate” and “Supper Carbonate” type water. Based on Total hardness groundwater of the study area is of “Very hard”.

According to drinking water quality standards the groundwater of the study area is harmful for public health as the arsenic concentration exceed the WHO guide line value (0.01 ppm). According to agriculture and irrigation water quality standards, the groundwater of the study area show very good quality but presence of arsenic make the potable use of groundwater dangerous.

Cross plot of Arsenic against Sulfate has a very strong positive correlation (R^2= 0.6866); Cross plots of arsenic with other parameters, on the other hand, show only

week relationships; Arsenic against Calcium shows a very low negative correlation (R^2= 0.007); Arsenic against the Magnesium a very low positive correlation ((R^2= 0.009); Arsenic against Sodium (Na^+) a positive correlation (R^2= 0.0185); Arsenic against Potassium (K^+) a low negative correlation (R^2= 0.0027); Arsenic against Total Iron a strong positive correlation (R^2= 0.015); Arsenic against Bicarbonate a positive correlation (R^2= 0.0008); Arsenic against the Chloride a positive correlation (R^2= 0.0027); and Arsenic against Nitrate ($NO3^-$) a positive correlation (R^2= 0.0218).

From the Piper Trilinear Diagram and Expanded Durov Diagram is seems that the contaminated groundwater of the study area is $Ca\text{-}Mg\text{-}HCO_3{}^-$ type, which are mainly recently recharged waters. Facies mapping approach of the groundwater of the study area indicates Calcium-Magnesium to Calcium-Sodium cation facies and Bicarbonate to Bicabonate-Chloride-Suphate anion facies.

As the groundwater is of good quality except arsenic, it can be used as potable water after treatment. From this point of view an attempt has taken aim to mitigate the arsenic contamination by ferric oxyhydroxide as an adsorbent. The performance of the mitigation technique is very good. It decontaminates 60 liters of contaminated groundwater of As concentration of 0.932 ppm to 0.01 within few minutes and the system runs 15 days with supplying 60 liters of fresh water per day arsenic concentration of the treated water of 15 th day is 0.045 ppm. It also decontaminates 60 liters of contaminated groundwater of arsenic concentration 0.25 ppm to 0.01ppm and supplies fresh water for 30 days with a an amount of 60 liters per day, arsenic concentration of treated water of the 30 th day is 0.05 ppm. The trend of the decontamination curves indicate that the efficiency of the system is decreasing after every day in the cycle as the medium becomes more saturated with ions.

From the sludge recycling data, it shows that the 90 % arsenic release from the sludge after washing it by sodium hydroxide solution. After several washes with water, it acts as initial ferric oxyhydroxide at neutral pH, and it decontaminates the arsenic contaminated groundwater like the original adsorbent. The performance of recycled sludge in case of arsenic decontamination is the same as it was first. The rate of flow (30 liters per hour) of water for the system is excellent. Taste of the treated water is good, and users accept the system very much as any body can maintain this system.

ACKNOWLEDGEMENTS

I would like to express my profound gratitude, appreciation to my reverend teacher and research supervisor Dr. Mushfique Ahmed, Professor, Department of Geology and Mining, University of Rajshahi for his valuable guidance, advice and encouragement throughout the completion of the whole research work.

I would also like to express my profound gratitude, appreciation to Dr. Richard Anstiss, Senior Lecturer, Department of Applied Science, Auckland University of Technology, Auckland, New Zealand for his valuable guidance and intellectual advice for this research work. I would like to offer my thanks to the New Zealand-South Asia Bilateral Development Program, New Zealand for partial financial support for this research work.

I would also like to express my profound gratitude, appreciation to my reverend teacher and research supervisor Dr. Quamrul Hasan Mazumder, Professor, Department of Geology and Mining, University of Rajshahi for his helpful attitude and generous co-operation in various sections such as mapping, hydrological interpretation of the research work.

My warmest thanks and sincere gratitude goes to the honorable Chairman and all respected teachers of the Department of Geology and Mining, University of Rajshahi for providing all sorts of departmental and personal help and suggestion during the research work.

My heartiest thanks and indebtedness goes to S. A. Roqibul Ferdous (Saafi) for using his computer to compose this thesis. I'm highly grateful to my brothers, sisters and obviously to my mother for their long encouragement, patience, sacrifice and tolerance during the whole study period.

The Author

CONTENTS

(Continued...)

CHAPTER – 5: WATER QUALITY AND HYDROGEOCHEMISTRY

CHAPTER – 6: SUSTAINABLE MITIGATION OPTION

CHAPTER – 7: CONCLUSION AND RECOMMENDATIONS

Annexure

List of Figures

List of Tables

ABBREVIATIONS

APHA	American Public Health Association
As	Arsenic
BGS	British Geological Survey
BMD	Bangladesh Meteorological Department
BMDA	Barind Multipurpose Development Authority
BOD	Biological Oxygen Demand
BWDB	Bangladesh Water Development Board
BWPCB	Bangladesh Water Pollution Control Board
°C	Degree Celsius (Centigrade)
cm	Centimeter
DOC	Dissolved Oxygen Content
DFID	Department for International Development
DPHE	Department of Public Health Engineering
DOE	Department of Environment
DTW	Deep Tube well
EC	Electrical Conductance
Eh	Redox Potential
gl	Ground Level
GoB	Government of Bangladesh
GSB	Geological Survey of Bangladesh
H_T	Total Hardness
Kg	Kilogram
Km	Kilometer
l	Liter
LGED	Local Government Engineering Department
Ltd.	Limited
m	Meter
meq	Milliequivalent
meq/l	Milliequivalent per liter
mg	Milligram
mg/l	Milligram per liter
mm	Millimeter
MSL	Mean Sea Level
NGO	Non Government Organization
NIPSOM	National Institute of Preventive and Social Medicine
pH	Hydrogen Ion Concentration
ppm	Parts per million
PI	Permeability Index
S	Sample
SAR	Sodium Absorption Ratio
SRDI	Soil Resource Development Institute
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TS	Total Sulfur
UNDP	United Nations Development Programme
UNICEF	United Nations International Children's Emergency Fund
WHO	World Health Organization
wt	Water Table
YDD	Younger Deltaic Deposit

CHAPTER-1

INTRODUCTION

- INTRODUCTION
- AIM AND OBJECTIVES
- MATERIALS AND METHODS
- GENERAL STATEMENT OF THE STUDY AREA
- REVIEW OF PREVIOUS STUDIES

Chapter –1: INTRODUCTION

1.1 INTRODUCTION:

Bangladesh is a land of rivers, the surface area of which is covered by alluvial sediment. Thus, it becomes a storehouse of huge amount of surface water as well as groundwater. Due to availability of surface water, most rural people of Bangladesh once used to depend on surface water sources (pond, river, channel, etc.). However, surface waters in most cases have not been safe, they were germ infested and consequently a large part of the population fell victim to many types of intestinal diseases. To overcome this problem, various institutions of GoB and NGOs with the assistance of various international organizations undertook an enormous program in Bangladesh for safe drinking water supply to all by sinking tube wells throughout the country. At present, the water supply system of Bangladesh is overwhelmingly based on groundwater providing 97% of population with tube well water (Ahmed, S.A., 2000). These tube wells were intended to supply safe drinking water, but they failed. These waters were found contaminated with Arsenic. The Arsenic contaminated groundwater is becoming a serious health problem for large number of people in Bangladesh. A sizeable population has already been affected by arsenicosis as well as related complications; and many of them are reported to have died.

In the early 1990s, arsenic contamination in groundwater was first exposed in the media. In mid 1990s, a number of scientists, doctors, engineers, and NGOs started reporting the arsenic scenario in detail. By this time, a number of affected people have been identified and the problem was recognized as a major health hazard in Bangladesh.

Chapter –1: INTRODUCTION

Various national and international organizations concentrate their attention to identify the causes of contamination and mitigation of this problem. From the debate and discussion in different scientific forums and publications, it was established that the cause of arsenic contamination in groundwater is natural and geologic. Natural geological processes of sediment transport and deposition are responsible for arsenic contamination of groundwater. During this process sediment carries arsenic adsorbed on to its surface in oxidizing conditions. After burial, the sediment rapidly become reducing, this triggers the release of arsenic from sediment into the groundwater.

Arsenic contamination in Bangladesh is widespread indeed. Almost the entire country is effected. The Statistical survey of (DPHE/BGS/DFID 2000) arsenic contamination of tube well water using stratified sampling has confirmed that with the exception of only a few districts, mainly in the northwest and southeast, the entire Bangladesh is exposed to the contamination. Twenty five percent (25%) of the well samples have arsenic in excess of Bangladeshi permissible limit (0.05 ppm) and 42% in excess of WHO Guide line value (0.01ppm) (WHO, 2001). The population drinking contaminated water exceeding the Bangladesh standard of 0.05 ppm has been estimated to at least 25 million (Water Aid, Bangladesh, 2000). Current estimates of magnitude of arsenic contamination show that 59 out of 64 districts have arsenic contaminated groundwater and 349 out of 460 *Upazilla*s are affected where more than 7000 patients have been identified (Water Aid, Bangladesh, 2000).

Chapter –1: INTRODUCTION

It is clear that the arsenic contaminated groundwater is an enormous problem for the people of Bangladesh and it needs to be mitigated immediately. To tackle the situation, the GoB, NGOs, academic institutions and the international donor organizations have been involved in identifying the technical, social and health issues related to the arsenic contamination of groundwater. The consensus that came out is supplying safe drinking water to the people is quite essential besides the social awareness. To supply arsenic free water, a number of techniques have been developed. These can provide safe drinking water at either community or household levels in some situations.

1. Arsenic free shallow or deeper tube wells.
2. Surface water purification, e.g., PSF.
3. Rainwater harvesting.
4. Dug wells (arsenic free with purification).

However, these options are not feasible for everywhere. Rainwater is not available throughout the year and it may become microbiologically contaminated. In addition, due to high evaporation it cannot be stored for long time. As for deeper aquifer, it is very difficult to sink wells in many parts of the country. In case of surface water, its source becomes dry during lean season in some areas and can become microbiologically contaminated. To provide safe drinking water in areas where the above options fail, decontamination of arsenic contaminated water by Chemical Processes can be used as an alternative. A number of treatment techniques of arsenic contaminated water by chemical process have been proposed by different individuals but most of them are neither working well nor properly sustainable (Table 1.1 through Table 1.8).

Table – 1.1: DPHE/Danida Bucket Treatment Unit

Process	**Oxidation/coagulation/filtration**
Chemical controls	Relies on enhanced coagulation Less dependent upon groundwater Fe Chemical oxidant enhances arsenite removal $PO_4^- > AsO_4^- >> SiO_4^- > F$ High HCO_4^- has -ve impact High Ca/Mg has +ve impact Ideal pH 6.5 to 8 for optima functioning of alum Possible residual Mn
Physical controls	Agitation and duration of coagulation Sand packing in filter Distribution of water over filter Sand grain size and clays Sand Fe and Organic C content Character and rate of flow through filter
Operating procedure	Pour water into the top bucket. Add mixture of aluminium sulphate and potassium permanganate and stir vigorously 20 times. Leave it to settle for 20 hours. Turn tap to send water to lower bucket where it passes through a sand filter. Turn tap in bottom bucket to get drinking water.
Flow - low turbidity	70 litres per hour (but 23 l/hr including 2 hours preparation)
- high turbidity	50 litres per hour (but 23 l/hr including 2 hours preparation)
Time for 20 litres to pass	Approx. 3 hours (1 hour settling + 1 hour filtration)
Litres in 12 hours	60 litres
Batches before deterioration -low turbidity	17 batches – no deterioration
-high turbidity	40% fall in flow after 6 batches, then constant to 15 batches
Examples of claims on effectiveness (Results and references)	Noakhali – 100% As below 50 ppb after treatment (initial levels 120-1000 ppb) DPHE/Danida Arsenic Mitigation Pilot Project Information leaflet 'Arsenic Removal at Household Level' Sitakunda and Gomastapur – 100% As below 50ppb after treatment (initial levels 116-201ppb) Water Aid, March 2000. Household Level Arsenic Removal Methodology, Preliminary Research Report.
Costs (capital and recurrent)	Tk. 300-350 depending on the production cost of the flat cover for the lower bucket.
Contact details	DPHE/Danida Water Supply and Sanitation Components, Arsenic Mitigation Component, 2888, Central Road, Harinarayanpur, Maijdee Court, Noakhali. Ph. 0321 5582

Table – 1.2: SONO 3-KOLSHI FILTER

Process	**Filtration**
Chemical controls	Relies on passive coagulation with Fe and/or adsorption to sand matrix $PO_4^- > AsO_4^- >> SiO_4^- > F$ High HCO_3^- has -ve impact High Ca/Mg has +ve impact
Physical controls	Sand/iron filing/charcoal packing in filter Distribution of water over filter Sand grain size and clays Sand Fe and Organic C content Character and rate of flow through filter
Operating procedure	Pour water into top kolshi. Use water from the bottom kolshi.
Flow - low turbidity	Approx.5 litres per hour
- high turbidity	Approx.5 litres per hour
Time for 20 litres to pass	Approx. 4 hours
Litres in 12 hours	Approx. 60 litres
Batches before deterioration	
- low turbidity	15 batches with no major deterioration
-high turbidity	15 batches with no major deterioration
Claims on effectiveness (Results and references)	As (III) from 800 ppb to less than 50 ppb (2 ppb) As (total) from 1100 ppb to less than 50 ppb (10 ppb) A.H.Khan et al., 'Appraisal of a Simple Arsenic Removal Method for Groundwater of Bangladesh', Journal of Environmental Science and Health, A35(7), 1021-1041 (2000)
Costs (capital and recurrent)	Tk. 325/-
Contact details	Professor A.H. Khan, Department of Chemistry, University of Dhaka, Dhaka – 1000, Dr. A.K.M. Munir, Director, SDC-Environmental Initiative, College More, Courtpara, Kustia 7000

Table – 1.3: STEVENS INSTITUTE TECHNOLOGY

Process	**Coagulation/filtration**
Chemical controls	Relies on enhanced coagulation and co-precipitation(ferrous sulphate) Less dependent upon groundwater Fe Chemical oxidant (chlorine-based) enhances arsenite removal PO_4^-> AsO_4^- >> SiO_4^- > F High HCO_3^- has -ve impact High Ca/Mg has +ve impact
Physical controls	Sand cleaning and packing in filter Distribution of water over filter Sand grain size and clays Sand Fe and Organic C content Character and rate of flow through filter
Operating procedure	Collect 20 litres in bucket, and chemicals and stir rapidly for a minute. Pour water into filter (bucket with holes on top of sand in larger bucket) and wait for water.
Flow - low turbidity	18 litres per hour
- high turbidity	18 litres per hour
Time for 20 litres to pass	Just over one hour
Litres in 12 hours	Approx. 240 litres
Batches before deterioration	
- low turbidity	Steady decline to 50% initial flow after 10 batches
- high turbidity	Steady decline to 50% initial flow after 10 batches
Claims on effectiveness (Results and references)	Kachua – less than 50ppb As Water (max. 25 ppb) from initial As concentration of 300-800 ppb BAMWSP testing programe Kishoreganj and Munshiganj – max. As was 19 ppb from initial untreated concentrations of 280 –468 ppb. Xiaoguang Mean and George P. Korfiatis, 'Removal of Arsenic from Bangladesh Well Water by the Stevens Technology for Arsenic Removal (STAR)'. Occasional Paper.
Costs (capital and recurrent)	Tk. 500/-
Contact details	Professor Meng, Center for Environmental Engineering, Stevens Institute of Technology, Hoboken, NJ 07030. Md. Suruzzaman, Earth Identity Project, House 13A, Road 35, Gulshan, Dhaka – 1212.

Table – 1.4: Ardasha

Process	**Filtration**
Chemical controls	Unknown
Physical controls	Character and flow rate through filter
Operating procedure	Pour water into the tray within bucket. Use tap to get treated water from bottom of bucket.
Flow - low turbidity	1.1 litres per hour
- high turbidity	1.1 litres per hour
Time for 20 litres to pass	19 hours
Litres in 12 hours	13 litres
Batches before deterioration - low turbidity	No deterioration in 15 batches
- high turbidity	No deterioration in 15 batches
Claims on effectiveness (Results and references)	DPHE R & D (Ishtishamul Hoque) have done some assessment and think it reduces As below 50 ppb. Not sure why.
Costs (capital and recurrent)	Tk. 550/-
Contract details	Mr. Sounir Mojumdar, CRS-Ardasha Filter Industries, Chagalnaya Bazar, Chagalnaya, Feni.

Table – 1.5: GARNET FILTER

Process	**Filtration**
Chemical controls	Relies on passive coagulation with Fe and/or adsorption to sand matrix $PO_4^- > AsO_4^- >> SiO_4^- > F$ High HCO_3^- has -ve impact High Ca/Mg has +ve impact
Physical controls	Sand packing in filter Distribution of water over filter Sand grain size and clays Sand Fe and Organic C content Character and rate of flow through filter
Operating procedure	Water frequently topped up in top bucket. Flow regulated to second bucket-regular checking required.
Flow - low turbidity	0.7 litres per hour
- high turbidity	0.4 litres per hour
Time for 20 litres to pass	Approx. 3 hours
Litres in 12 hours	Approx. 7 litres
Batches before deterioration	
- low turbidity	50% initial flow after 7 batches
- high turbidity	50% initial flow after 5 batches
Claims on effectiveness (Results of references)	Removal efficiencies of 70-100 % cited in GARNET's own literature, depending on the presence of As and Fe in the feed water.
Costs (capital and recurrent)	Tk. 250 – 600/- based on material for stand and containers
Contact details	Shah Monirul Kabir, Programme Officer/GARNET Secretary, GARNET-SA, 1/7, Block-E, Lalmatia, Dhaka-1207.

Table – 1.6: BUET ACTIVATED ALUMINIUM FILTER

Process	**Oxidation, sedimentation, filtration, active alumina**
Chemical controls	Semi-reversible adsorption to Al_2O_3 Arsenite removal occurs (through oxidative step)
Physical controls	Formulae to calculate bed-volumes to exhaustion (for 0.1 mg/l AsO_4, 15000 bed volumes) Potentially prone to clogging by FeOH
Operating procedure	Fill the top bucket and add chemicals as directed. Stir vigorously and leave for one hour. Turn tap to allow water into the activated alumina column. Retrieve water from bottom of column.
Flow - low turbidity	Approx. 8 litres per hour
- high turbidity	Approx. 8 litres per hour
Time for 20 litres to pass	Approx. 2.5 hours
Litres in 12 hours	Approx. 96 litres
Batches before deterioration	
- low turbidity	Steady gentle deterioration (<10% over 15 batches)
- high turbidity	Steady gentle deterioration (<10% over 15 batches)
Examples of claims on effectiveness (Results of references)	
Costs (capital and recurrent)	Tk. 1000/-
Contact details	Dr. M.A. Jalil, Department of Civil Engineering, BUET,

Table – 1.7: ALCAN ACTIVATED ALUMINIUM FILTER

Process	**Sedimentation, filtration, active alumina (AAFS-50)**
Chemical controls	Semi-reversible adsorption to Al_2O_3 Arsenite removal occurs (through oxidative step-chlorine)
Physical controls	Formulae to calculate bed – volumes to exhaustion (for 0.1 mg/l AsO_4, 15000 bed volumes) Potentially prone to clogging by FeOH
Operating procedure	Usually attached to well head and pump directly into the filter
Flow rate - low turbidity	>300 litres per hour
- high turbidity	>300 litres per hour
Time for 20 litres to pass	3-5 minutes
Litres in 12 hours	>3600 litres
Batches before deterioration - low turbidity	No deterioration
- high turbidity	No deterioration
Claims on effectiveness (Results and references)	Studies by Department of Chemistry, Dhaka University, and BRAC (Sonargaon) show a removal rate of 100%.
Costs (capital and recurrent)	Tk. US$ 100 (5 year warranty, expected life 10 years). Annual filter material costs US$ 200. Costs expected to fall.
Contact details	M. Saber Afzal, MAGC Technologies Ltd., House 15, Road 5, Dhanmondi, Dhaka-1205.

Table – 1.8: PASSIVE SEDIMENTATION

Process	**Sedimentation- co-precipitation with iron on oxidation**
Chemical controls	Relies on passive coagulation with iron Main control is iron in the water PO_4^-> AsO_4^- >> SiO_4^- > F High HCO_3^- has -ve impact High Ca/Mg has +ve impact
Physical controls	Duration of settling Final water could be contaminated by stirring Bacteriological contamination could be an issue
Operating procedure	Fill kolshi and leave to settle for over 12 hours. Pour top 2/3rds for use and discard lower 1/3 rd.
Flow rate - low turbidity	N/A
- high turbidity	N/A
Time for 20 litres to pass	12 hours (depends on size of kolshi-12 hrs = 30 l kolshi)
Litres in 12 hours	20 litres (depends on size of kolshi-20 litres = 301 kolshi)
Batches before deterioration	
- low turbidity	N/A
- high turbidity	N/A
Claims on effectiveness (Results and references)	2 out of 17 wells tested took As below 50 ppb. Greatest influence seen was negative correlation between As removal and Electrical Conductivity. Water Aid, March 2000. Household Level Arsenic Removal Methodologies, Preliminary Research Report.
Costs (capital and recurrent)	20 litre aluminium kolshi – approx. Tk. 200/-
Contact details	-

The present work has been initiated to develop a sustainable mitigation technique as well as sludge recycling process to make the system renewable and environmentally friendly.

1.2 AIMS AND OBJECTIVES:

The aims of current research work are to develop a sustainable mitigation technique namely a technique to treat the arsenic contaminated tube well water. This work has been carried out under the auspices of New Zealand – Bangladesh Bilateral Development Programme.

Objectives:

Water is a valuable natural resource but we do not care for it, as we should. Only when we buy a bottle of mineral water can we realize that it is almost as valuable as gasoline. Now the groundwater resource of Bangladesh has been contaminated with arsenic creating a serious public health disaster. About 25 million people of Bangladesh are exposed to arsenic poisoning. To find out a simple and appropriate way to mitigate the arsenic problem the present work has been initiated considering the following objectives –

1) To find out the water quality and hydrogeochemistry of the study area, including the magnitude of arsenic contamination.
2) To develop a simple arsenic mitigation technique at households level.
3) To develop a simple sludge recycling process.
4) To make the system sustainable and replicable even at community level.

1.3 MATERIALS AND METHODS:

The study was conducted using following methods:

1) Review of literature and collection of previous works: Books, report and papers related to this study were studied thoroughly and relevant data collection was made.

2) Field investigation: Several field investigations were done in different arsenic contaminated areas to select a suitable site for the study and implementation of the system. After selecting the site, the implementation of the system involved two field trips to the study area every month (15 day intervals). During each visit, new chemicals were added to the system and exhumed sludge was recollected for storage and recycling. At that time, water samples were collected for quality analysis.

✓3) Laboratory Analysis: All laboratory analyses were done in the Hydro geochemistry Laboratory of the Department of Geology and Mining, University of Rajshahi.

    a) Arsenic Decontamination: Decontamination of contaminated water was done by adsorption method, i.e., the adsorption of arsenic on to the surface of ferric oxyhydroxide (FeOOH) at neutral pH. The technique was performed by mixing ferric oxyhydroxide in the contaminated water.

    b) Sludge Recycling: Sludge produced by the mitigation system was recycled by dissolving in HCl then precipitating in Sodium hydroxide solution.

    c) Arsenic Determination: Arsenic in the water was determined by SDDC (Silver diethyldietheo carbamate) method.

d) Water Quality Analysis: The water quality analysis was done by following standard methods (APHA, 1995).

1.4 GENERAL STATEMENT OF THE STUDY AREA:

The study area is situated in the northwestern part of Bangladesh. It is a well-known locality of Chapainawabganj town named Rajarampur.

1.4.1 SITE SELECTION, LOCATION, EXTENT AND COMMUNICATION:

1.4.1.1 Site Selection: To select a suitable location for the study, several field investigations have been conducted in a few seriously arsenic contaminated districts of the country like Jessore, Natore, Pabna and Chapainawabganj. Finally Rajarampur, a seriously arsenic affected locality of Chapainawabganj town one of the arsenic hot spots of Bangladesh has been selected. The reason for the selection of Rajarampur, Chapainawabganj town was its proximity to the University of Rajshahi along with its high arsenic concentration.

1.4.1.2 Location, Extent and Communication: The study area is located in Nawabganj Municipality of Nawabganj Sadar Thana of Chapainawabganj, a northwestern district of Bangladesh. The area is a semi urban locality of Nawabganj Municipality and lying between 24°34′ E to 24°35′ E Latitude and 88°15′ N to 88°18′30′ N Longitude, covering with area of about 4.5 sq. kilometer (Fig. 1.1). This locality is well connected to the main town by several metal roads. Highway and Railway connect the Chapainawabganj town to Rajshahi City.

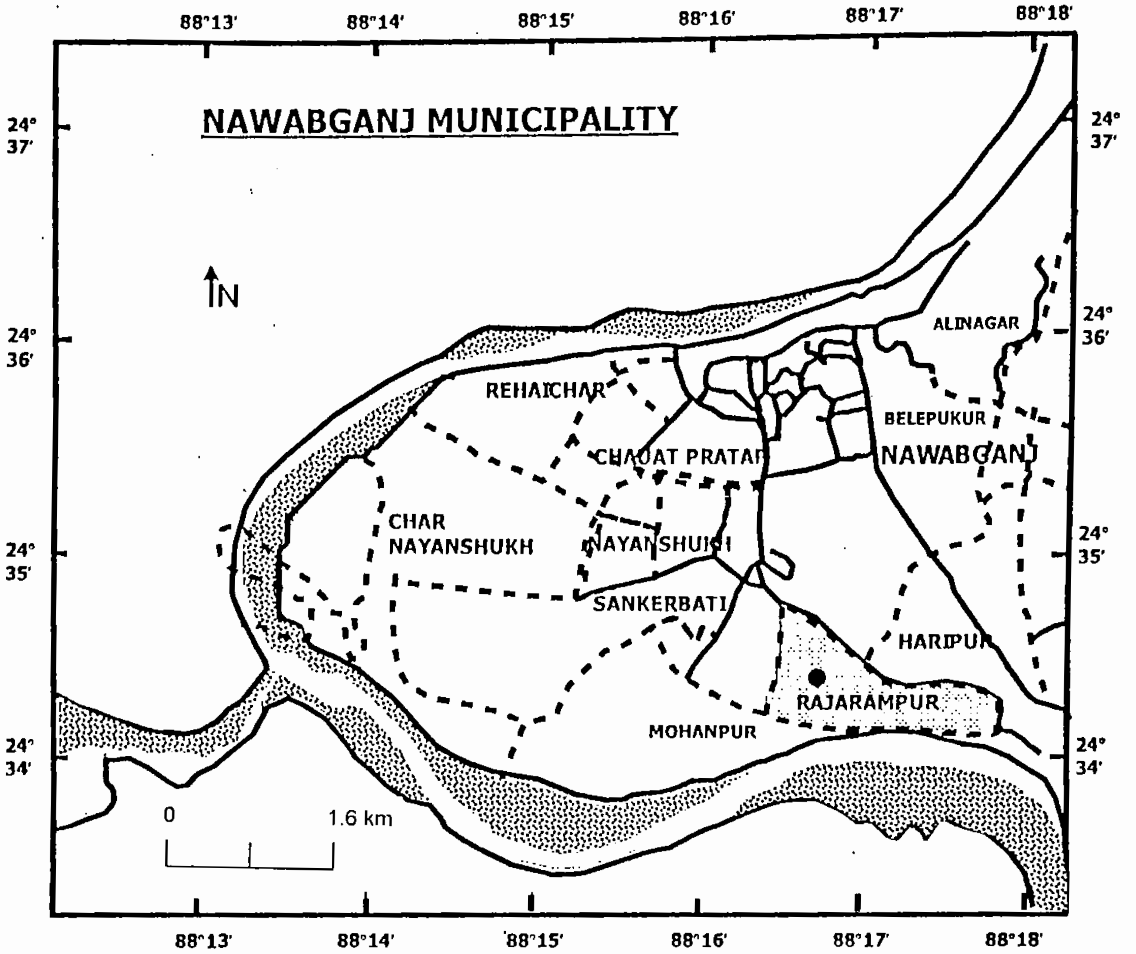


Fig. 1.1: Figure showing the location map of the study area, Rajarampur.

1.4.2 POPULATION AND CULTURE:

The study area has a population of 3,500 persons with male female ratio 49:51. Agriculture is the main profession for most of the families of the area. However, there are some office workers or businesspersons in every family. Most of the households live in *pukka* house and some in tin shade or bamboo structure house. The literacy rate of this area is 87 %. (Bangladesh Bureau of Statistics, 1997)

1.4.3 CLIMATE AND VEGETATION:

The study area experiences hot humid climate during summer and cold in winter. The area is covered by tropical vegetation. Rice is the main agricultural product, besides this dale, sugarcane, wheat, as well as vegetables and fruits. Mango is the main fruit of this area, which is the main cash crop too.

1.5 REVIEW OF LITERATURE AND PREVIOUS STUDIES:

In this subcontinent, diseases caused by arsenic poisoning were first reported in West Bengal, India in 1983 by the experts of the Department of Dermatology, School of Tropical Medicine when they surveyed some villages of 24-Pargonas district. In 1989, the School of Environmental Studies of Jadavpur University, Kolkata initiated vigorous research in this field and found 1.5 million people in West Bengal taking highly arsenic contaminated groundwater regularly with 0.2 million identified as arsenicosis patients. Scientists of Bangladesh became aware of the arsenic problem as the border belt districts of this country are sharing the similar aquifer system. In 1994, the Department of Public Health Engineering (DPHE), Government of Bangladesh, conducted a survey in Chapainawabganj district and identified highly arsenic contaminated groundwater in four tube wells of Chamagram village of the Baraghoria union. By 1996-97, national and international organizations undertook projects to understand the arsenic problem in groundwater and by determining the causes, concentration, effects and mitigation.

In December 1997, a multi-phase project entitled 'Groundwater Studies for Arsenic Contamination in Bangladesh' was undertaken by the Government of Bangladesh, which was originally proposed by World Bank Fact-

Finding Mission, to assess the arsenic problem in Bangladesh and to suggest its mitigation measures. The UK Department of International Development (DFID) gave financial support to the project and appointed the British Geological Survey (BGS) as overall consultant for the project. BGS appointed Mott MacDonald Ltd. (MML) to carry out the bulk of the phase-I work (January 1998). Under the prescribed work, MML carried out an extensive investigation in soil and groundwater with aim to:

- Collate and review existing data for arsenic in the groundwater of Bangladesh.
- Carry out statistical survey of arsenic contamination of the entire Bangladesh (Approximately the southern and eastern two thirds of Bangladesh).
- Carry out a detailed study of three small areas (Thana) to assess the possible source, mobility and fact of arsenic in aquifers.

They had investigated Nawabganj Sadar Thana and its surroundings and in November 1998, they completed their work with submitting the project report.

Department of Public Health Engineering under the financial assistance of UNICEF launched an extensive program to search for safe and uncontaminated aquifer throughout the country for drinking water supply. Under this program, Geohazard Research Group of Dhaka University has been assigned to a project entitled 'Subsurface investigation in the arsenic problem areas of Rajarampur, Chanlai, and Baraghoria in Nawabganj District". They submitted project report in June 1998. In this report, they presented geophysical characteristic of the area as well as mineralogical and sedimentological characteristics of the aquifer materials.

These reports and projects, conducted on arsenic issue in Bangladesh, are presented below.

DPHE, Bangladesh and BGS, UK and DFID, UK, 2000, Groundwater Studies for Arsenic Contamination in Bangladesh, Draft Final Report Summery.

British Geological Survey (BGS) and Mott MacDonald Ltd., UK, 1999, Groundwater Studies for Arsenic Contamination in Bangladesh- Phase-I, Volume S1, S2, S3, S4, S5 and Main Report.

Main Report-Germany, 1999, Arsenic Contamination of Drinking Water in Bangladesh.

British Geological Survey (BGS), 1999, Arsenic Problem in Groundwater in the Bengal Basin: report of a fact-finding visit to West Bengal, Technical Report WD/99/50C.

British Geological Survey (BGS), 1998, Groundwater Studies for Arsenic in Bangladesh, Technical Report WD/91/19.

CHAPTER-2

GENERAL GEOLOGY OF THE STUDY AREA

- GEOMORPHOLOGY
- GEOLOGIC SETTING
- STRATIGRAPHY

Chapter –2: GENERAL GEOLOGY OF THE STUDY AREA

2.1 GEOMORPHOLOGY:

The study area is situated in the north-western part of Bangladesh. It lies within the Ganges-Mahananda flood plain; characterized by gentle topography where mean elevation ranges from 20-25 meter. The Mahananda is the major river in the study area. The Ganges flows regionally in the southwest part of the study area. During rainy season, water volumes of both rivers increase rapidly in short span of time. A considerable part of the area is flooded at that time. The river Mahananda in the study area is guided by a major fault. The straight edge escarpment of the river suggests about the existence of such structural weak zone (Khandoker, 1987).

2.2 GEOLOGIC SETTING:

Bangladesh occupy the major part of the Bengal Basin, which is one of the largest sedimentary basins in the world. The study area is situated in the stable part of the basin named the Rangpur Platform, which is bounded by Rajmahal trap in the west, Bogra Shelf in the south, and Himalayan fore deep in the north. According to Khan & Rahman (1992), the study area is within the Nawabganj-Gaibandha Intracratonic High (Fig. 2.1). It is a well-defined tectonic element in the northwestern Precambrian platform delineated by major basement fault in the north, south and west (Fig. 2.2). The investigated area is southwesterly tilted fault block. The western margin is demarcated by southwestern extensions of Kishangaj-Malda fault. Within the Intracratonic high, the study area represents a depression resulted by the upliftment of the Barind in the eastern margin. It is believed that the upliftment of the Barind was initiated due to crustal movement along the previously described Basement faults (Khan and Sattar, 1994).

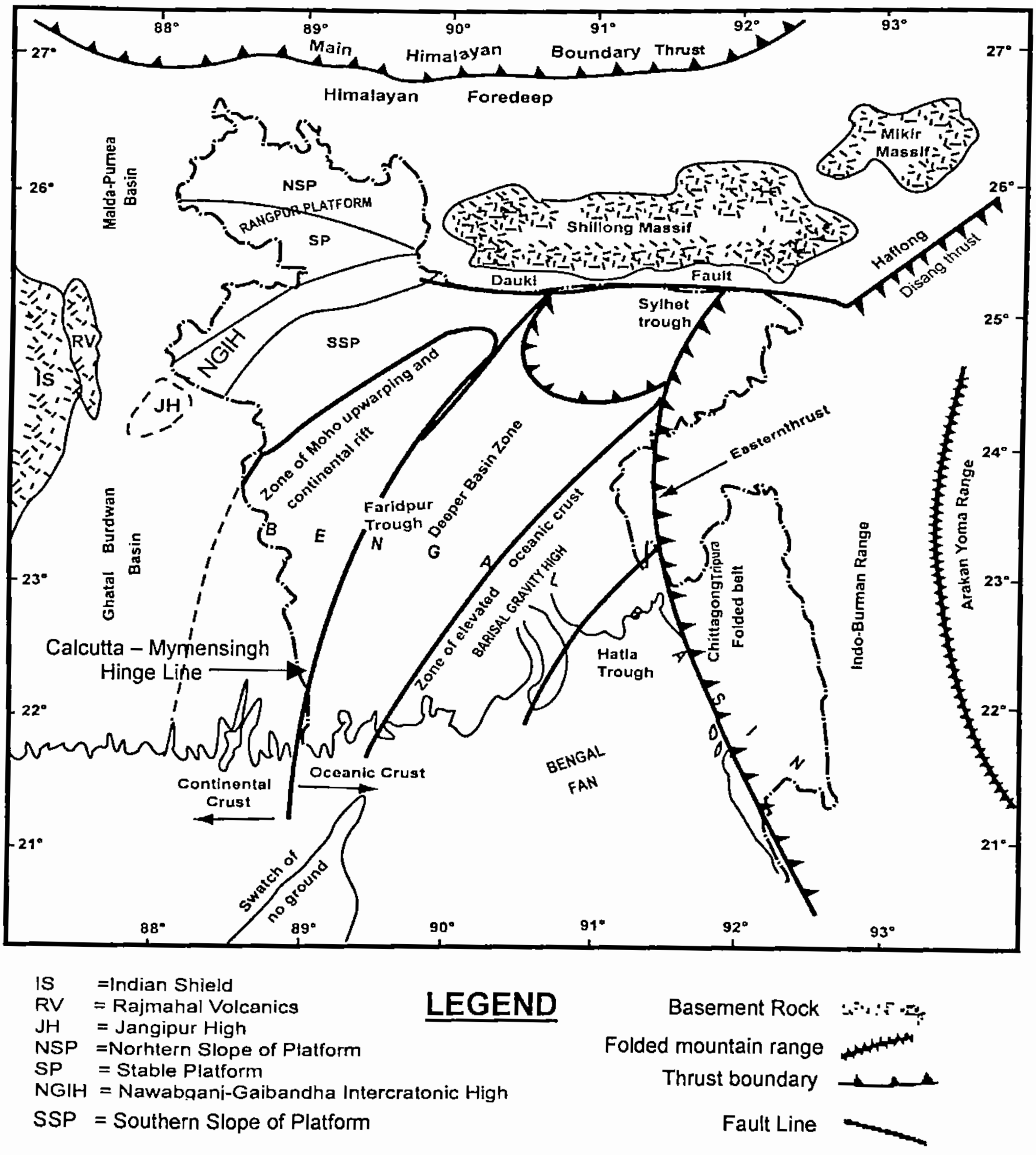


Fig. 2.1: Geotectonic map of Bengal Basin (Chaudhury & Datta 1973, Khan 1991, Khan & Rahman 1992 Khan & Agarwal, 1993).

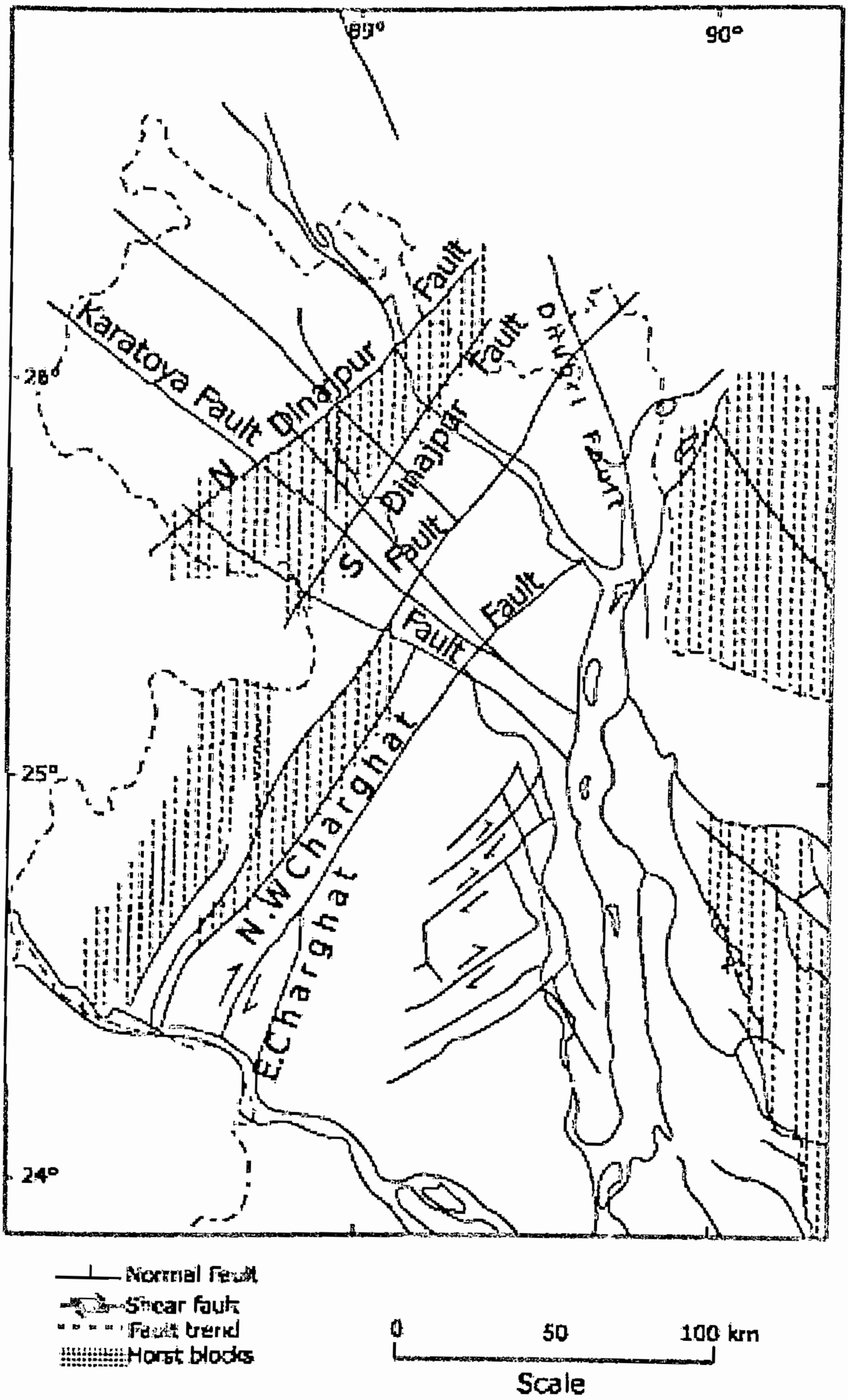


Fig. 2.2: Major tectonic features and structures of north-western part of Bangladesh (Sir M. McDonald & Partners, 1977).

2.3 STRATIGRAPHY:

There is no borehole data in the study area to determine the stratigraphic sequence. The Geological Survey of Bangladesh (GSB) has drilled boreholes in Sibganj and Kansat, which are about 25 kilometer north from Nawabganj Sadar. The depth of the first well is 900 meter at Sibganj and that of the second is 788 meter at Kansat (Fig. 2.3). Regional stratigraphy of the area as proposed by Khan and Mominullah (1980) shows that the area is characterized by a thick sequence of Cretaceous to Recent sediments overlying the Archean basement. Quaternary sediments in the area range in thickness from 65-111 meter and have been deposited over Tura Sand.

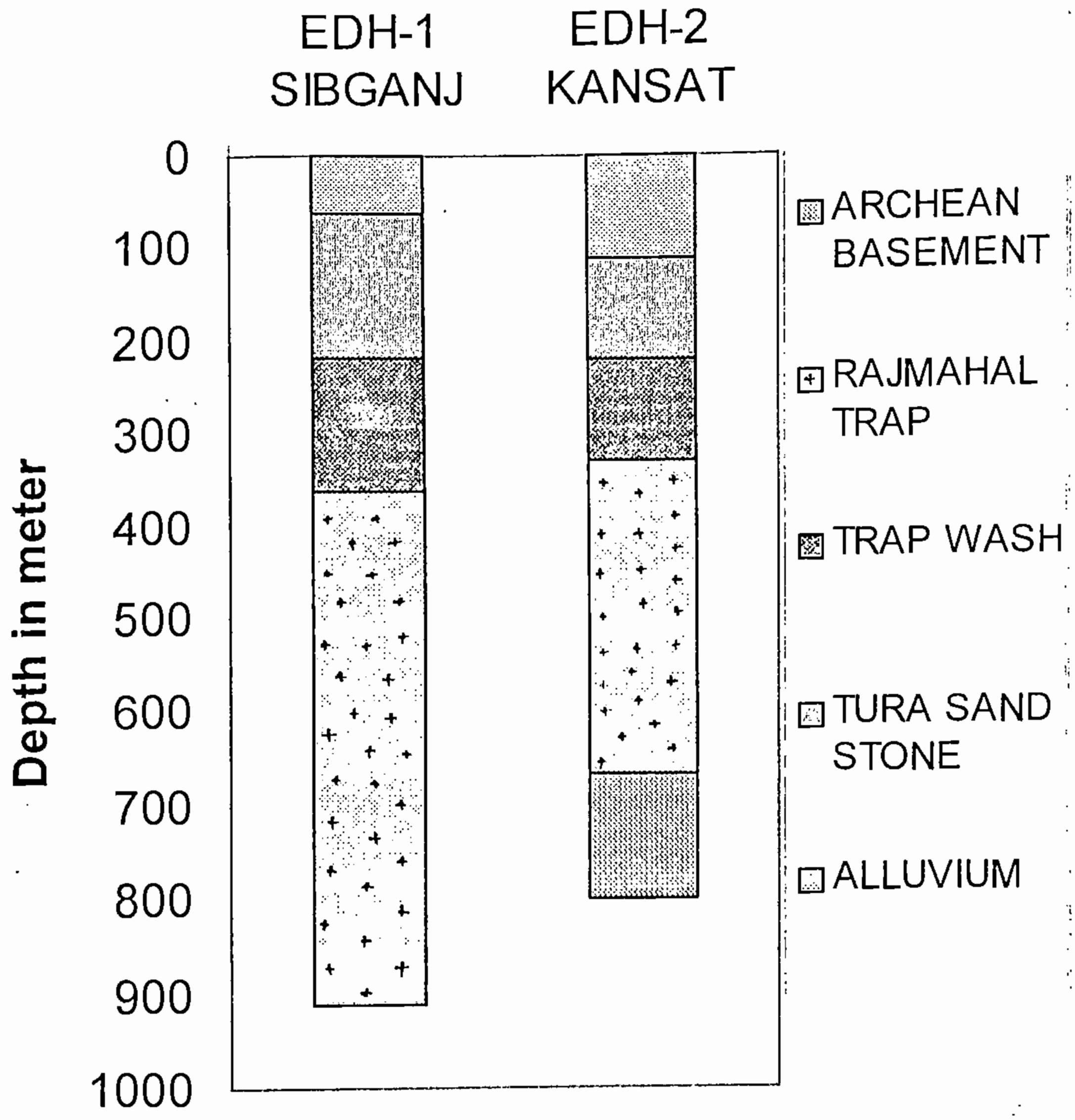


Fig. 2.3: Vertical section of drill holes EDH-1 and EDH-2.

CHAPTER-3

GENERAL STATEMENT OF ARSENIC

- ARSENIC AND ITS GENERAL TOXICITY
- AN OVERVIEW ON WORLD ARSENIC PROBLEM
- ARSENIC PROBLEM IN BANGLADESH
- ARSENIC PROBLEM IN THE STUDY AREA

3.1 ARSENIC AND ITS GENERAL TOXICITY:

Arsenic is one of the fifteenth group elements of the new periodic table. Its chemical symbol is 'As', atomic number 33, atomic weight 74.92 and specific gravity 5.73. Physical characters of this element indicate that it is a metal, but in some special cases, it acts as a nonmetal as well. Hence, it is usually known as metalloid.

The elemental arsenic is gray or tin color, very ductile and a supper conductor for heat and electricity. It evaporates directly from solid state at 615°C and melts at 817°C under 36 atmospheric pressure. Arsenic is stable in four oxidation states (5^+, 3^+, 0 and 3^-). Arsenic with zero oxidation state is insoluble and not absorbed by aqueous solution but with 3^+ and 5^+ do so. The solubility of arsenic increases with increasing pH.

Arsenic occurs abundantly in nature mainly with igneous rocks and ores. There are 254 detected arsenic ores. Arsenic associated mainly with the following ore elements-Copper, Iron, Nickel, Lead, Cobalt, Gold, Silver, Zinc, Uranium and Tin, etc. Besides these, arsenic occurs also with natural coal. According to the quantity of occurrence, arsenic is the 20th element of the earth crust, 14th of seawater and 12th in human body.

Arsenic compound occurs in both organic and inorganic form. Inorganic arsenic compounds are extremely poisonous and harmful, while the organic species are less poisonous (toxicity 200 times less than that of inorganic), but not safe although. Among the arsenic compound, arsenite with valency 3 is 60 times harmful than arsenate with valency 5. Arsenic is tasteless, colorless and odorless. It is an invisible enemy for the humankind for long time and known as the king of the poisons.

3.1.1 ARSENIC IN NATURE: Arsenic is unstable in nature. It is circulated in nature though oxidation, reduction, radiation, methylation and adsorption processes. Arsenic is distributed in nature through the lithosphere, hydrosphere and atmosphere.

ARSENIC IN SOIL:

The average arsenic content of soil is 10 mg/kg throughout the world but increase through using fertilizer, dumping industrial wastage and insecticide. Arsenic content of sandy soil is 4.25 ppm, silty soil 7.73 ppm and clay 10.6 ppm. The allowable limit of arsenic content for agricultural soil is 20 ppm (Ahmad, S.A., 2000).

IN WATER:

Arsenic content of seawater is 0.09-24 μg/l and varies from place to place. In surface water arsenic concentration is generally 0.15-0.45 μg/l (Ahmad, S.A., 2000). Penta valent arsenic compound are mainly found in seawater and trivalent ones are in non oxidized surface water and groundwater. Water in mineral may contain 50 times of normal arsenic level while the arsenic content of the hot spring is 300 times the normal level.

ARSENIC IN AIR:

Trivalent arsenic is present in air as dusty particles. The normal arsenic content of air of rural and urban area is 1-10 nanogram/cubic meter and 20-nanogram/cubic meter respectively (Ahmad SA, 2000).

ARSENIC IN PLANT:

Pants absorb arsenic indirectly from soil while spreads into their different organs. The highest amount of arsenic is present in plant's root and decreasing towards the top. Naturally occurring arsenic content in plant can not cross the limit 1µg/g (Ahmad, S.A., 2000). Due to excess in arsenic in plant it would show the abnormal growth.

ARSENIC IN FOOD:

Arsenic is also present more or less in all kinds of food products & drinks like food grain, vegetables, fruits, meat, fish, diary and poultry product; Generally arsenic in food products bellow 1mg/kg (dry weight) which is not harmful to public health (Ahmad, S.A., 2000).

3.1.2 ARSENIC CYCLE IN NATURE:

The amount of Arsenic in soil and water depends largely on the geologic input from weathering process. It is present in all living animals; some species marine plants such as algae and seaweed and marine organisms, e.g., crustaceans and some species of fish often contain high concentration of arsenic. The arsenic cycle in nature is shown in Fig. 3.1.

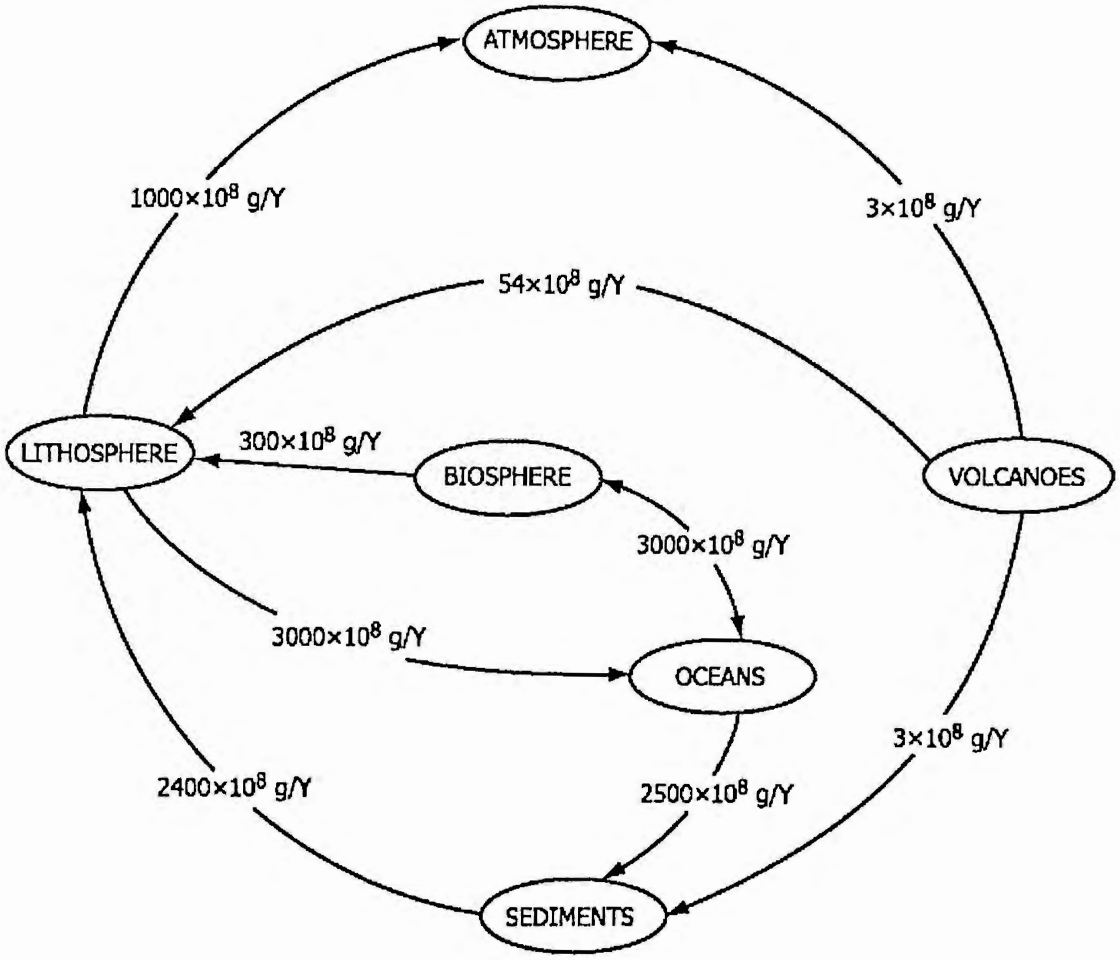


Fig. 3.1: The cycle of arsenic in nature (After Ahmad, S.A., 2000).

3.1.3 ALLOWABLE LIMITS OF ARSENIC:

Allowable limit of arsenic in different foods and drinking water is given in Table-3.1.a and 3.1.b.

Table-3.1.a: Maximum Allowable limit of Arsenic in different food and Drinking water (Ahmad, S.A., 2000).

FOOD	Arsenic/kg
Total food	<0.5 mg (dry weight)
Vegetables and Fruits	3.5 mg
Poultry products	<0.5 mg

Table 3.1.b: Maximum Allowable limit of Arsenic in Drinking water in different countries (Ahmad, S.A., 2000).

Countries	Arsenic in drinking water
European Union	0.01 ppm
Australia	0.007 ppm
Japan	0.01 ppm
Canada	0.025ppm
USA	0.05 ppm 0.02 ppm (to be changed by 2002)
Bangladesh	0.05 ppm
India	0.05 ppm

3.2 AN OVERVIEW ON WORLD ARSENIC PROBLEM:

From ancient times, arsenic is known as the worst poison to the human civilization and identified as a cause of environmental pollution, which is harmful to public health. In many countries, environmental pollution is occurred due to arsenic and patients have been identified. Groundwater contamination due to arsenic pollution in different countries is described as bellow-

Argentina: Information about patients due to arsenic contaminated water in Argentina came to light first early in this century in 1938. Where the diseases was known as 'Bell valley diseases' due to it first came out as famine in Bell valley. After this, arsenic was detected in east and middle area of Argentina where the level of concentration was 0.1 ppm (maximum allowable limit 0.05 ppm). The cause of this contamination was natural arsenic minerals in shallow aquifer.

Chili: It has known that about four lakhs people of one of the northern provinces of Chili were affected by arsenic pollution where the source of water is three rivers following down from the mount Andes with high concentrations of arsenic. The igneous rocks and minerals of the mount Andes were identified as the cause of this contamination. People used to drink arsenic contaminated water (0.8-1.3 ppm) since 1957 and first patient was identified in 1962. In 1970, the water treatment plants were set up in this area to keep arsenic concentration within 0.04 ppm in supply water.

Mexico: Arsenic has been detected in 11 localities of Laguna county of Mexico in 1963. This contamination was caused from natural arsenic richen land surface. About 1,27,000 people this area used to drink water with arsenic concentration from 0.1-0.5 ppm for a long time.

Taiwan: In Taiwan, arsenic contamination problem was known in 1968. The source of this contamination is arsenic rich land surface. In Taiwan arsenic related diseases were not only skin diseases but also there were a lot of cases of infection in toes, so this diseases here known as 'Black Foot Diseases'. Here 19% of the 83,000 wells tasted show arsenic contamination above 0.05. More than a million of citizens were used to drink water with arsenic concentration above 0.5 ppm for forty years.

Japan: Arsenic contamination was caused in some parts of Japan. The hilly village of Matsuo of Toroku district in Miajaki prefecture is one of the most contaminated ones. From 1920, this contamination was caused from the arsenic acid producing industries, which used to produce arsenic acid, by purification arsenopyrite of the hilly mine. The arsenic sulfurous gas used to release from these industries and wastes discharged in the river caused this contamination. Consequently, the workers in this industries and villagers became affected by arsenic contamination. In 1971, it was first known that the citizens and workers of this area were suffering from arsenicosis for long time.

USA: USA is by far the only arsenic affected country where extensive survey program has been conducted throughout the country to detect the condition of arsenic contaminated water though the level of contamination is varied. About 3,47,000 people used to drink water with arsenic concentration above 0.05 ppm and 25,00,000 people used to drink water with arsenic concentration between 0.025 ppm and 0.05 ppm. Arsenic contamination was 0.046 ppm in California county and 0.092 ppm in the two counties of Nevada. It is known that the source of this contamination in the USA is geologic.

China:

Jhing Jhiawng province: Arsenic contamination that was detected in 1980 in Jhing Jhiawng province was the first one in China. This contamination was caused from burning of arsenic rich coal. About half of the inhabitants of this region, where total population was 20,000 became the first to face this problem. To mitigate this problem supply of decontaminated water was started from 1988.

Middle Mongolia Province: Arsenic affected patient was first detected here in 1990. Most of the arsenic contaminated areas are located in the arid region (annual rainfall 200-300 mm). About 90% of the tube wells were shown arsenic concentration above 0.05 ppm with a maximum of 1.088 ppm. About 35% of the detected people are suffering from chronic arsenic diseases and some already died of cancer. Contamination occurred in about 655 villages of 11 counties. About 3,00,000 people of 627 villages were exposed to arsenic contamination in 1994 and 1,774 patients were detected. The maximum level of contamination was 1.86 ppm.

Hungary: Arsenic in groundwater of Hungary was first detected in 1981. It was found in some samples of water treatment plants. After this it was known from an extensive survey throughout the country that about 4,00,000 people used to drink water with arsenic concentration above 0.05 ppm. The cause of groundwater arsenic contamination in Hungary is geologic. At the depth of 100-200 m from the surface, the maximum arsenic contamination of about 0.7 ppm was detected. Arsenic concentration in all of the water treatment plants of Hungary has been reduced to bellow 0.05 ppm.

Thailand: Arsenic contamination was first detected in Thailand in Rhonphibool district of Nakhon Sri Thammarat province on the skin of a woman. After testing arsenic was detected in some shallow tube well waters of this district. This contamination is thought to be spreaded from a tin mine rich in arsenopyrite minerals. The levels of concentration were 0.001–5.1 ppm.

Philippine: The river water and well water of Mindanao were found contaminated with arsenic in 1992 when a geothermal electricity plant was constructed in the area. The level of contamination was 0.1ppm. Thirty-nine 39 patients suffering from skin diseases due to arsenic contamination were detected in 1995.

West Bengal (India): Arsenic contamination in groundwater of West Bengal of India is the second largest arsenic problem in the history. The cause of arsenic contamination of this region is assumed geologic. In 1983 a distinguished skin specialist, K.C. Shaha first detected a patient suffering from arsenicosis caused from drinking arsenic contaminated tube well water in West Bengal. In a survey of 1987, a total of 197 arsenicosis patients have been detected in five districts of West Bengal. In the survey of 1998, this number has been increased and eight districts (38,678 sq. km.) of West Bengal with population of 3,80,00,000 was known to be in the arsenic- risk prone area. About 45,00,000 people in West Bengal used to drink water for long time with arsenic concentration above 0.05 ppm. The average concentration of arsenic in water is 0.2 ppm with a maximum of 3.7 ppm. 45% of the tested tube wells shows arsenic concentrations above 0.05 ppm. Skin diseases due to arsenic contamination were found in about 2,30,000 people.

Information about arsenic contamination in different parts of the world and the arsenicosis patients are given in the following table.

Table-3.2: Arsenic Contamination and Number of Arsenicosis Patients (Ahmad, S.A., 2000).

No.	**Name of Country**	**Period**	**People in influence/risk of contamination**	**Syndrome in skin In 20%**
1.	West Bengal, India	1978-1995	1000,000	20
2.	Taiwan	1961-1985	103,000	19
3.	Chili Antofagasto	1958-1970	130,000	16
4.	Argentina, Monty Quimado	1938-1981	10,000	Uncountable
5.	Mexico, Laguna	1963-1983	200,000	21
6.	Thailand Rhonphibool	1987-1988	14,000	18
7.	Bangladesh	1993-1999	50,000,000*	7-10

3.3 ARSENIC PROBLEM IN BANGLADESH:

In early 1990s, high arsenic contamination was reported in the groundwater of Chapainawabganj, one of the western districts of Bangladesh. Research team of the Department of Occupational Health and Environmental Health of National Institute of Preventive and Social Medicine (NIPSOM), Dhaka first detected patient of arsenic contamination in Chamagram village of Baraghoria union of Chapainawabganj district. Since then, different government, non-government and individual organizations are involved in understanding various issues of arsenic problem in Bangladesh. Every round of water quality tests, the numbers of contaminated tube-wells are increasing that exceed the Bangladesh standard limit (0.05 ppm) as well as the WHO Guide Line value (0.01 ppm) for arsenic in drinking water.

3.3.1 MAGNITUDE OF THE PROBLEM:

At this time, at least 25 million people are exposed to arsenic contamination, 59 out of 64 districts have been found with arsenic contamination in ground water, 249 out of 464 *Upazilla*s are affected and over 7,000 patients have been identified so far. The British Geological Survey's (BGS, 1999) National Survey (3500 statistical random samples) found that 27% of shallow tube wells exceeds the Bangladesh Standard Limit (0.05 ppm) and 42% exceeds the WHO Guide Line value (0.01 ppm) for arsenic in drinking water.

Arsenic Contaminated Districts:

The arsenic contaminated districts, where the arsenic affected patients have been found are as follows-

Kushtia, Comilla, Kishoreganj, Kurigram, Khulna, Gopalganj, Gazipur, Gaibandha, Chuadanga, Jamalpur, Chandpur, Jhenidah, Tangail, Dhaka, Nawabganj, Noakhali, Narayanganj, Narshindhi, Netrokona, Narayil, Pirojpur, Pabna, Feni, Faridpur, Barishal, Brahmanbaria, Bogra, Bagerhat, Meherpur, Munshiganj, Magura, Manikganj, Mymensingh, Rajbari, Rajshahi, Laxmipur, Jessore, Shariatpur and Satkhira.

Table-3.3: Chronology of arsenic detection in different districts of Bangladesh (Ahmad, S.A., 2000).

Year	Number Of Contaminated District
1993	1
June, 1995	8
December, 1997	23
September, 1997	42
June, 1998	48
December, 1998	60

Recently, the arsenic contaminated groundwater has become a serious problem in Bangladesh. To mitigate this problem, it is necessary to identify the safe tube wells but it is difficult to know which tube-wells are unaffected. There are 4 million tube wells in Bangladesh supplying groundwater to 97% of the population (Ahmad, S.A., 2000). Before, detecting arsenic in groundwater, the tube-wells water was regarded as safe water by all including UNICEF and ICDDR, B.

3.3.2 ORIGIN OF THE PROBLEM:

It is now generally accepted that arsenic contamination of groundwater in Bangladesh is geogenic. The contaminant derives from the geological strata underneath the soil (Water Aid, Bangladesh, 2000).

There are two main schools of thoughts regarding the release of arsenic into the groundwater:

Pyrite Oxidation: It states that in response to excess pumping for extraction of groundwater, air or dissolved oxygen in water penetrates into the subsurface which leads to decomposition of arsenic bearing minerals (pyrite, realgar, orpiment, etc.) and ultimately arsenic is released into the groundwater.

Oxyhydroxide Reduction: Arsenic was transported from the upstream region through the river systems absorbed onto the surface of fine-grained iron or manganese oxyhydroxide with sediments and deposited in flood plain and buried within the sedimentary column. After deposition when it goes into a strongly reducing state in the sedimentary strata due to anaerobic condition arsenic released into the groundwater.

The release mechanism of arsenic in groundwater of Bangladesh is still hotly debating issue but the second theory is thought to be the more likely explanation. In the present study, the decontamination of arsenic from contaminated water is related to this theory.

3.3.3 CURRENT ACTIVTIES ON ARSENIC ISSUE:

The arsenic contaminated groundwater becomes a serious problem to the nation, which needs immediate mitigation. Now, the numbers of GoB, donors, NGOs, and academic institutions are involved in the technical and social issues related to the arsenic contamination in groundwater. The goal of the present national program is to screen out the all contaminated wells throughout the country as well as to provide mitigation options. The organizations working on arsenic issue are:

Department of Public Health Engineering (DPHE): The DPHE has conducted a number of different arsenic program at various levels of implementation and still working with a variety of development organizations like UNICEF, World Bank, DANIDA, WHO, UNDP, IAEA and FAO etc.

Ministry of Health and Welfare (MoHFW): The MoHFW has started a technical project in 1997, which identified 400 arsenic-affected patients at Chapainawabganj district and 3200 in other seven districts.

Other Organizations: A number of NGOs and universities are working on different issues of arsenic problem independently.

3.4 ARSENIC PROBLEM IN THE STUDY AREA:

The study area, Chapainawabganj, is one of the arsenic contaminated districts of Bangladesh where arsenic in groundwater was first detected. It was 1993, a research team of the Department of Occupational Health and Environmental Health of NIPSOM first detected a patient of arsenic contamination at Chamagram village under Baraghoria union of Chapainawabganj district. After this, a number of organizations including Rajshahi University, BGS and GSB have determined arsenic concentrations of the tube-well water in the districts with the highest concentration of 2.4 ppm. However, most of the samples having concentrations >0.05 ppm in and around of Chapainawabganj town (BGS,1998; Department of Geology and Mining, University of Rajshahi, unpublished data, 1996; Nickson *et. al.,* 1998) making it an arsenic hot spot.

CHAPTER-4

HYDROGEOLOGY

- REGIONAL HYDROGEOLOGY
- HYDROGEOLOGICAL UNITS IN CHAPAINAWABGANJ
- HYDROGEOLOGICAL CROSS SECTIONS
- DEVELOPMENT OF GROUNDWATER FLOW

4.1 REGIONAL HYDROGEOLOGY:

From the geologic, hydrogeologic and hydrodynamic point of view, most parts of Bangladesh are suitable for the occurrence and development of large quantity of groundwater, because large portion of this country is underlain by unconsolidated to poorly consolidated sediments of Tertiary to Recent age. These sediments are generally thick which cover almost entire the country with a good water bearing capacity. Moreover, a high rate of precipitation and large number of rivers continually recharge the source groundwater.

To classify the potential groundwater area of Bangladesh several schemes were conducted by different organizations. According to the schemes hydrogeology of the study area is as follows-

Jones (1972) recognized four major groundwater area in Bangladesh on the basis of geological criteria: sequence, lithology, thickness and structure of rock formations which were later modified by Hyde (1979) (Fig. 4.1)

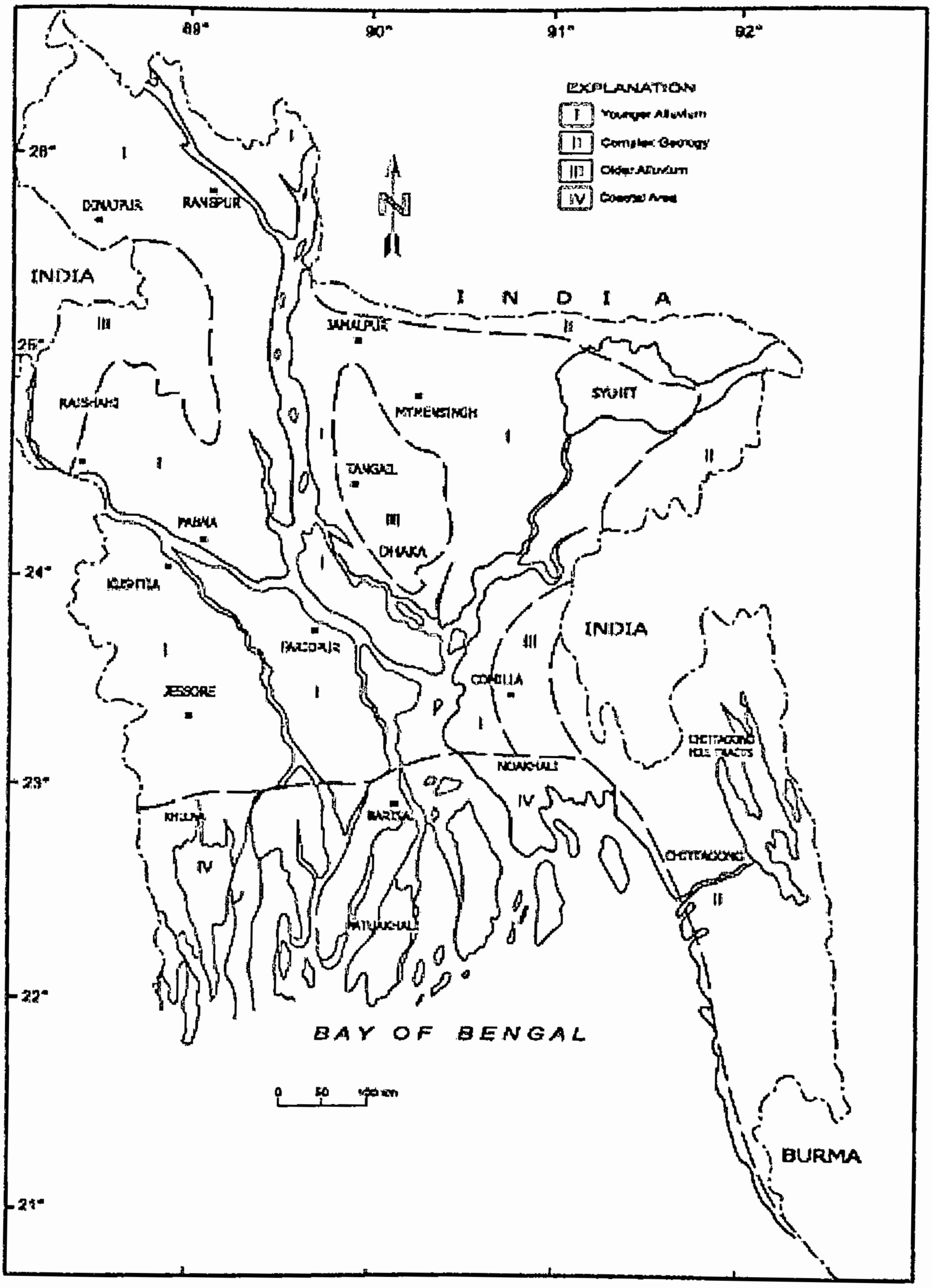


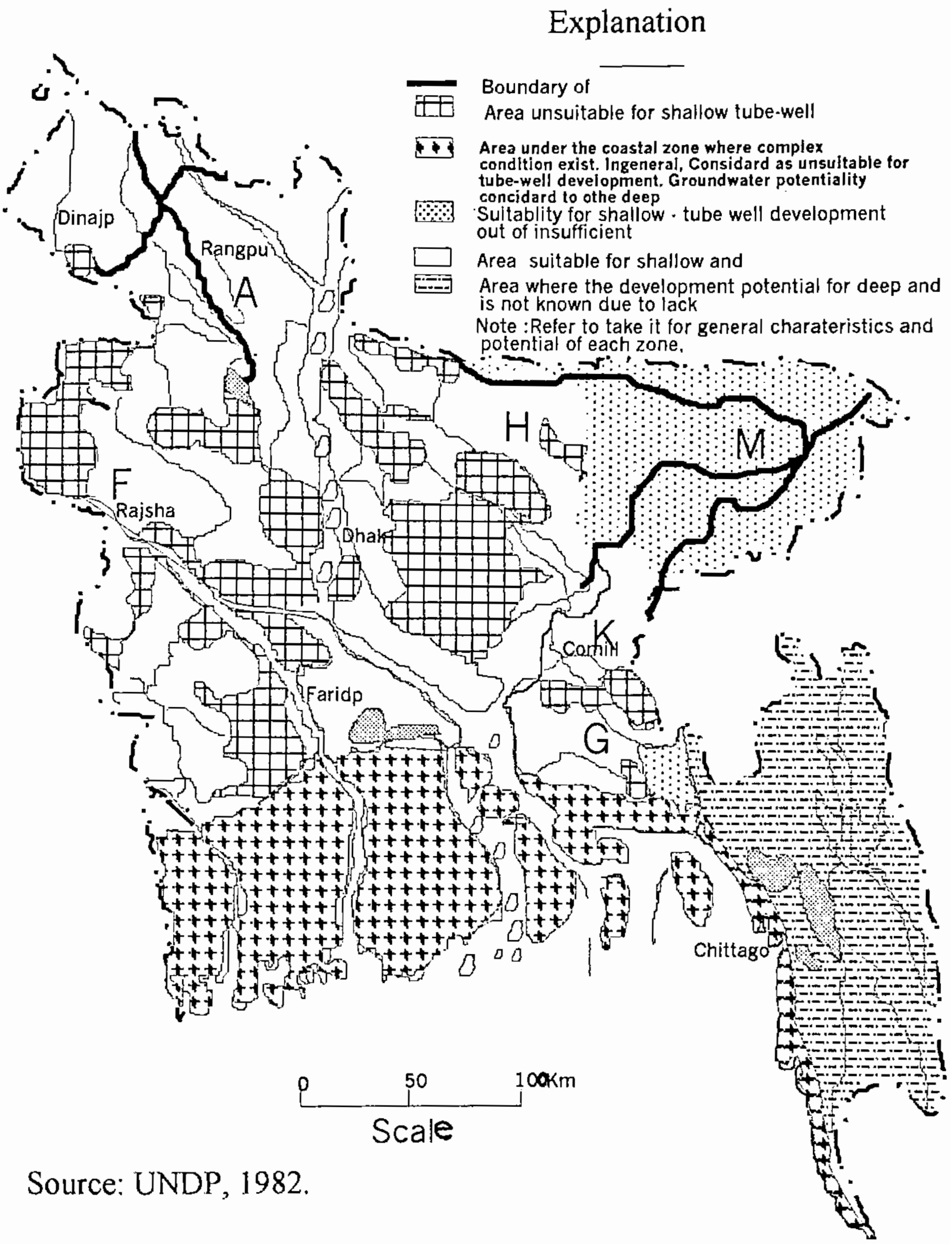
Fig. 4.1: Major Hydrogeologic divisions of Bangladesh (After Hyde, 1979).

According to this classification the four major groundwater areas are as follows:

I - Younger alluvium
II - Complex geology
III - Older alluvium
IV – Coastal area

The study area is characterized by simple geology comprising of younger alluvium of recent flood plain deposits.

UNDP (1982) identified 15 zones for groundwater development in Bangladesh (Fig. 4.2). Each zone had been evaluated for its development based upon aquifer characteristics and considering various constraints. According to UNDP (1982), the study area is included in zone 'F' that covers the flood plain of Chapainawabganj district.



Source: UNDP, 1982.

Fig. 4.2: Potential zones for groundwater development in Bangladesh.

WARPO (former MPO), a project of Ministry of Irrigation and Water Development of the Governments of Peoples Republic of Bangladesh, has now prepared a draft National Water Plan (NWP) where the country has divided into five regions for the convenience of the study. These five regions are further subdivided into planing areas, which are the largest sub-regional units used in National Water Planing. The planing areas are again subdivided in to 163 chatchment areas (Fig. 4.3). The present study area is included in the chatchment area no. 31 of planing area no. 12 of the NW region.

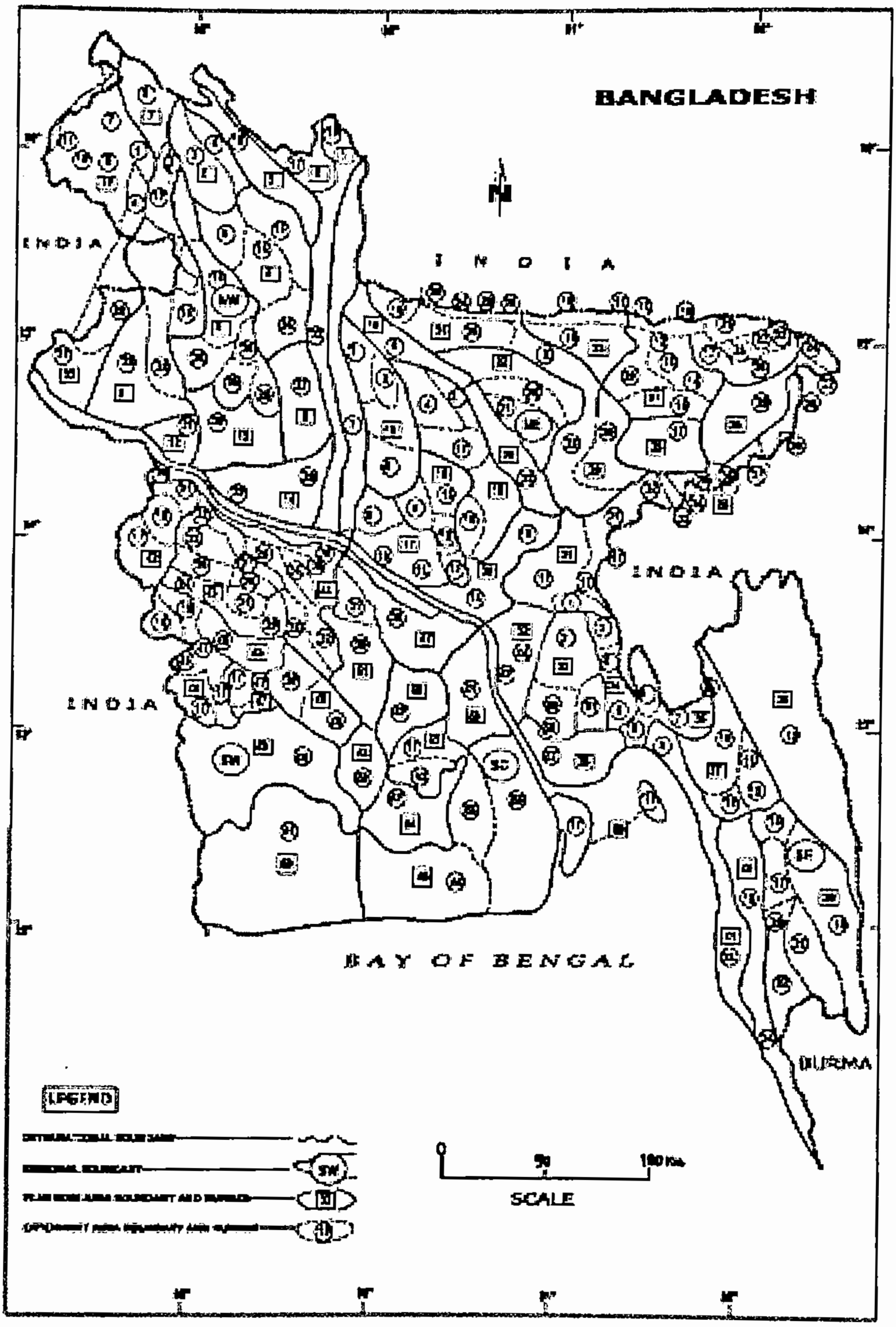


Fig. 4.3: Catchment planning areas and regions (WARPO, 1986).

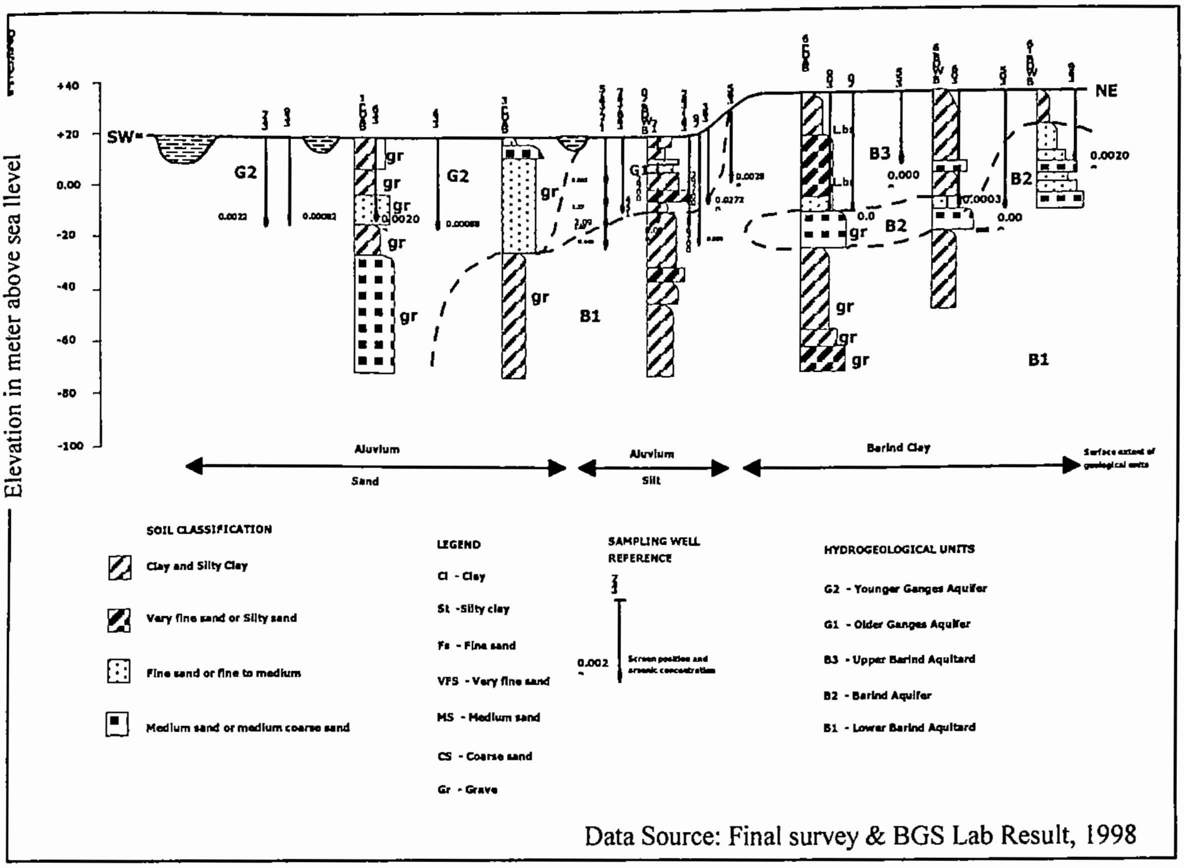
4.1.1 HYDROGEOLOGICAL UNITS IN CHAPAINAWABGANJ:

There are five hydrogeological units identified in Chapainawabganj area (BGS & MML, 1998). These units are shown in Table-4.1.

Table-4.1: Hydrogeological Units in Chapainawabganj (BGS & MML, 1998).

Abbreviation	Hydrogeological unit	Equivalent Surface Geological Unit	Arsenic Concentration
G2	Younger Ganges Aquifer	Alluvial Sand	Very little concentration
G1	Older Ganges Aquifer	Alluvial Sand	Severe concentration
B3	Upper Barind Aquitard	Barind Clay	No data
B2	Barind Aquifer	Barind Clay	Uncontaminated
B1	Lower Barind Aquifer	Barind Clay	No data

Sections are shown in Fig. 4.4



Data Source: Final survey & BGS Lab Result, 1998

Fig 4.4: Hydrogeological units in Nawabganj (BGS & MML, 1999).

- Lower Barind Aquifer (B1) is laterally and vertically extensive and extends to a depth of at 160 m.
- Barind Aquifer (B2) is thin, confined and reduces in thickness towards the Ganges. Most possibly, it has no hydraulic continuity with younger aquifer.
- Upper Barind Aquitard (B3) is laterally extensive and confined in nature.
- Old Ganges Aquifer (G1) contains most of the contaminated wells. It is of limited extent and in the conventional standards, it is not consider as aquifer. However, in the study area these thinly bedded and fine-grained sands are an important source of drinking water.
- Younger Ganges Aquifer (G2) extends beneath the Ganges flood. The G2 aquifer is subjected to minimal confinement -by thin silt. This pattern raises the question as to whether this difference is due to a change in the source area of the sediment.

4.1.2 HYDROGEOLOGICAL CROSS SECTIONS OF THE STUDY AREA:

Hydrogeological cross-sections of the study area presented in different directions (Fig. 4.5 and Fig. 4.6 to 4.11), which imply that there are three hydrogeological units underneath the study area. These are (a) an upper aquitard, mainly of clay and silt, with thickness of 10-50 meter (b) middle composite aquifer (main aquifer), composed mainly of fine to medium sand, thickness is of 20-60 meter, and (c) a lower aquitard, composed mainly of clay, thickness ranges from 10-30 meter.

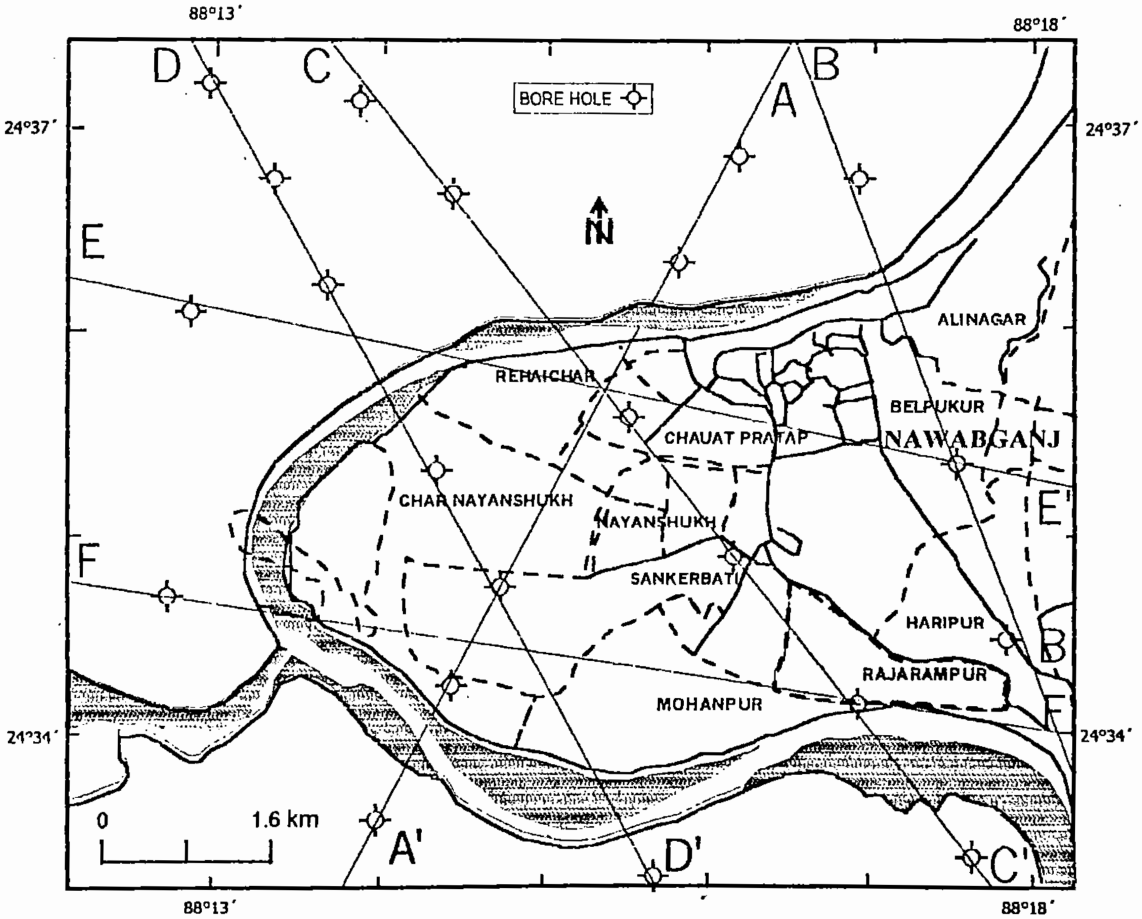


Fig. 4.5: Bore log (BWDB & BMDA) location map for lithological cross-section of Rajarampur and adjoining area.

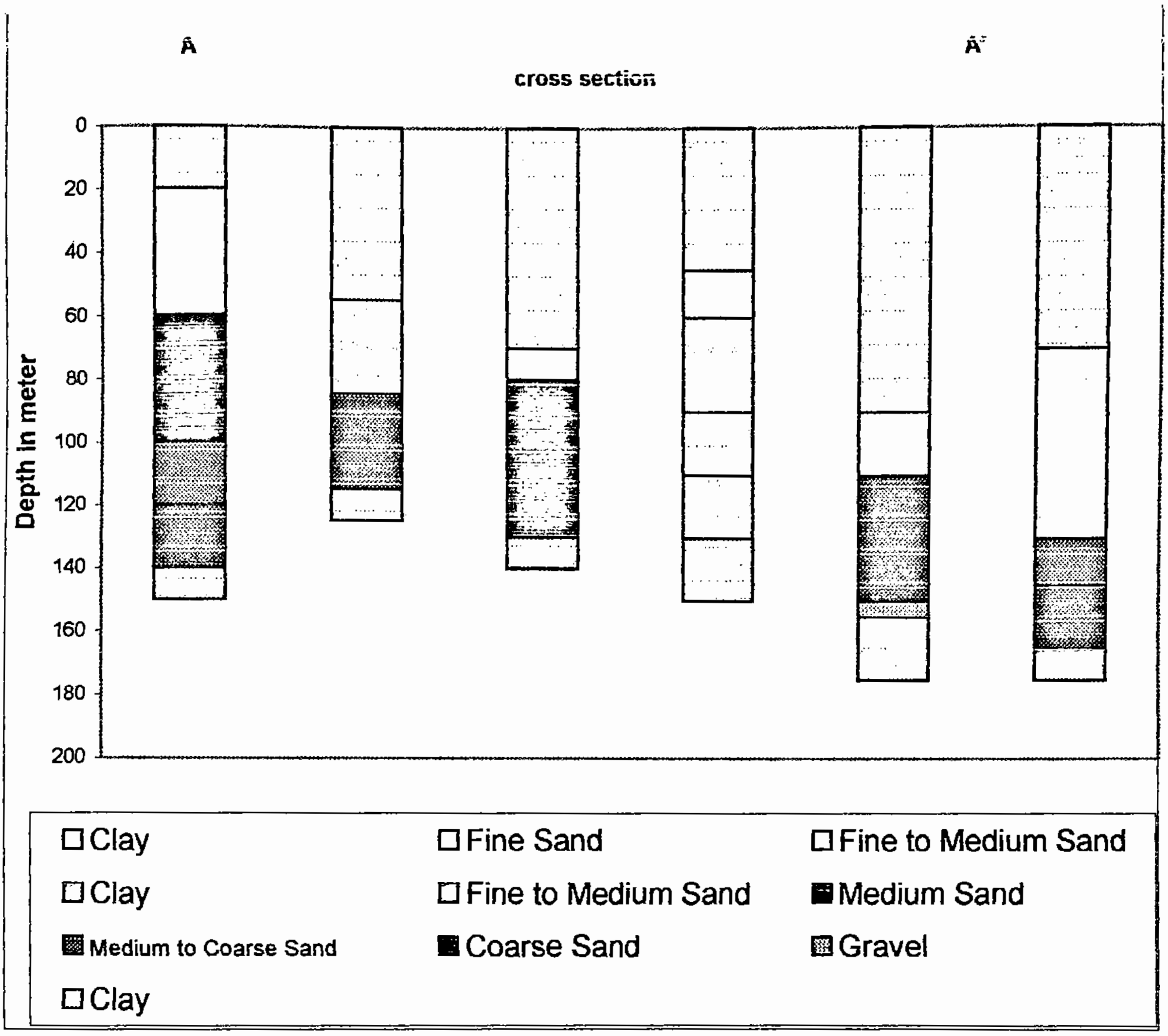


Fig. 4.6: Hydrogeological cross-section along AA'.

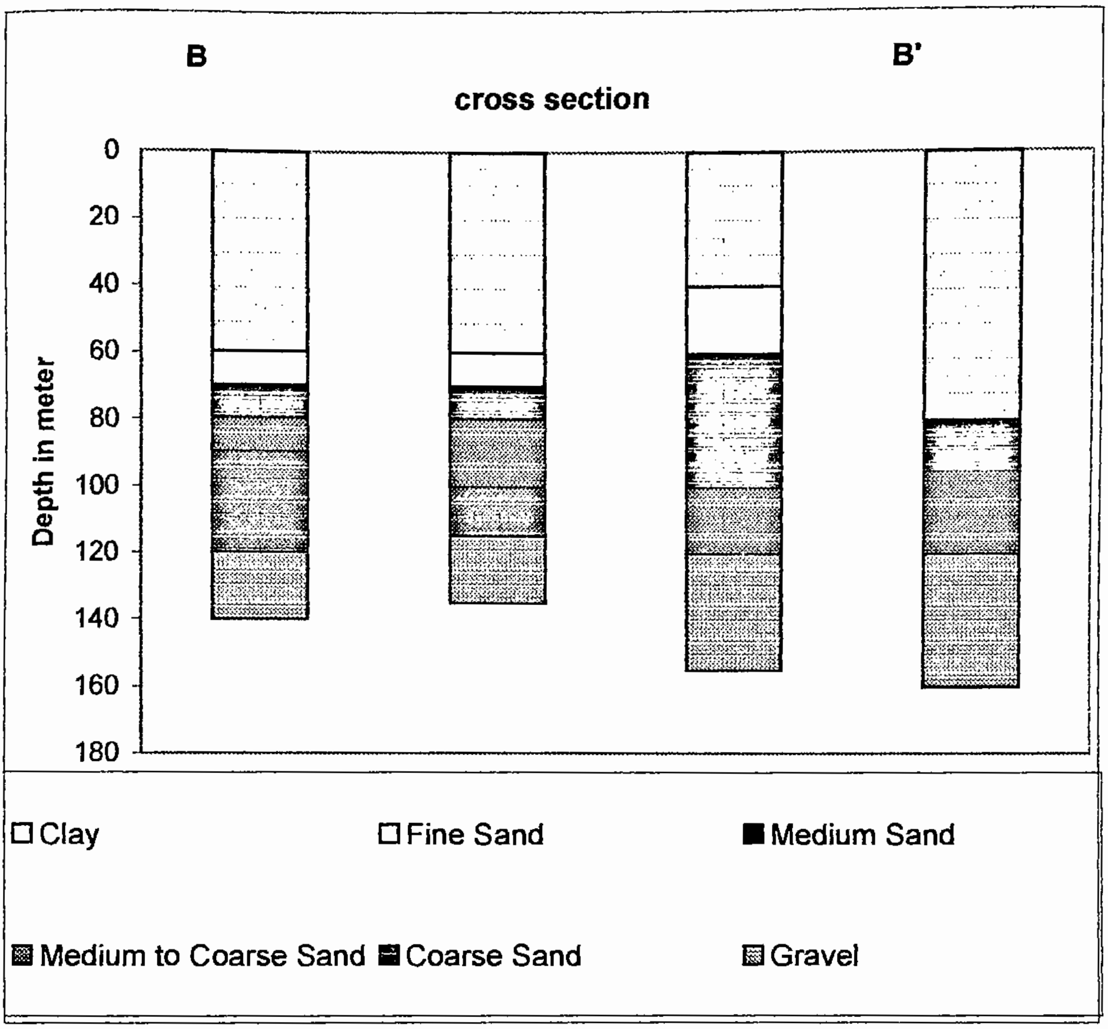


Fig. 4.7: Hydrogeological cross-section along BB'.

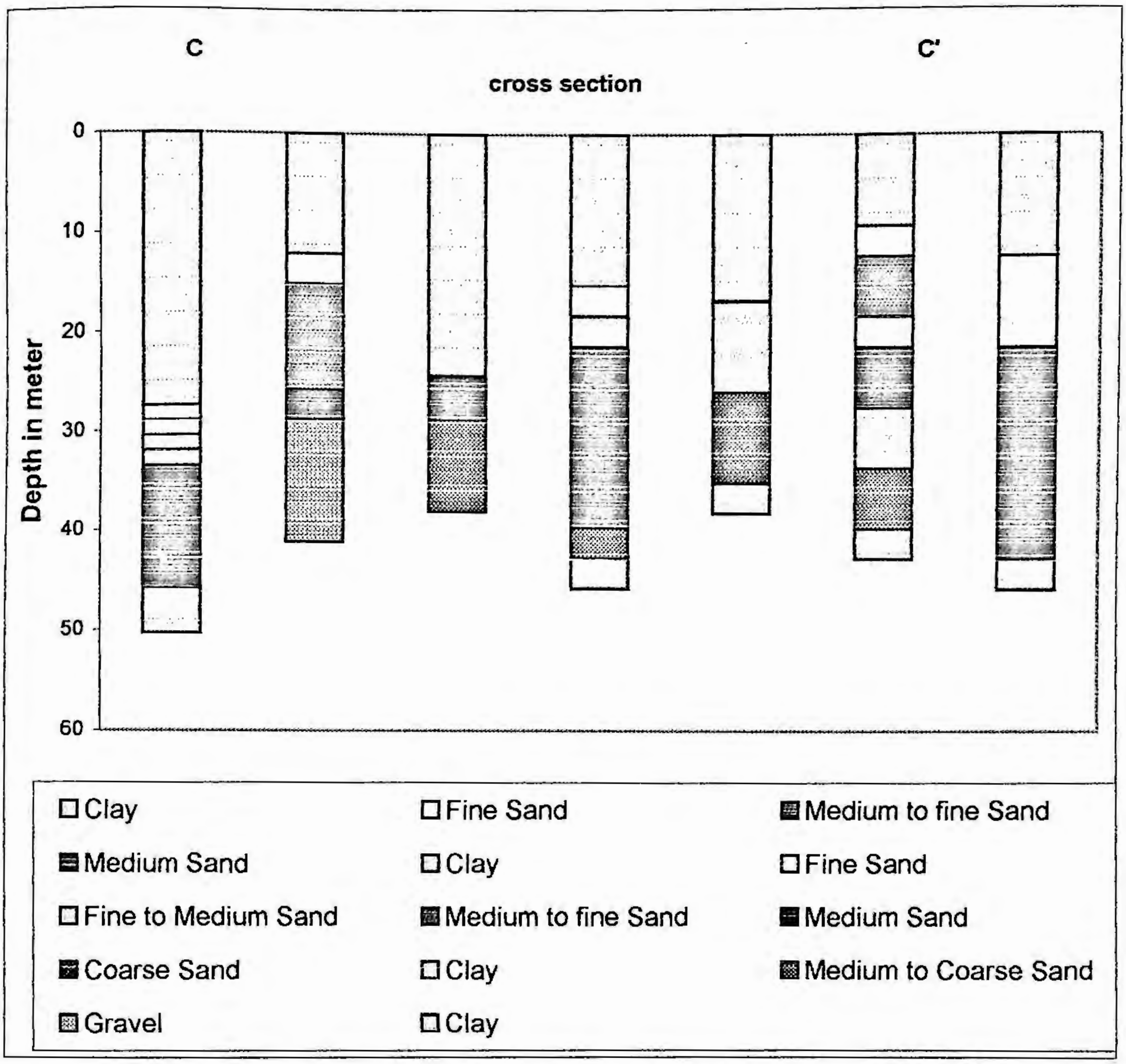


Fig. 4.8: Hydrogeological cross-section along CC'.

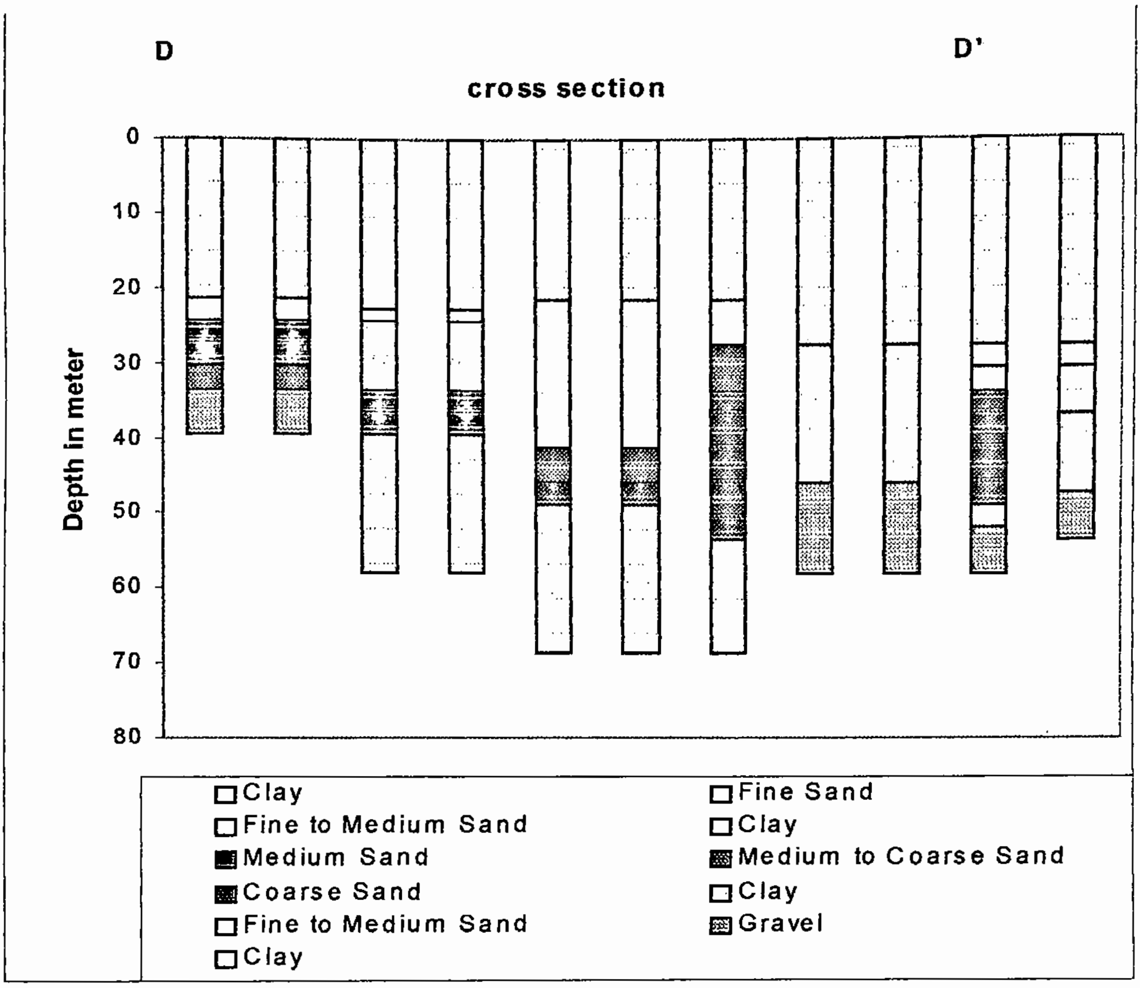


Fig. 4.9: Hydrogeological cross-section along DD'.

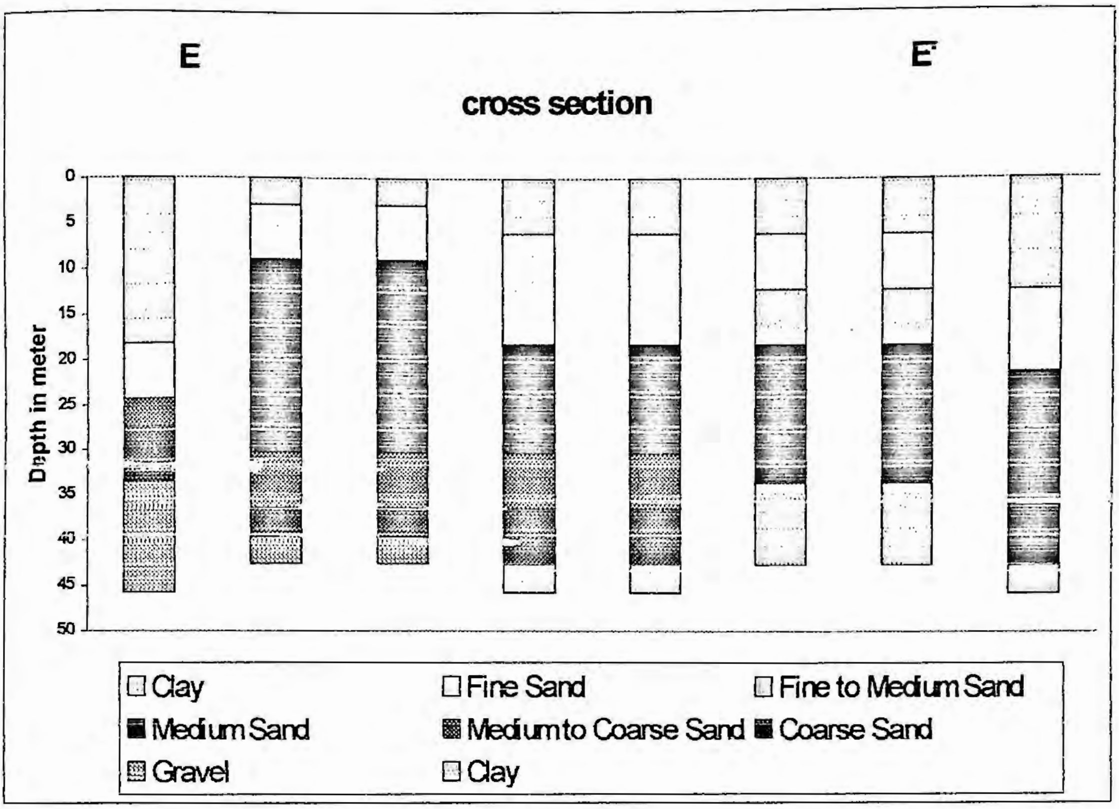


Fig. 4.10: Hydrogeological cross-section along EE'.

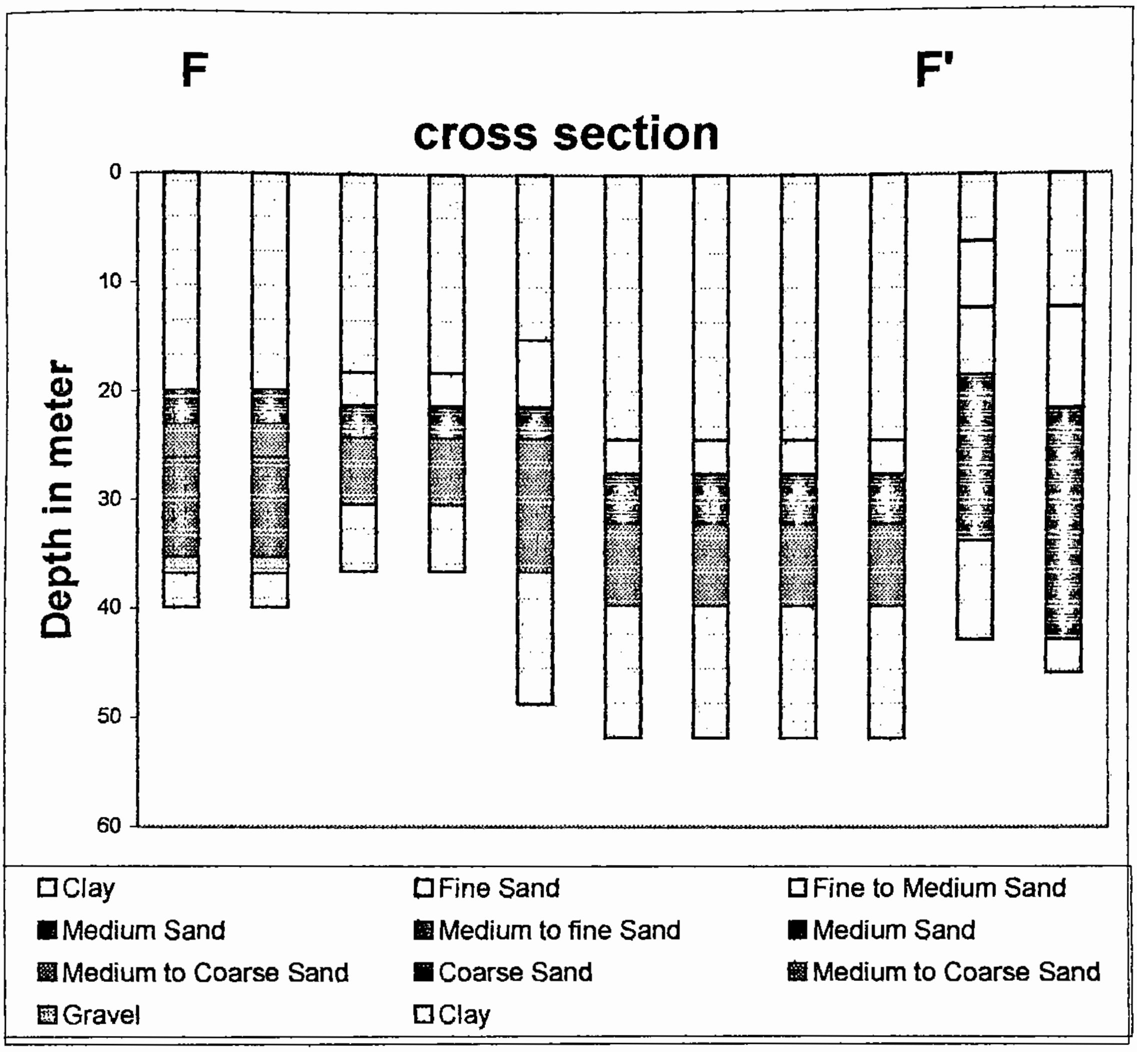


Fig. 4.11: Hydrogeological cross-section along FF'.

4.2 DEVELOPMENT OF GROUNDWATER FLOW:

BGS and MML (1999) have developed a groundwater flow model for Chapainawabganj town. The model extends only to the north of the river Ganges and the Mahananda River as an internal river boundary. Three layers, included in the model, are as follows:

a) Layer-1 composes of low permeability clay and silt in the High Barind but is more permeable (fine sand and silt) in the flood plain area. Layer-1 ranges from about 10 m in the flood plain to over 35 m in the High Barind.

b) Layer-2 composes of fine to medium sands up to about 25 m that forms the composite aquifer.

c) Layer-3 composes the main aquifer underneath the High Barind and the Ganges flood plain with thickness up to 25 m and 60 m respectively. In the central area, the model Layer-3 forms effective bases to the aquifer.

Table-4.2: Parameter Setting Chapainawabganj Thana Model (BGS and MML, 1999).

Layer	**Thickness**	**Horizontal/Vertical permeability (m/d)**	**Confined/Unconfined Storage**	**Porosity**
1	10 to 35	1/0.1 to 10/1	0.001/0.1 to 0.1	0.1
2	20	20/2	0.001/0.15	0.4
3	10 to 60	1/0.1 to 50/5	0.001/0.2	0.4

Groundwater levels are elevated in the High Barind area with steep gradient on the flanks of the High Barind. In the plain, the ground surface elevation and that of the main rivers largely control groundwater levels. Seasonal variation in groundwater levels shows the general range from about 30.5 m in the inter fluvial area in the floodplain, while variation up to 7 m are observed near the main rivers and on the High Barind.

Seasonal variation in the Mahananda River level ranges from 7-10 m (BWDB gauging station on the Mahananda River at Godagari and Chapainawabganj).

CHAPTER-5

WARER QUALITY AND HYDROGEOCHEMISTRY

- INTRODUCTION
- DISTRIBUTION OF WATER QUALITY PARAMETERS
- CLASSIFICATION OF GROUNDWATER
- HYDROGEOCHEMISTRY
- RELATION OF ARSENIC WITH OTHER PARAMETERS

5.1 INTRODUCTION:

To determine groundwater quality and understand the relation between groundwater and aquifer materials of any area, it is necessary to study the hydro geochemistry of that area. In the present study, a hydro-geo-chemical study has been conducted to ascertain the groundwater quality and to find out the inter-elemental parametric relationship. This study was conducted several field works, sampling and laboratory analyses.

5.1.1 FIELD INVESTIGATION:

For hydro-geo-chemical study, a comprehensive fieldwork was undertaken on twelve randomly selected tube wells (Fig. 5.1). In the field, parameters like pH, EC and Arsenic concentration have been measured.

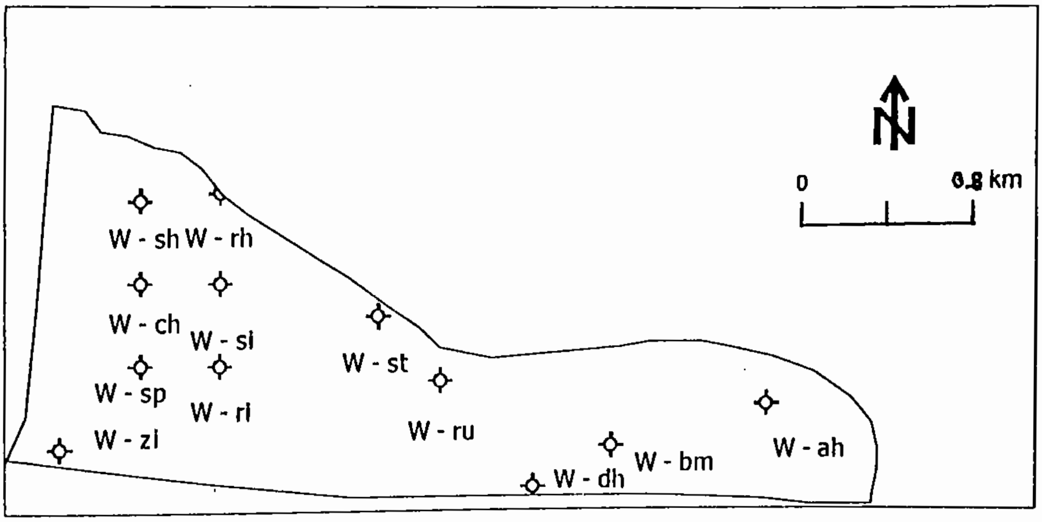


Fig. 5.1: Sampling well location map of the study area, Rajarampur.

5.1.2 COLLECTION OF GROUNDWATER SAMPLES:

Groundwater samples have been collected in high-density plastic bottles. Sample bottles were thoroughly cleaned by rinsing with 8M HNO_3 and de-ionized distilled water, followed by repeated washing with sample groundwater to avoid any contamination. Samples were then carefully collected and sealed with proper labeling. During sampling –

i) One sample was taken normally for major cation and anion analysis;

ii) Another sample, from the same well, was collected by acidifying to pH of about 2 with concentrated nitric acid to prevent any reaction namely adsorption of arsenic before arsenic determination;

iii) Acidifying to low pH with 0.5N HCl to measure iron concentration the third one was collected. Aeration during sampling was avoided as far as possible. Using portable EC-meter (HANNA HI 7039P) and pH -meter (HANNA pocket pH) have measured variable parameters such as EC and pH. Samples collected from the study area were carefully transported to the laboratory and preserved in a refrigerator at temperature of about 4°C until analysis. Analyses were carried out in the Hydro Geochemistry Laboratory of the Department of Geology and Mining, University of Rajshahi, using standard procedures.

5.1.3 LABORATORY ANALYSIS:

Level of different ionic parameters were determined using the method given below:

Na^+ and K^+ were determined by using flame photometer (model JENWAY PEP 7). Ca^{2+} and Mg^{2+} were determined by EDTA titration method. HCO_3^- and Cl^- were determined by titration method. SO_4^{2-}, NO_3^- and Fe^+ were determined with 1-10 phenanthrolaine by using Spectrophotometer (SPECTRONIC 21 D, Optima) and total arsenic concentration was analyzed with silverdiethyldithiocarbamate method (SDDC/AgDDTC) by using Spectrophotometer (SPECTRONIC 21 D, Optima).

5.2 DISTRIBUTION OF WATER QUALITY PARAMETERS:

The result of chemical analysis of groundwater of the study area is as presented bellow:

Field Test Parameters:

Hydrogen Ion Concentration (pH): The pH of the study area ranges from 7.5 to 9.8 with a decreasing trend from northeast to southwest. Groundwater pH distribution of the study area is shown in Fig. 5.2.a and 5.2.b.

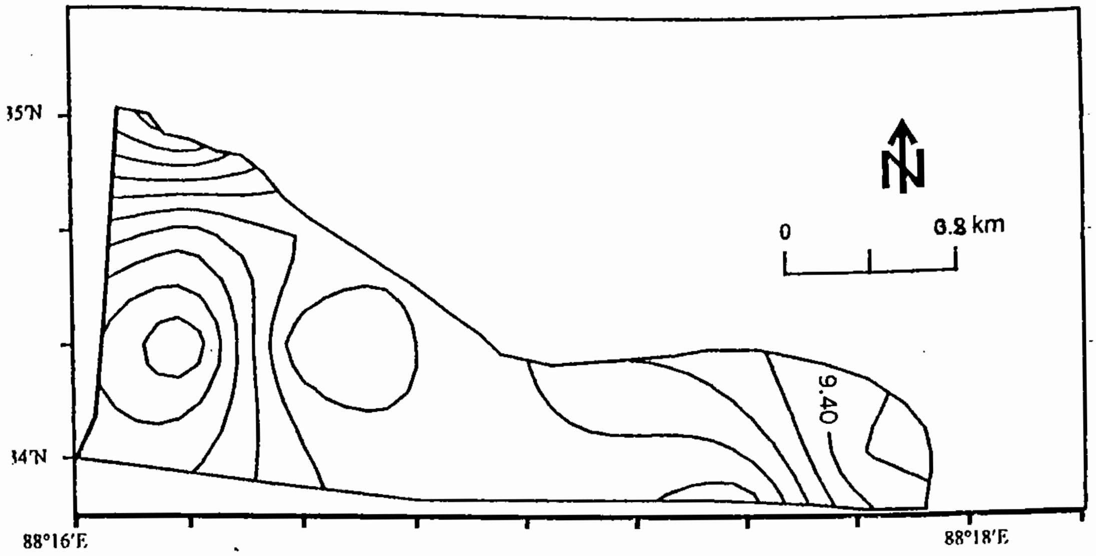


Fig. 5.2.a: Contour map showing pH distribution in groundwater of the study area.

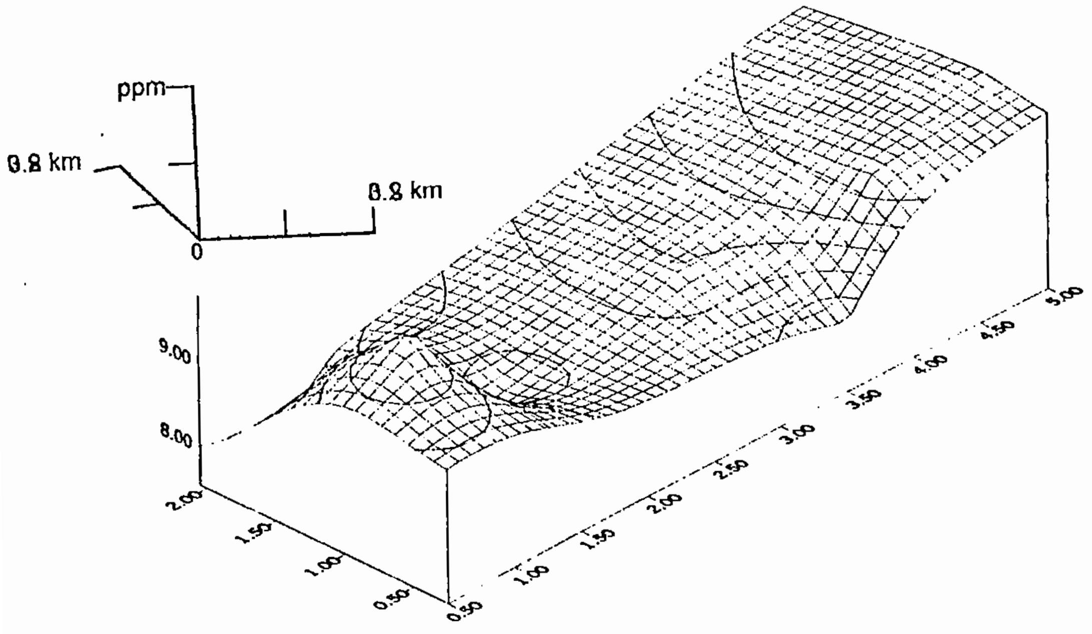


Fig. 5.2.b: 3D view of pH distribution in groundwater of the study area.

Electric Conductance (EC): EC of groundwater of the study area ranges from 550 µS/cm to 745 µS/cm. EC distribution in groundwater of study area is shown in Fig. 5.2.c and 5.2.d.

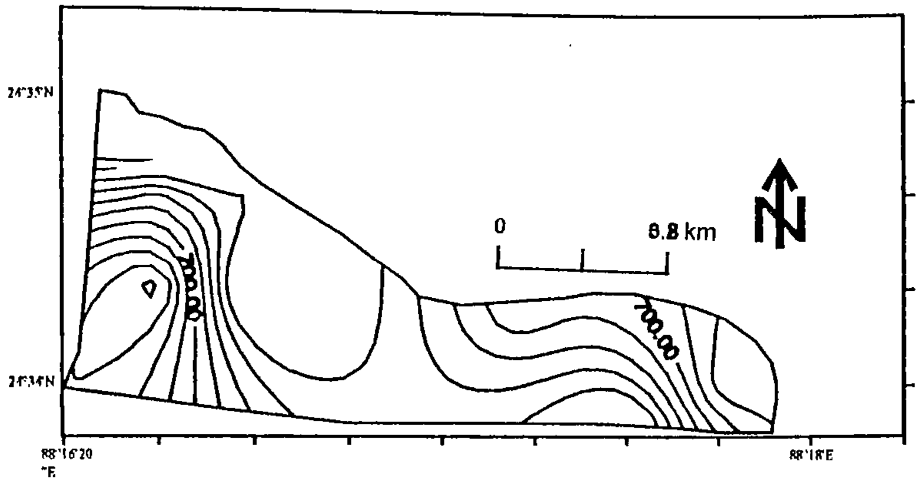


Fig. 5.2.c: Contour map showing EC distribution in groundwater of the study area.

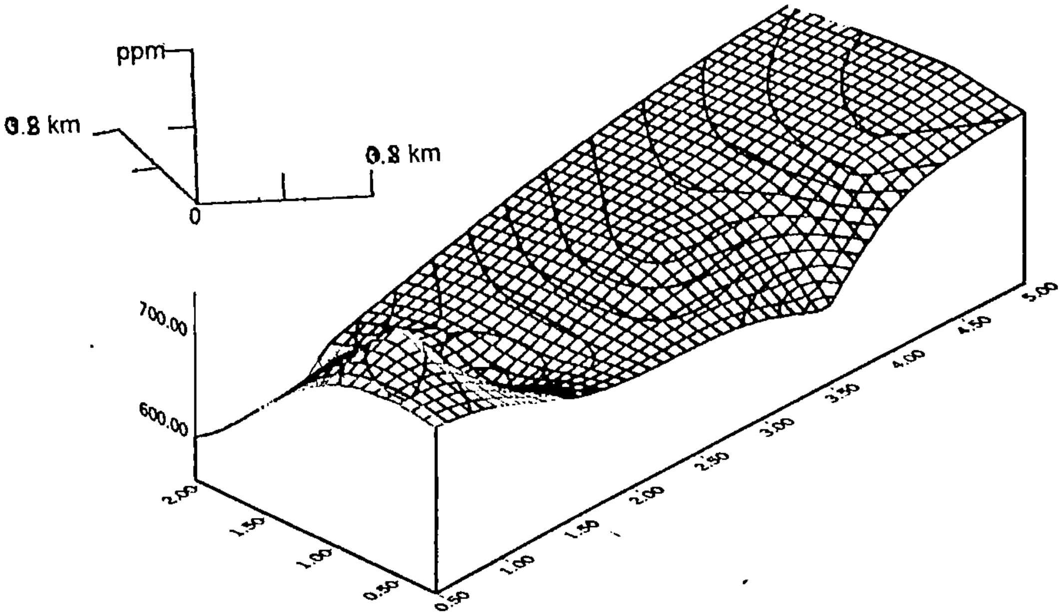


Fig. 5.2.d: 3D view of EC distribution in groundwater of the study area.

Total dissolve solids (TDS): TDS value of groundwater of the study area ranges from 357.5 ppm to 484.25 ppm. Groundwater TDS distribution of study area is shown in Fig. 5.2.e and 5.2.f.

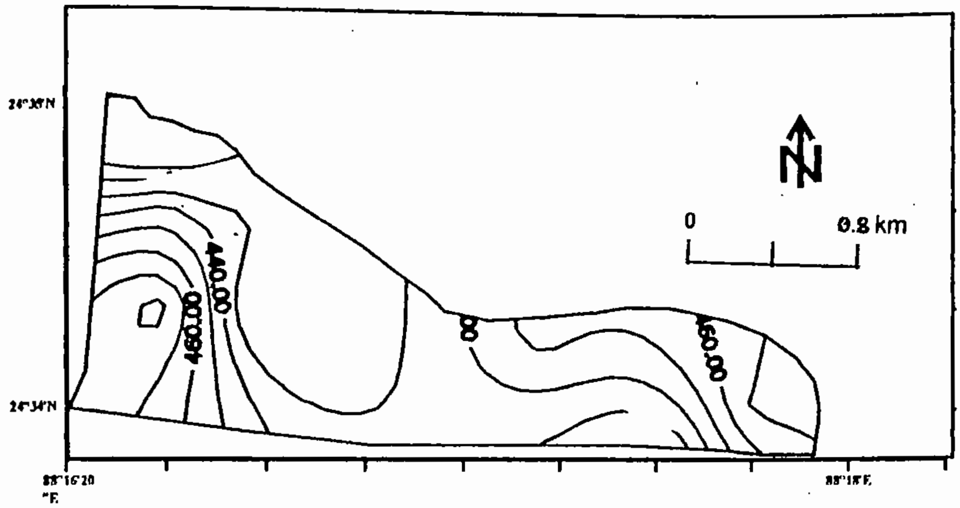


Fig. 5.2.e: Contour map showing TDS distribution in groundwater of the study area.

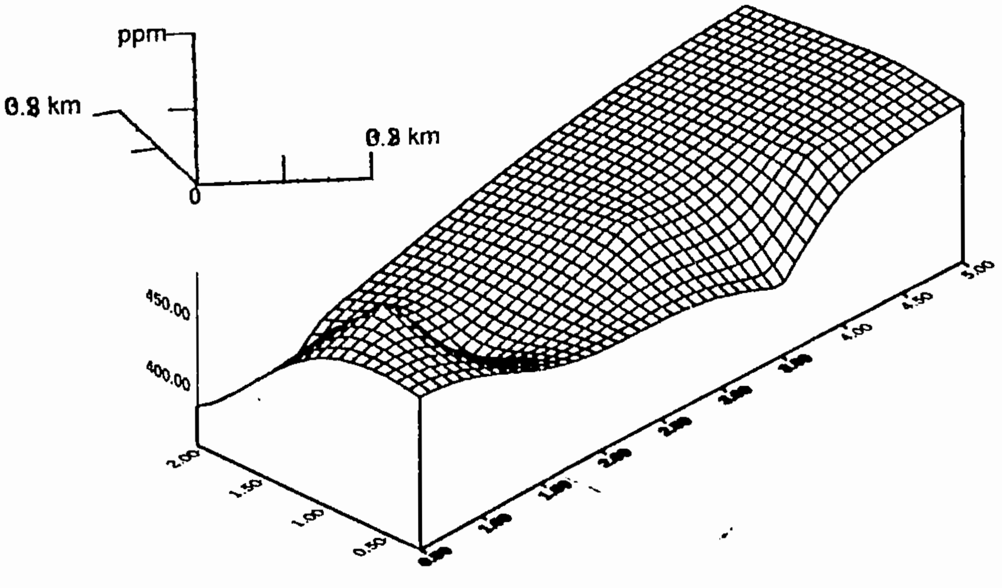


Fig. 5.2.f: 3D view of TDS distribution in groundwater of the study area.

Chemical parameters:

Cation:

Calcium (Ca^{2+}): The highest concentration of Calcium ion in groundwater of the study area was 150 ppm and the lowest concentration was 67.13 ppm. The highest concentration is above the maximum acceptable limit according to WHO standard guideline (WHO, 1984) value (Ca^{2+} 75 ppm). Distribution of Calcium ion concentration in groundwater of the study area is shown in Fig. 5.2.g and 5.2.h.

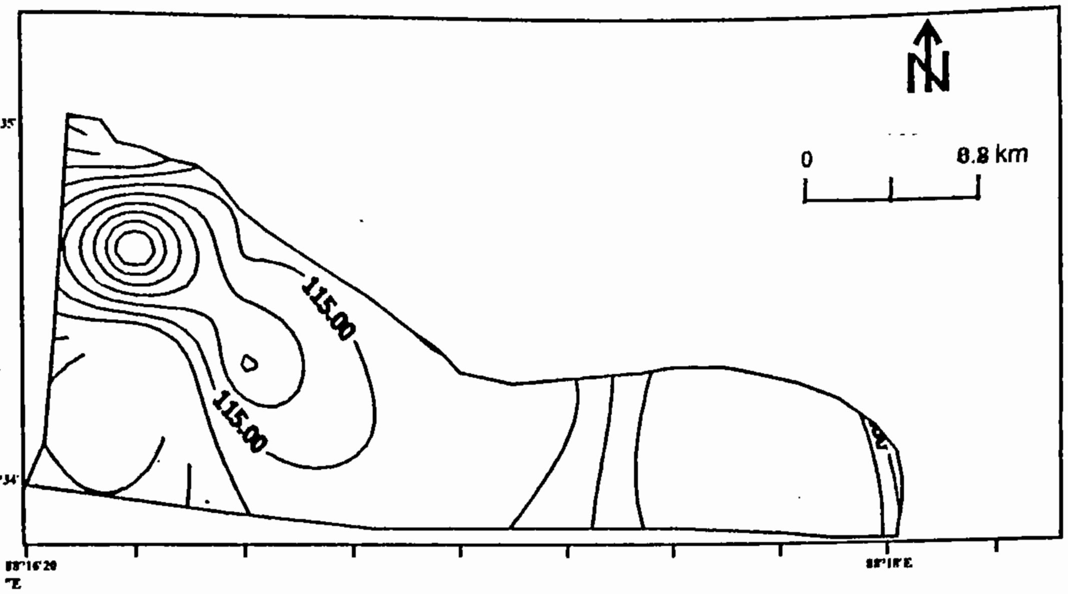


Fig. 5.2.g: Contour map showing Calcium distribution in groundwater of the study area.

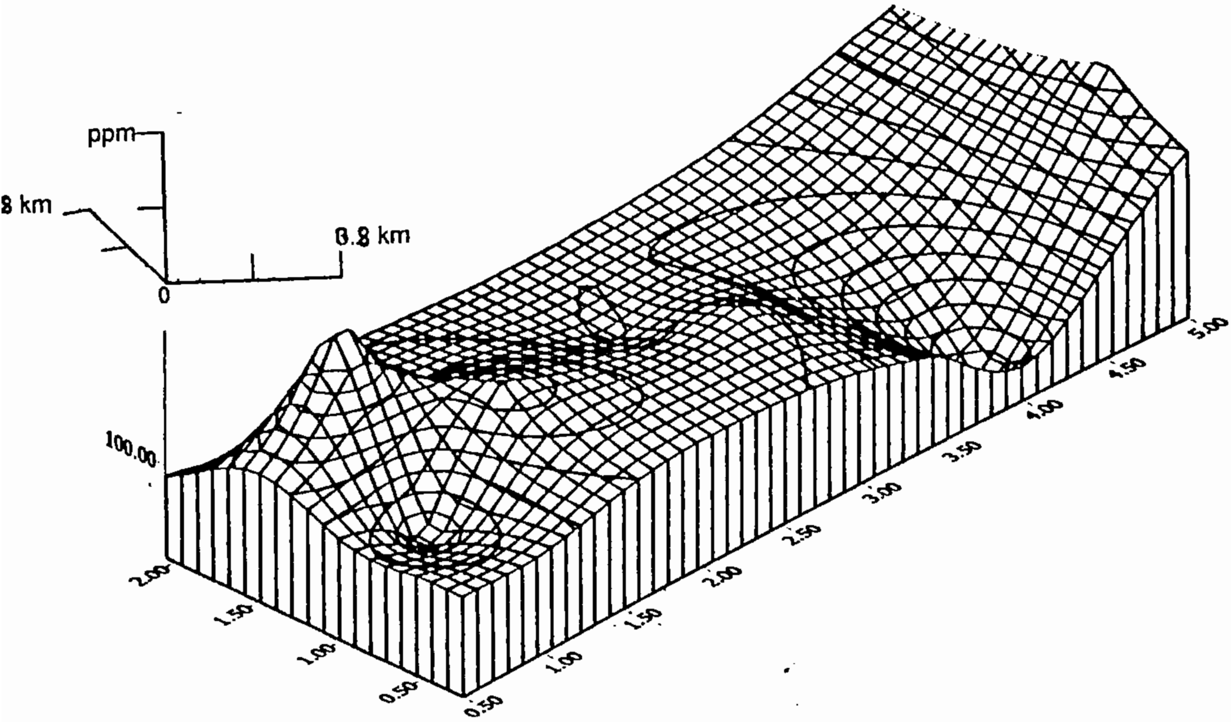


Fig. 5.2.h: 3D view of Calcium distribution in groundwater of the study area.

Magnesium (Mg^{2+}): The Magnesium concentration in groundwater of the study area ranges from 2 ppm to 41.63 ppm, which is below the WHO Guideline value (Mg^{2+} 50 ppm to 150 ppm) (WHO, 1984). Distribution of Magnesium concentration in groundwater throughout the study area is shown in Fig. 5.2.i and 5.2.j.

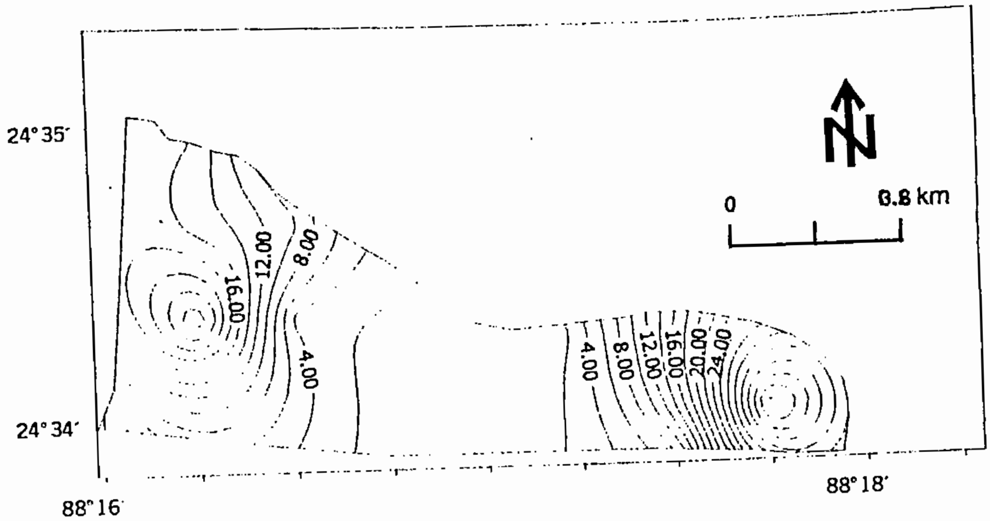


Fig. 5.2.i: Contour map showing Magnesium distribution in groundwater of the study area.

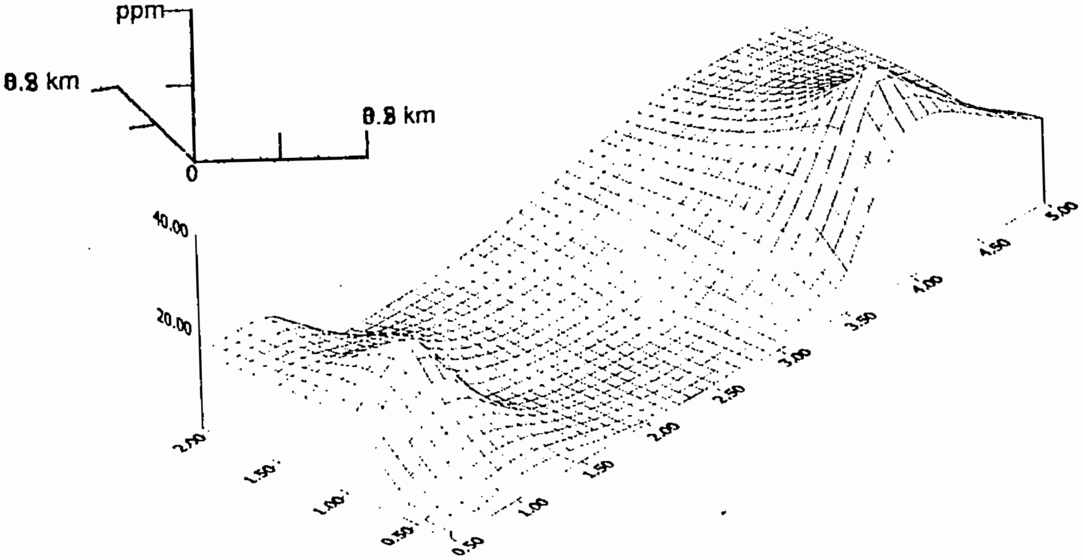


Fig. 5.2.j: 3D view of Magnesium distribution in groundwater of the study area.

Sodium (Na^+): Sodium content in groundwater of the study area ranges from 1.25 ppm to 15 ppm. Distribution of Sodium concentration in groundwater throughout the study area is shown in figs 5.2.k and 5.2.m.

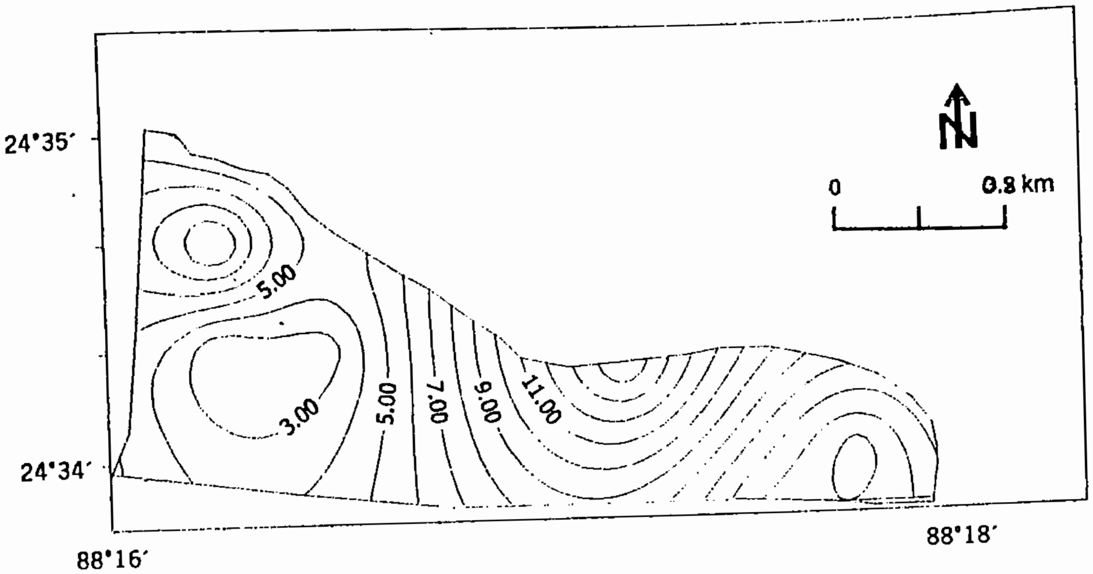


Fig. 5.2.k: Contour map showing Sodium distribution in groundwater of the study area.

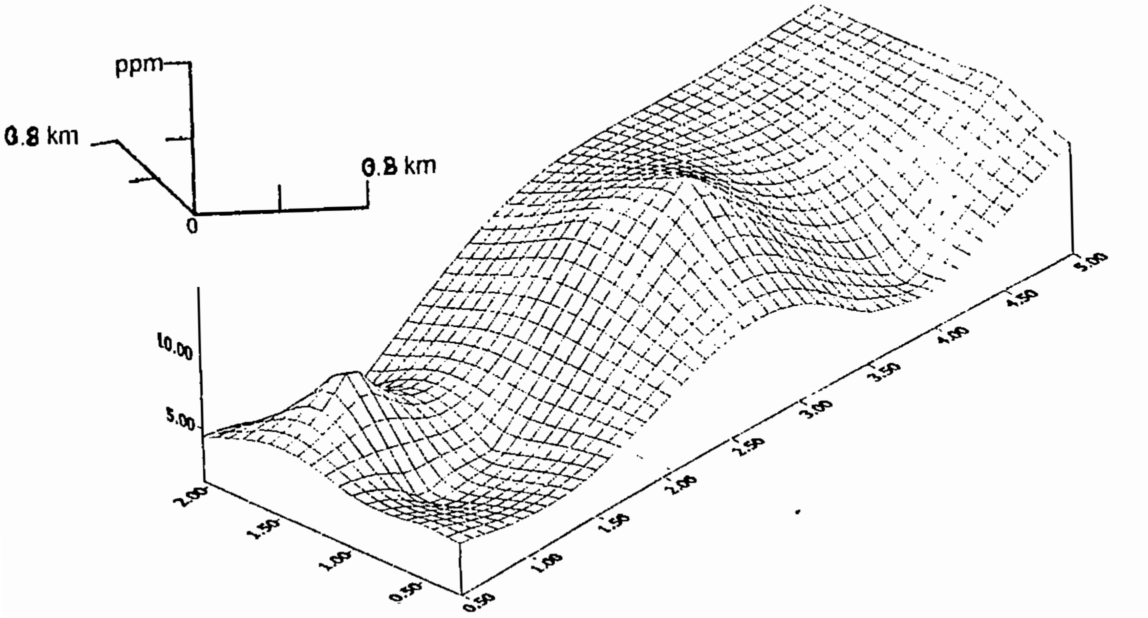


Fig. 5.2.m: 3D view of Sodium distribution in groundwater of the study area.

Potassium (K^+): The potassium content value in groundwater of the study area ranges from 0.3 ppm to 7.2 ppm. Distribution of potassium concentration in groundwater of the study area is shown in Fig. 5.2.n and 5.2.p.

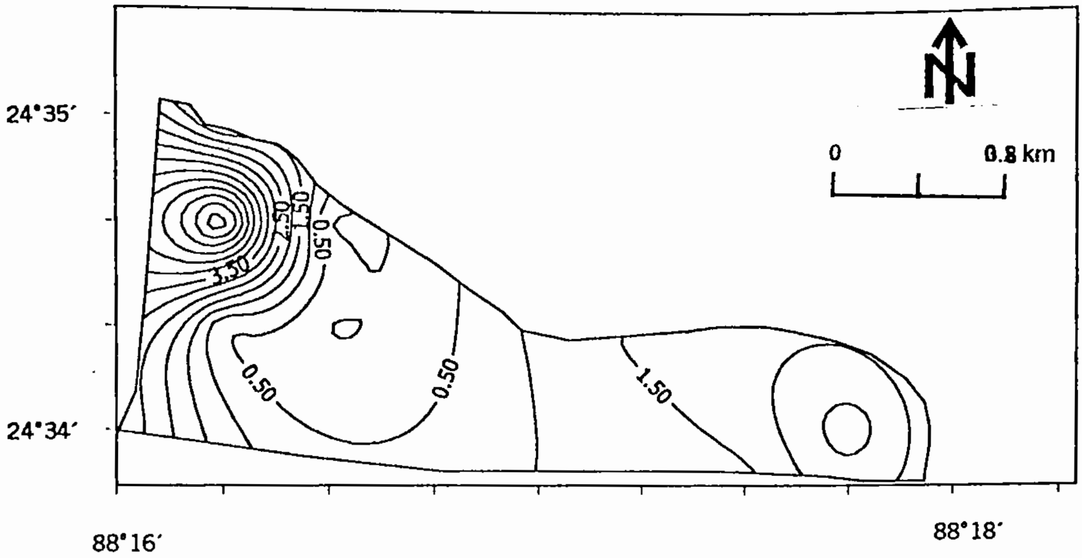


Fig. 5.2.n: Contour map showing Potassium distribution in groundwater of the study area.

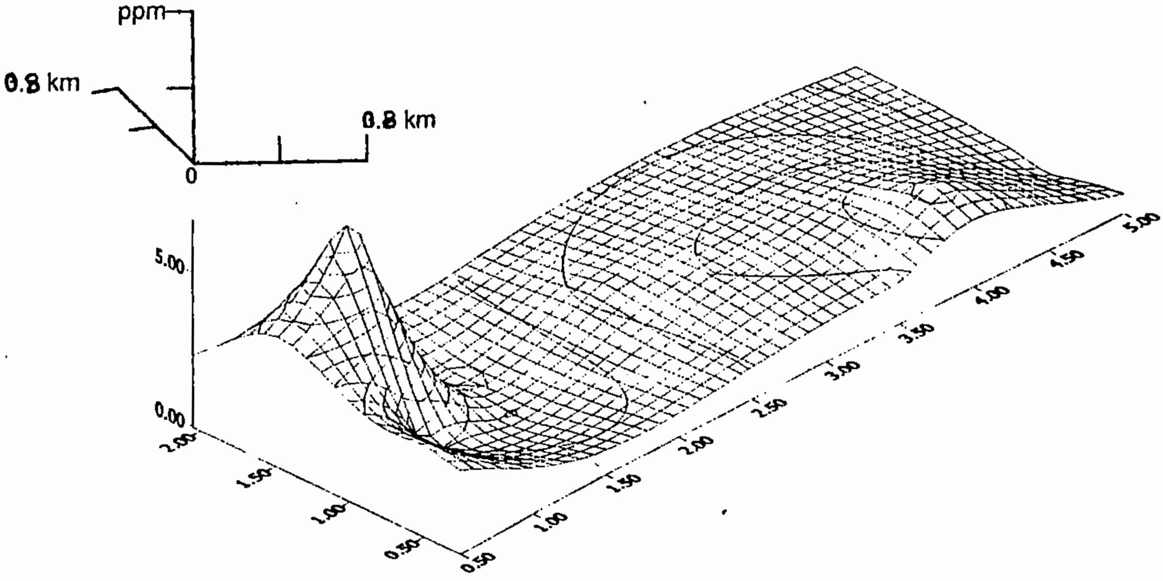


Fig. 5.2.p: 3D view of Potassium distribution in groundwater of the study area.

Total Iron (Fe^{total}): The total iron concentration in groundwater of the study area ranges from .11ppm to 6.4 ppm. The concentrations in the study area show much higher value than the WHO standard guideline value (Fe^{total} 0.03 ppm) (WHO, 1984). Distribution of total iron concentration in groundwater of the study area is shown in Fig. 5.2.q and 5.2.r.

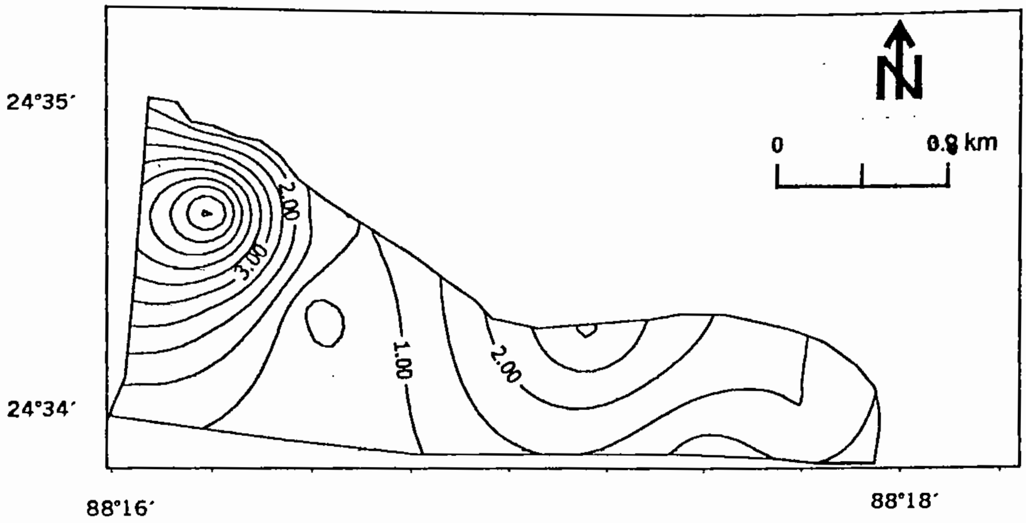


Fig. 5.2.q: Contour map showing Iron distribution in groundwater of the study area.

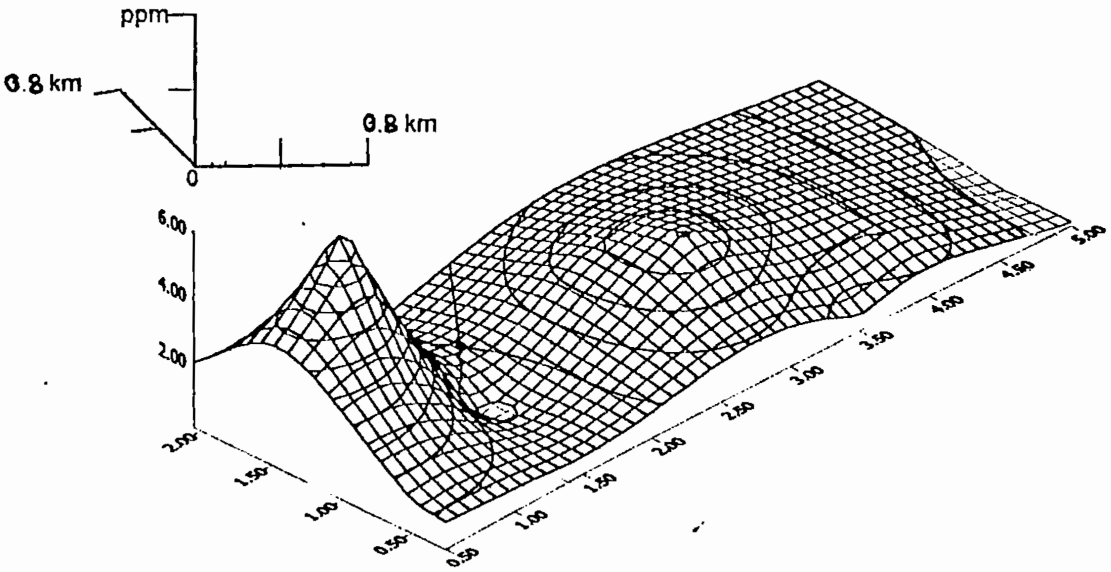


Fig. 5.2.r: 3D view of Iron distribution in groundwater of the study area.

ANION:

Bicarbonate (HCO_3^-): Among the chemical constituents have so far determined, either cation or anion, HCO_3^- shows the highest concentration in the study area. The HCO_3^- in groundwater of the study area ranges from 273 ppm to 483 ppm. Distribution of bicarbonate concentration throughout the study area is shown in Fig. 5.3.a and 5.3.b.

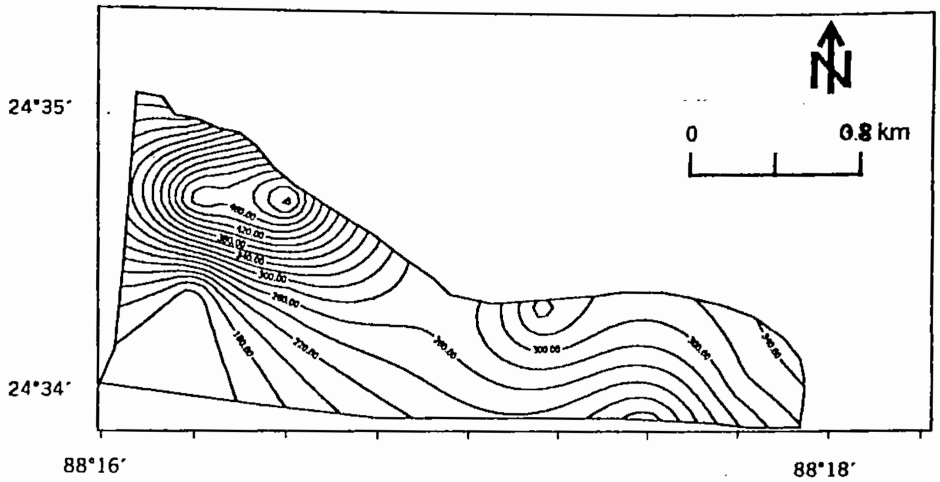


Fig. 5.3.a: Contour map showing Bicarbonate distribution in groundwater of the study area.

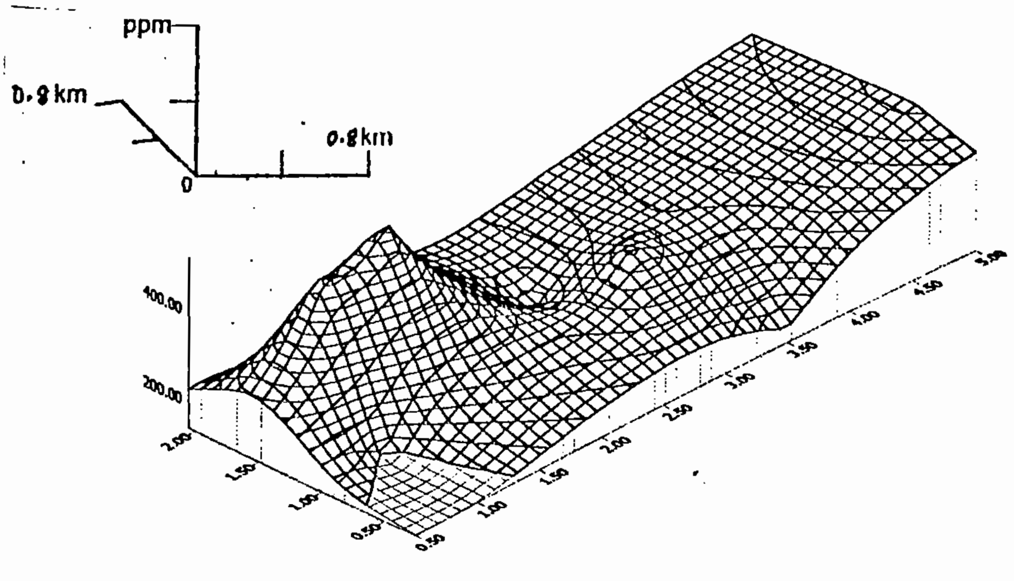


Fig. 5.3.b: 3D view of Bicarbonate distribution in groundwater of the study area.

Chloride (Cl^-): The chloride concentration of groundwater in study area ranges from 12 ppm 23.7 ppm, which is below the WHO standard guideline value (Cl^- 200 ppm to 600 ppm; WHO, 1984). Distribution of chloride concentration in the study area is shown in Fig. 5.3.c and 5.3.d.

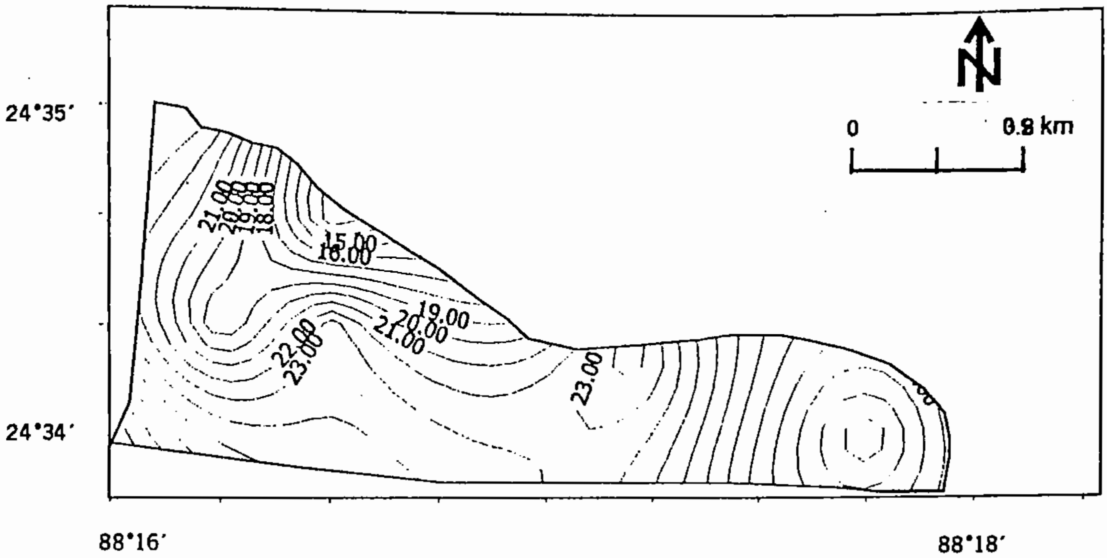


Fig. 5.3.c: Contour map showing Chloride distribution in groundwater of the study area.

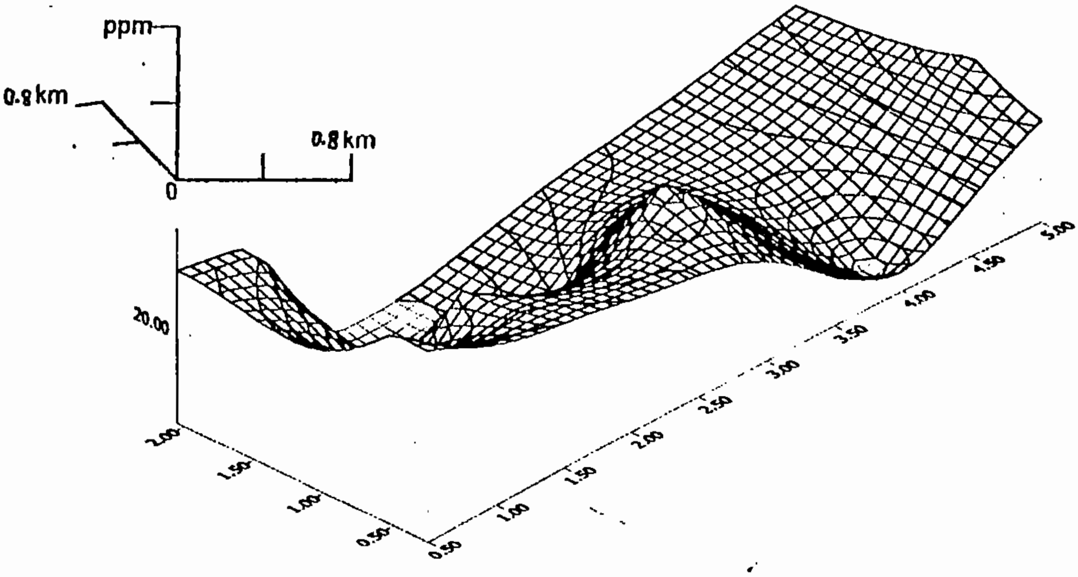


Fig. 5.3.d: 3D view of Chloride distribution in groundwater of the study area.

Nitrate (NO_3^-): Nitrate concentration in groundwater of the study area ranges from 0-0.12 ppm, which is less than the WHO standard guideline value (NO_3^- 10 ppm) (WHO, 1984). Distribution of nitrate concentration in groundwater throughout the study area is shown in Fig. 5.3.e and 5.3.f.

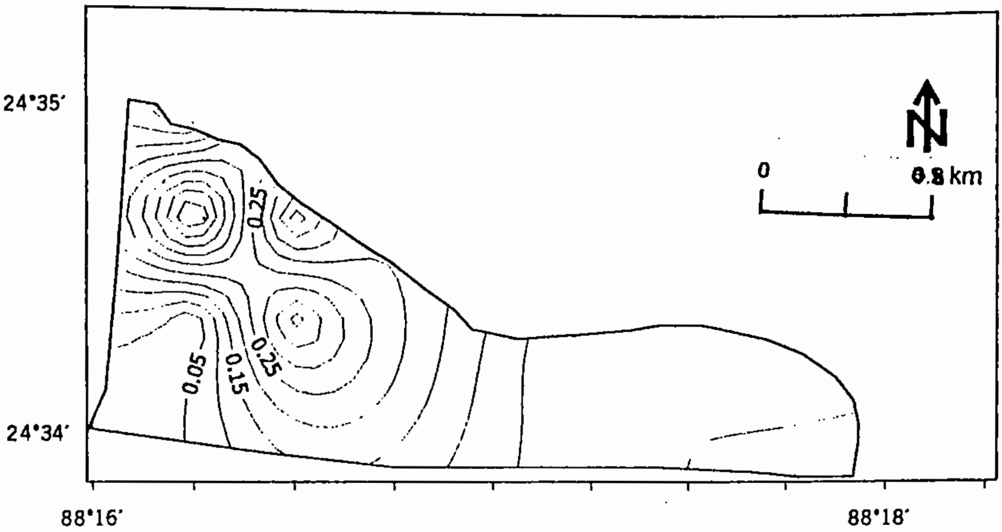


Fig. 5.3.e: Contour map showing Nitrate distribution in groundwater of the study area.

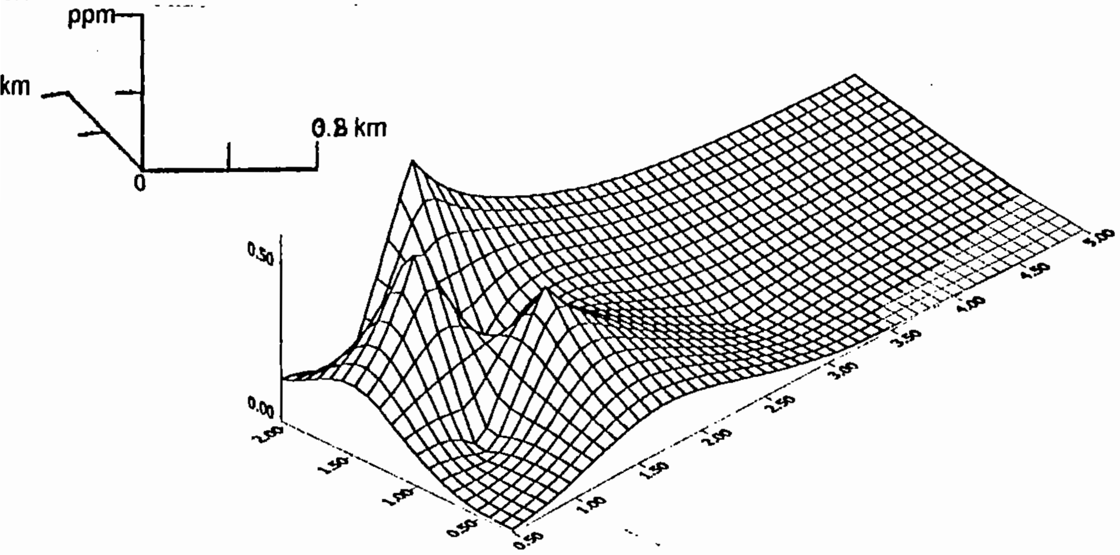


Fig. 5.3.f: 3D view of Nitrate distribution in groundwater of the study area.

Sulfate (SO_4^{-2}): The sulfate concentration in groundwater of the study area ranges from 0-1.00 ppm, which is less than the WHO standard guideline value (SO_4^{-2} 10 ppm) (WHO, 1984). Distribution of sulfate concentration in groundwater of the study area is shown in Fig. 5.3.g and 5.3.h.

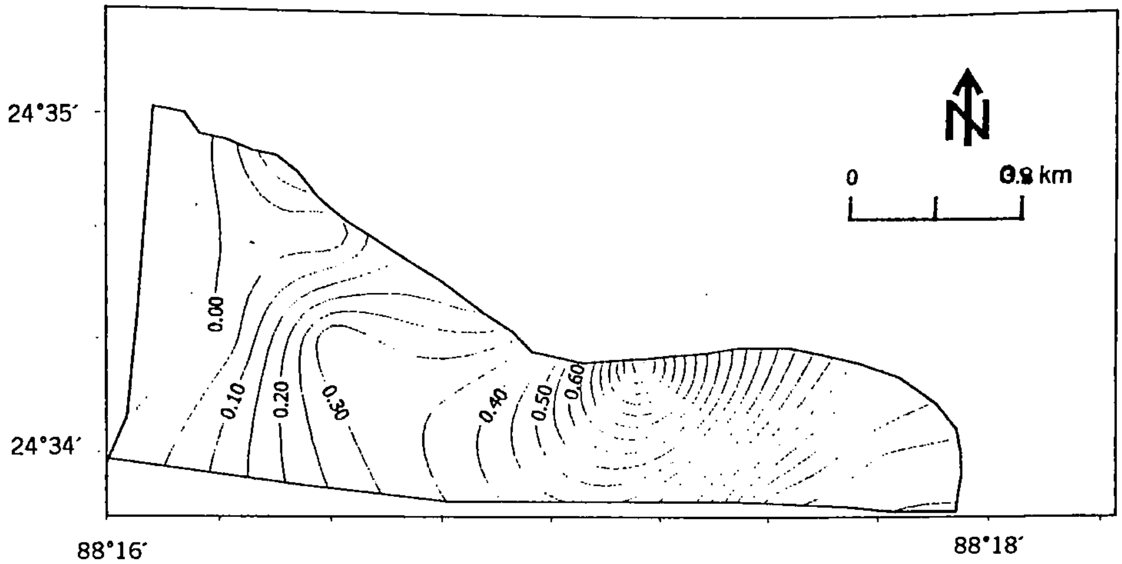


Fig. 5.3.g: Contour map showing Sulfate distribution in groundwater of the study area.

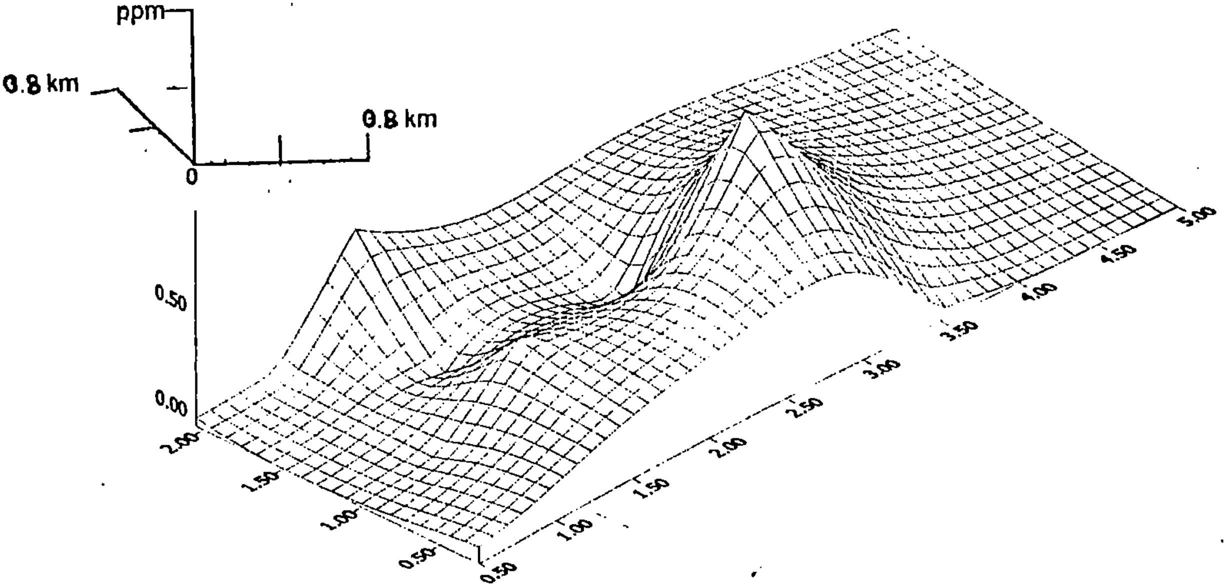


Fig. 5.3.h: 3D view of Sulfate distribution in groundwater of the study area.

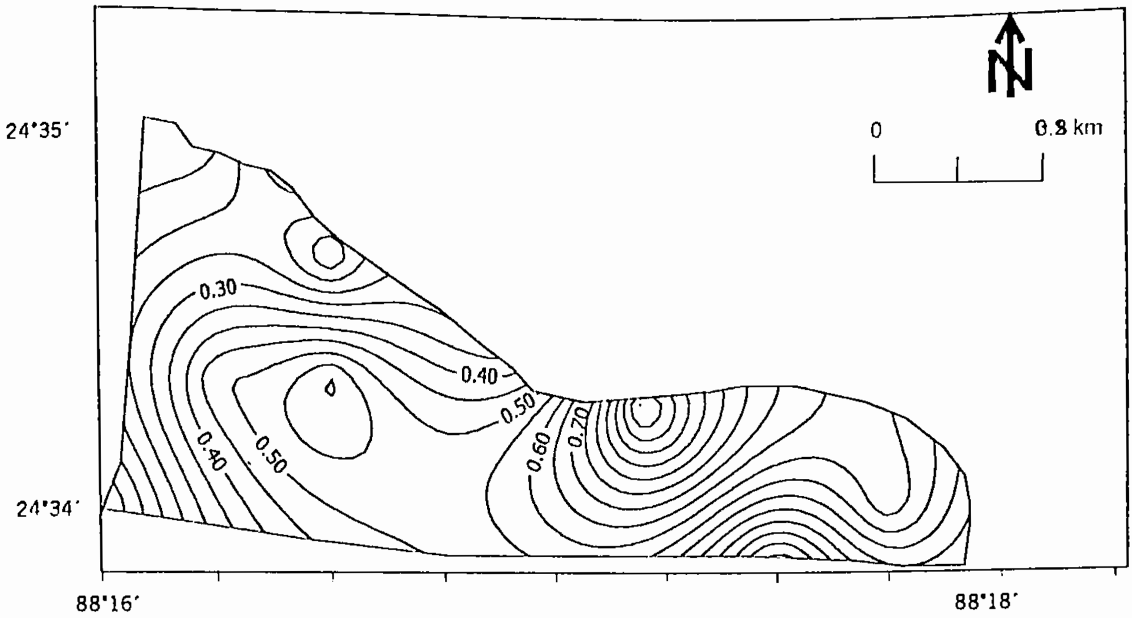


Fig. 5.3.i: Contour map showing Arsenic distribution in groundwater of the study area.

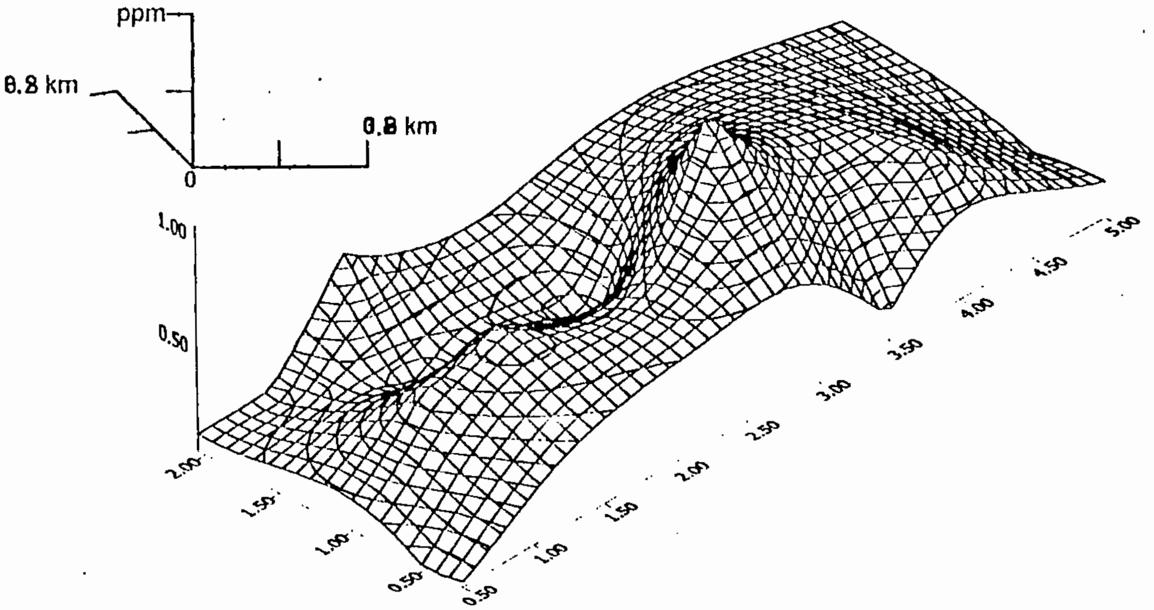


Fig. 5.3.j: 3D view of Arsenic distribution in groundwater of the study area.

Arsenic (As): Arsenic concentration in groundwater of the study area was much higher than the WHO standard guideline value (As 0.01 ppm) (WHO, 2001). Arsenic concentration in groundwater of the study area ranges from 0.035 ppm to 1.08 ppm. Distribution of groundwater arsenic concentration in the study area is shown in Fig. 5.3.i and 5.3.j.

5.3 CLASSIFICATION OF GROUNDWATER:

It is very much essential to classify the groundwater to ascertain the suitability of water for various purposes (domestic, agricultural or industrial). Depending upon the hydrochemical parameter, the groundwater of the study area has been classified as follows:

5.3.1 Genetic classification: Schoeller (1962) has classified water from several points of view such as Cl^- concentration, SO_4^{-2} concentration and concentration of HCO_3^-, CO_3^{-2} etc (Table-5.1, Table-5.2 and Table-5.3).

Table-5.1: Classification based on Cl^- concentration (Schoeller, 1962).

Water classes	Ranges of Cl^- concentration in meq/l	Remarks.
Super Chloride	> 700	
Marine Chloride	700 – 420	Cl^- content varies about the average sea water content of 560 –140 meq/l
Strong Chloride	420 – 140	
Medium Chloride	140 – 40	Cl^- content of 40 meq/l corresponds to the upper limit for normal human consumption.
Oligo-chloride	40 – 15	
Normal Chloride	<15	

Chloride ion concentration in the study area ranges from 0.34 to 0.7 meq/l. Therefore, it is concluded that the groundwater of the study area is "Normal Chloride" water.

Table-5.2: Classification based on SO_4^{-2} concentration (Schoeller, 1962).

Water classes	Ranges of SO_4^{-2} concentration in meq/l	Remarks
Super sulfate	> 58	58 meq/l is the concentration of sea water
Sulfate water	58 – 24	24 meq/l is the upper limit for normal human consumption.
Oligo sulfate	24 – 6	
Normal Sulfate	< 6	

The sulphate (SO_4^{2-}) concentration of the study area ranged from 0.00 to 0.02 meq/l, which indicates that the groundwater of that area is "Normal Sulfate" water.

Table-5.3: Classification based on CO_3^{-2} and HCO_3^- concentration (Schoeller, 1962).

Water classes	Ranges of $(CO_3^{-2} + HCO_3^-)$ concentration in meq/l
Super Carbonate	> 7
Normal Carbonate	2 – 7
Under Carbonate	< 2

The concentration of CO_3^{-2} of the samples was not measured. Only HCO_3^- concentration was measured and ranged from 4.16 meq/l to 7.9 meq/l which indicates the "Normal Carbonate" (Well # sh, si, ri, zi, sp, ru, st, dh, bm and ah) to "Super Carbonate" (Well # rh and ch) water.

From the above discussions of genetic classification it may be concluded that the ground water of the study area is predominate "Normal Chloride", although "Normal Sulfate" and "Normal Carbonate" to "Super Carbonate" water characters.

5.3.2 Classification Based on Hardness:

The presence of bivalent metallic cations mainly Calcium and Magnesium in the water causes hardness (Todd, 1980). Disadvantage of hard water is its effect on soap precipitation (increasing of soap requirement) and boiler incrustation.

The total hardness of water in the study area has been calculated by using the formula proposed by Raghunath (1987), as follows:

$$\text{TH in mg/l} = \sum (\text{Ca} + \text{Mg}) \text{ meq/l} \times 50$$

Water is classified according to its hardness (mg/l hardness as $CaCO_3$) by USGS as follows:

Table-5.4: Water classification according to its hardness by USGS.

Water Class	Ranges of hardness in (mg/l) as $CaCO_3$	Remarks
Soft	0 – 55	Require little or no softening
Slight hard	56 – 100	
Moderately hard	101 – 200	Require softening
Very hard	201 –500	

The total hardness of groundwater of the study area ranges from 239.48 mg/l to 367.68 mg/l, which implies that the groundwater of the study area is "very hard".

5.3.3 Classification Based on Water Use Criteria:

Depending upon the toxicological and ecological effect of groundwater, it may also categorized as domestic, industrial and agricultural.

5.3.3.1 Drinking Water Quality Standards: Domestic water quality generally has universally accepted standards. The drinking water quality standards showed satisfy the criteria recommended by Public Heath Organizations. The guideline values recommended by World Health Organization (WHO, 1983) and Bangladesh Water Pollution Control Board (BWPCB, 1976) for drinking water are given in the Table 5.5. According to WHO (1984) standard guideline value, the major cations and anions in the groundwater of study area is suitable but due to presence of high concentration of arsenic, it is unsafe for drinking.

Table-5.5: Comparison of Groundwater Quality of the Study Area with WHO (1984) and Bangladesh Standard (BWPCB, 1976) for Drinking Purpose.

Sl. no	Water Quality Parameter	Unit	WHO Standard		Bangladesh Standard		Concentration in Study Area	Undesirable Effect Produce
			Max. accept. limit	Max. allow. limit	Max. accept. limit	Max. allow. limit	Max – Min	
1	pH		6.5	8.5	6.5	8.5	7.5-9.8	Taste
2	EC	µS/cm					550-745	
3	TDS	ppm					357.5-484.25	Taste
4	Calçium (Ca^+):	ppm	75	200			67.13-150	Excessive scale formation
5	Magnesium (Mg)	ppm	50	150			2-41.63	Excessive scale formation
6	Sodium (Na)	ppm		200			1.25-15	
7	Potassium (K)	ppm			12		0.3-7.2	
8	Iron (Fe)	ppm	0.3	1.00	1.00	5.00	0.11-6.4	Can impart brownish color to clothing and cause staining of bathroom fittings and incrustation in water modes. May effect the taste
9	Bicarbonate (HCO_3)	ppm					273-483	Excessive scale formation
10	Chloride (Cl)	ppm	200	600	600	1000	12-23.7	Salty taste
11	Sulfate (SO_4)	ppm	200	400		400	0.00-1.00	Laxative effect on human system
12	Nitrate (NO_3)	ppm	10		45	50	0.00-1.00	Blue baby diseases in children
13	Arsenic (As)	ppm	0.01		0.02	0.05	0.035-1.08	Skin disease and cancer
14	Total Hardness	ppm	100	500	100	500	239.46 – 398.46	Excessive scale formation

The comparison of groundwater of the study area with WHO and Bangladesh Standards for drinking purposes is shown in Table-5.5. From this comparison chart, it can be concluded that all the values of the hydrochemical parameters of the studied water samples suitable for drinking and public health purpose except for the fact arsenic pollution (high concentration 0.035 ppm to 1.08 ppm) which exceeds the allowable limit. However, the groundwater of the study area can be made suitable for drinking after remaining arsenic by treatment.

5.3.3.2 Agriculture Water Quality Standards: Like drinking water standards or guidelines, the agriculture water also has some standards depending upon the suitability of water for livestock and irrigation purposes.

5.3.3.2.1 Quality of Water Required for Livestock: Though most animals can drink water with moderately high dissolved solid (about 10g/L) when NaCl is the chief constituent, it is evident, that like human beings livestock needs some standard guidelines for its water use. The Department of Agriculture, Western Australia in 1950 has suggested the following upper limits of Total Dissolved Solids (TDS) concentration in water for livestock consumption.

Table-5.6: Upper limits of total dissolved solids (TDS) in water for Livestock consumption.

Livestock	Upper limit in mg/l	Remarks
Poultry	2860	In the groundwater of the study area, the TDS concentration ranged from. 357.5-484.25 mg/l
Pigs	4290	
Horses	6435	
Dairy cattle	7150	
Beef cattle	10100	
Lambs (lalleming)	12900	

Therefore, it may be concluded that the groundwater of the study area is suitable for the livestock. However, presence of high concentration of arsenic makes the water dangerous for livestock health.

5.3.3.2.2 Irrigation Water Quality Standards: The suitability of groundwater for irrigation is significant due to effects of the mineral constituents of water on both the plants and soil. Because this mineral constituents (impurities) of water may be interfere with the plant growth by some physical (effect on osmotic processes) and chemical (metabolic reaction caused by toxic constituents) actions. They may also causes changes in soil structure, permeability and aeration. The most important characteristic properties of irrigation water which are used to determine its quality are as follows:

a) Electrical Conductance (EC): If the TDS of water increases it is difficult for plants to extract water. As TDS in ppm = 0.65 × EC in μS/cm, Wilcox (1967), classified water for irrigation based on EC.

Table-5.7: Classification of water for irrigation based on EC (Wilcox, 1967)

Water class	Specific Conductance in μS/cm
Excellent	< 250
Good	250-750
Permissible	750-2000
Doubtful	2000-3000
Unsuitable	> 3000

The EC distribution in groundwater of the study area ranges from 550 to 745 μS/cm. Thus, it can be concluded that the groundwater of the study area is of good quality for irrigation.

b) Sodium Absorption Ratio (SAR): SAR is important for determination of irrigation water quality, because it is responsible for the sodium hazard. SAR is defined by –

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

Where, the constituents of the ions are measured in meq/l.

The high value of SAR (>18) implies a hazard of Sodium (alkali) replacing Calcium and Magnesium of the soil through cation exchange process. This situation eventually causes damage to soil structure, which ultimately affects fertility status of soil and reduces crop yield (Gupta *et al.*, 1987). The quality of classification of water for irrigation depending upon SAR (Raghunath, 1987) is given as follows:

Water class	SAR
Excellent	< 10
Good	10 – 18
Medium	18 – 26
Bad	> 26

The SAR values in groundwater of the study area ranges from 0.081 to 0.4. From the classification table of SAR, it may be concluded that no alkali hazard is anticipated in the study area and the water is of excellent quality for irrigation.

c) Residual Carbonate (RC): When the sum of Carbonates and Bicarbonates is more than Calcium and Magnesium a complete precipitation of residual carbonate occurs given by the formula (Raghunath, 1987) –

$$RC = \{(CO_3^{2-} + HCO_3^{-}) \sim (Ca^{2+} + Mg^{2+})\} \text{ meq/l}$$

The quality classification of water for irrigation purposes depending upon the residual carbonates proposed by Ragunath (1987) is as:

Water class	RC in meq/l
Excellent	< 1.25
Good	1.25 to 2.5
Poor	> 2.5

From the calculation of residual carbonate it has been observed that the results of residual carbonate of groundwater of the study area does not exceeds 1.25 meq/l. The maximum value of RC is 0.65 meq/l. Therefore, it may be concluded that the groundwater of the study area is excellent for irrigation water.

d) Integrated Effect of two properties viz. EC and SAR: USDA performed a graphical classification of water for irrigation based on EC and SAR. The calculated SAR and EC values of the groundwater of the study area are plotted in this diagram. All of the water samples fall in the class of low alkali hazard (S_1) and medium salinity hazard (C_2). Therefore, it may be concluded that the groundwater of the study area implies the category (C_2-S_1) (Fig 5.4) quality for irrigation with low alkali hazard and medium salinity hazard.

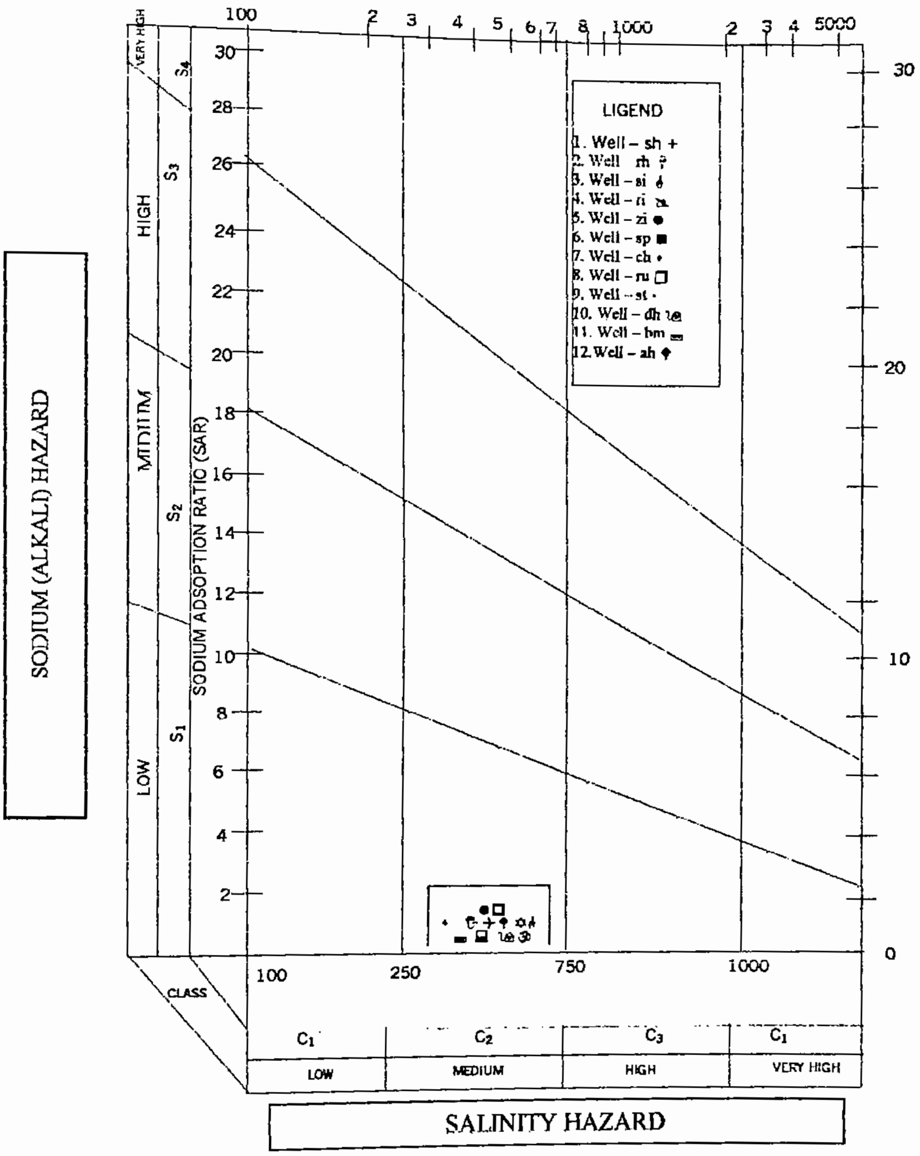


Fig. 5.4: Classification of irrigation water (USDA, 1955).

e) **Sodium Percentage (Na %):** The Sodium percentage was calculated by the formula – Na % = (Na + K) / (Ca +Mg +Na + K) × 100 where, the concentration of ions are measured in meq/l.

The quality classification of irrigation water depending upon the Na percentage proposed by Wilcox (1967) is as follows:

Water class	Ranges of Na %
Excellent	< 20
Good	20-40
Permissible	40-60
Doubtful	60-80
Unusable	> 80

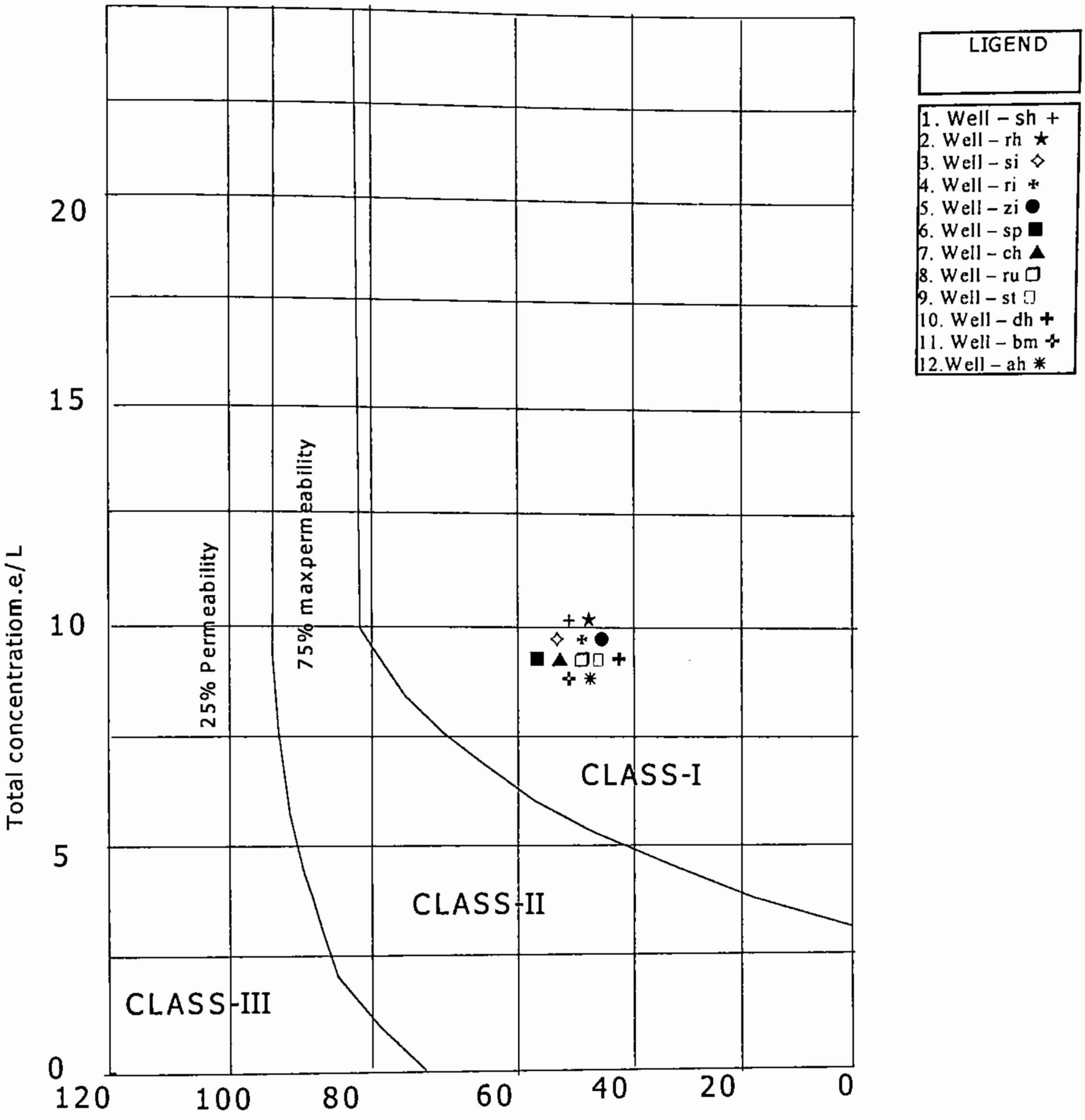
In the study area, the Na percentage in groundwater ranged from 1.31 to 11.25. Hence, it may conclude that the groundwater of the study area is of excellent quality.

f) **Permeability Index (PI):** The Permeability Index is defined by –

$$PI = (Na^{+} + \sqrt{HCO_3}) / (Ca^{2+} + Mg^{2+} + Na) \times 100$$

Where, the concentrations are measured in meq/l.

Doneen (1962) has proposed a chart for classification of irrigation water based on permeability index (PI) (Fig. 5.5). The groundwater samples of the study area fall in the class-I, which implies that the groundwater is of good to very good quality for irrigation purpose. Classification of groundwater for irrigation purposes depending upon the content of dissolved materials and other physicochemical parameters as proposed by various authors is given below in the Table-5.8 and 5.9.



$$\text{Permeability Index (PI)} = \frac{Na + \sqrt{HCO_3}}{C} \times 100$$

Fig. 5.5: Classification of irrigation waters (Doneen, I.D., 1962).

Table–5.8: Quality classification of water for irrigation (Wilcox, 1967).

Water class	Percent Sodium (Na %)	Specific conductance in μS/cm	Boron		
			Sensitive crops	Semi tolerant crops	Tolerant crops
Excellent	< 20	< 250	< 0.33	< 0.67	< 1.00
Good	20-40	250-750	0.33-0.67	0.67-1.33	1.00-2.00
Permissible	40-60	750-2000	0.67-1.0	1.33-2.0	2.00-3.00
Doubtful	60-80	2000-3000	1.0-1.25	2.0-2.50	3.00-3.75
Unsuitable	> 80	> 3000	> 1.25	> 2.50	> 3.75

Correlating with the above table, results of Na percentage and Specific conductance in μS/cm of the study area signifies that the groundwater of the study area is good for irrigation purposes.

Table–5.9: Quality classification of water for irrigation according to Raghunath (1987).

Water class	Salinity hazard		Alkali hazard SAR	RC in meq/l
	EC in µS/cm	Salt conc. (meq/l)		
Excellent	< 250	< 0.25	Up to 10	< 1.25
Good	250-750	0.25-7.5	10-18	1.25-2.50
Medium	750-2250	7.5-22.5	18-26	> 2.50 (poor)
Bad	2250-4000	22.5-40	> 26	
Very bad	> 4000	> 40		

Correlation from the above table and studied results of EC, SAR, and RC, it may be concluded that the groundwater of the study area is good to excellent for irrigation.

Although it has shown in section 5.3, that the tube wells water in the study area is of good quality based on different water use criteria, but the high concentration of As alone makes the water totally unsafe for use.

5.4 HYDROGEOCHEMISTRY:

5.4.1 Graphical Presentation of Chemical Analysis Data:

The results of chemical analysis of water samples have been presented in various graphical forms to systematically describe the water quality variations and geo-chemical characteristics of groundwater.

The most commonly used graphical forms such as the Stiff's (1951) pattern diagram; the Collin's (1923) bargraph and the Maucha's (1949) Radial vector diagram are used to interpret the water quality variation. Again, the Piper (1953) Trilinear diagrams, the Expanded Durov diagrams and the facies approach are used to study the geochemical characteristics and classification of groundwater of the study area.

5.4.1.1 Water Quality Variation: Analyzed chemical data are plotted in the following graphical forms to describe the groundwater quality variations from well to well.

a) The Stiff's (1951) Pattern Diagram:

In Stiff's pattern diagram, three horizontal axes and one vertical axis are used. Four cations are plotted on one side and four anions on the other side of the vertical axis. The vertices of the polygon are connected to give a shape characteristics of the type of water.

The concentration of cations and anions (in meq/l) of each well of the study area is shown in the Stiff's pattern diagram (Fig. 5.6), where groundwater quality variation of individual well is determined from the sharp change in the shapes of Stiff's pattern diagram.

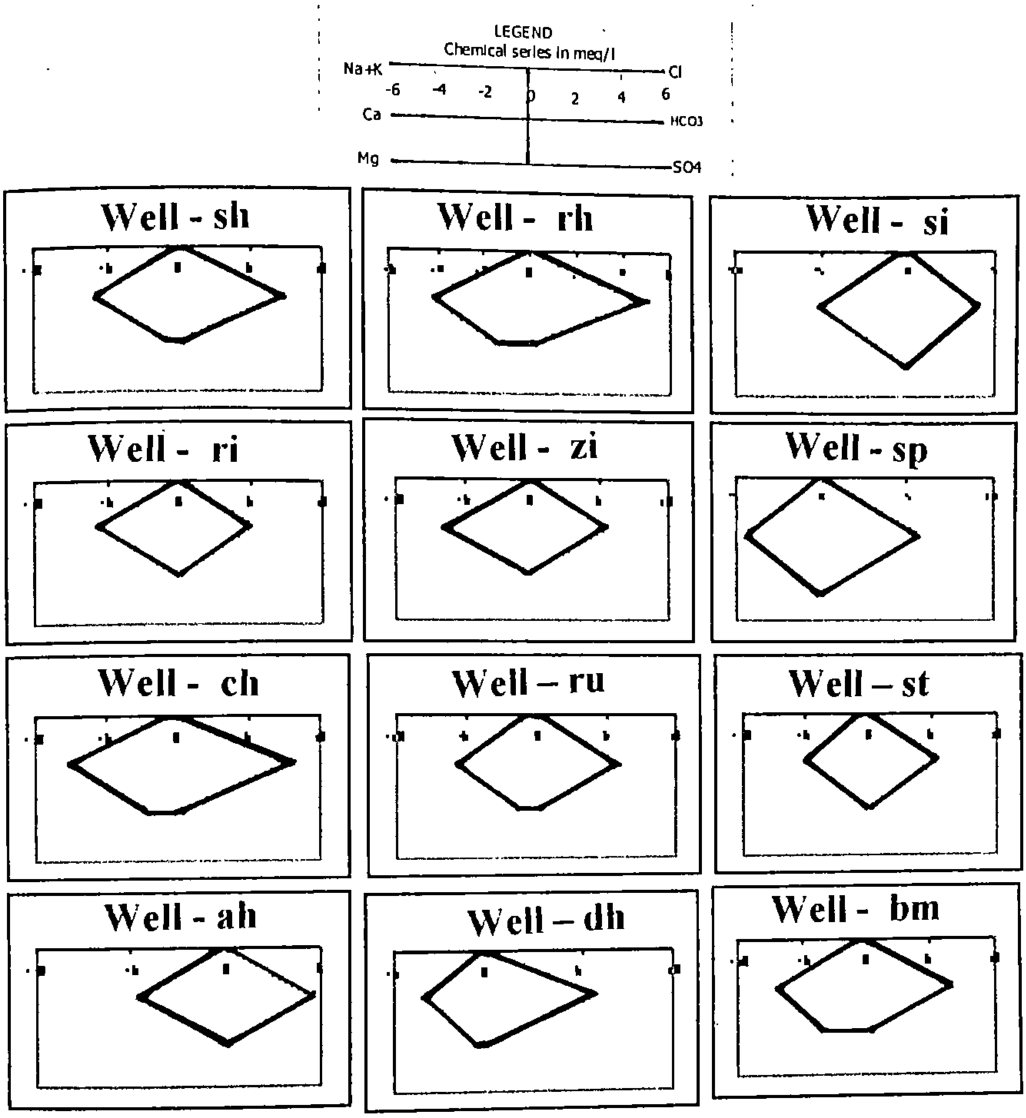


Fig. 5.6: Figure showing the Stiff pattern diagram of each tube wells water of the study area.

b) The Collin's (1923) Bargraph: The Collin's bargraph of the concentration of cations and anions (in meq/l) of every well of the study area are shown in figure (Fig. 5.7). From this bargraph, the variation of ionic concentration is demarcated by the variation of individual height (meq/l) of each cation or anion in the cation or anion bar.

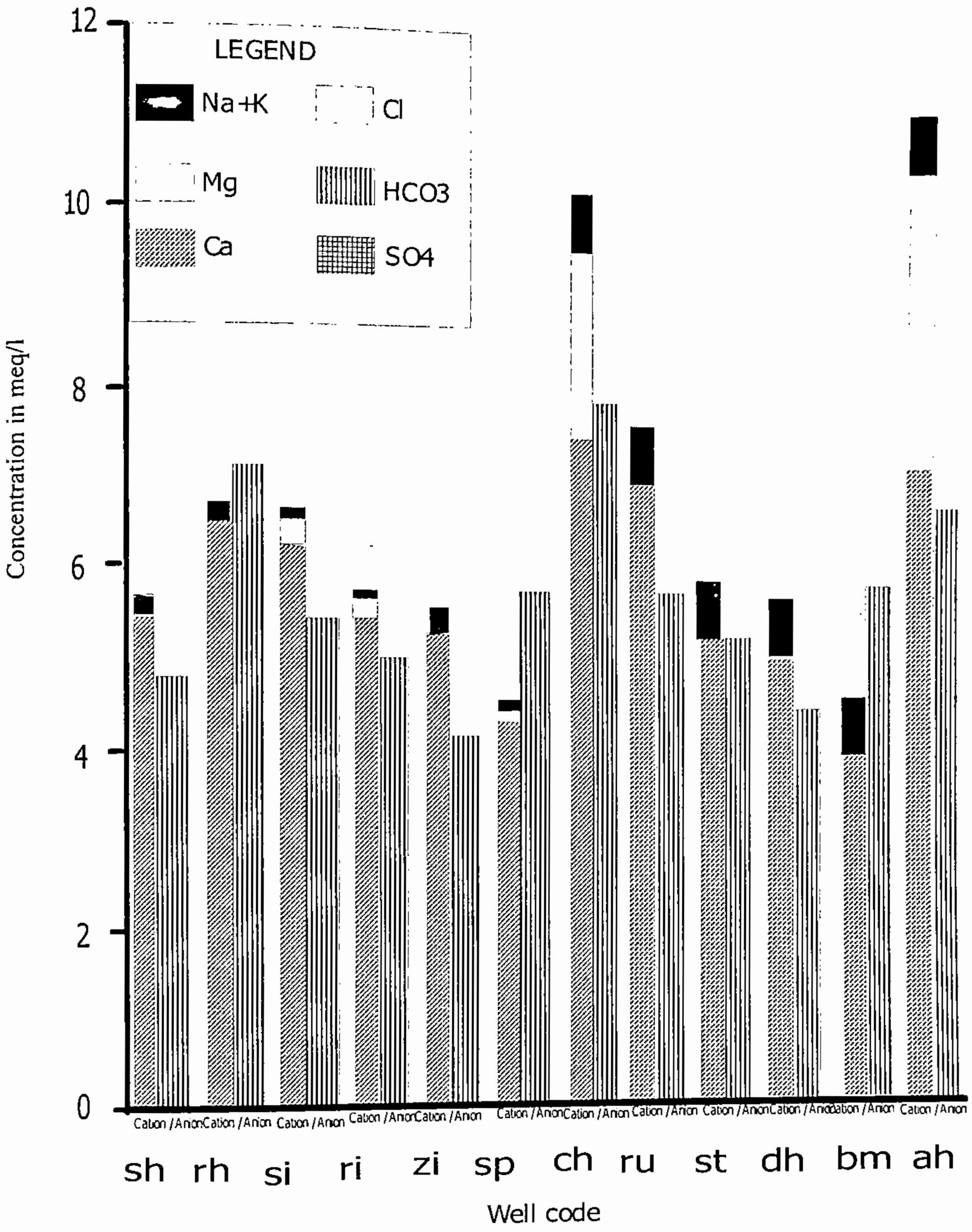


Fig. 5.7: Figure showing the Collin's bargraph diagram of each tube wells water of the study area.

5.4.1.2 Geochemical and Hydrochemical Character of Groundwater:

The characteristics geochemical behavior of groundwater and hydro-chemical types of groundwater of the study area can be represented by Piper's Trilinear and Expanded Durov diagram. The types and hydrogeochemical characteristics of the study area are discussed below using these diagrams.

a) Piper's (1953) Trilinear Diagram: The Trilinear diagram developed by Piper (1953) is one of the most important and useful diagram for presenting and comparing water quality analysis. It is an effective tool in separating hydrochemical analysis data for critical studies with respect to the sources of dissolved constituents (major cations; Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} and major anions; HCO_3^-, Cl^-, SO_4^{2-} and NO_3^-) in waters, modifications in the character of water as it passes through an area, and related geochemical problems.

Major anions and cations are plotted in the two base triangles of the diagram as cation and anion percentages of milli equivalents per liter (meq/l). Total cations and anions are separately considered as 100 percent. The respective cation and anion location for an analysis are projected into the rectangle that represents the total ion relationships, as shown in Fig. 5.8. The central plotting field (diamond shape) of the trilinear diagram is divided into nine areas and water is classified into nine types depending upon the area in which the analysis results fall. Here, alkali cations (Na^{+} and K^{+}) are called primary constituents and the alkaline earth cations (Ca^{2+} and Mg^{2+}) are called secondary constituents. The strong acid cations (SO_4^{2-}, Cl^- and NO_3^-) are treated as saline constituents and CO_3^{2-} and HCO_3^- are treated as weak acid. Mutual balancing of these cations and anions determine the chemical character of water.

The chemical characteristics of groundwater samples of the study area fall in different subdivisions of diamond shaped field of the Piper's Trilinear Diagram for individual wells has shown in Fig. 5.8. These are also summarized in Table-5.10. It is observed that all the samples fall in the Field-1, which indicate alkaline earths exceed alkalis. All of these samples also fall in the Field-3 suggesting weak acids exceed strong acids. Finally, the most of the groundwater samples have dominant carbonate hardness as they belong to the area of Field-5 and indicated that the carbonate hardness (secondary alkalinity) exceeds 50% in groundwater. It may be concluded that the groundwater of the study area has the dominance of alkaline earth's (Ca^{2+} and Mg^{2+}) and weak acids (HCO_3^-).

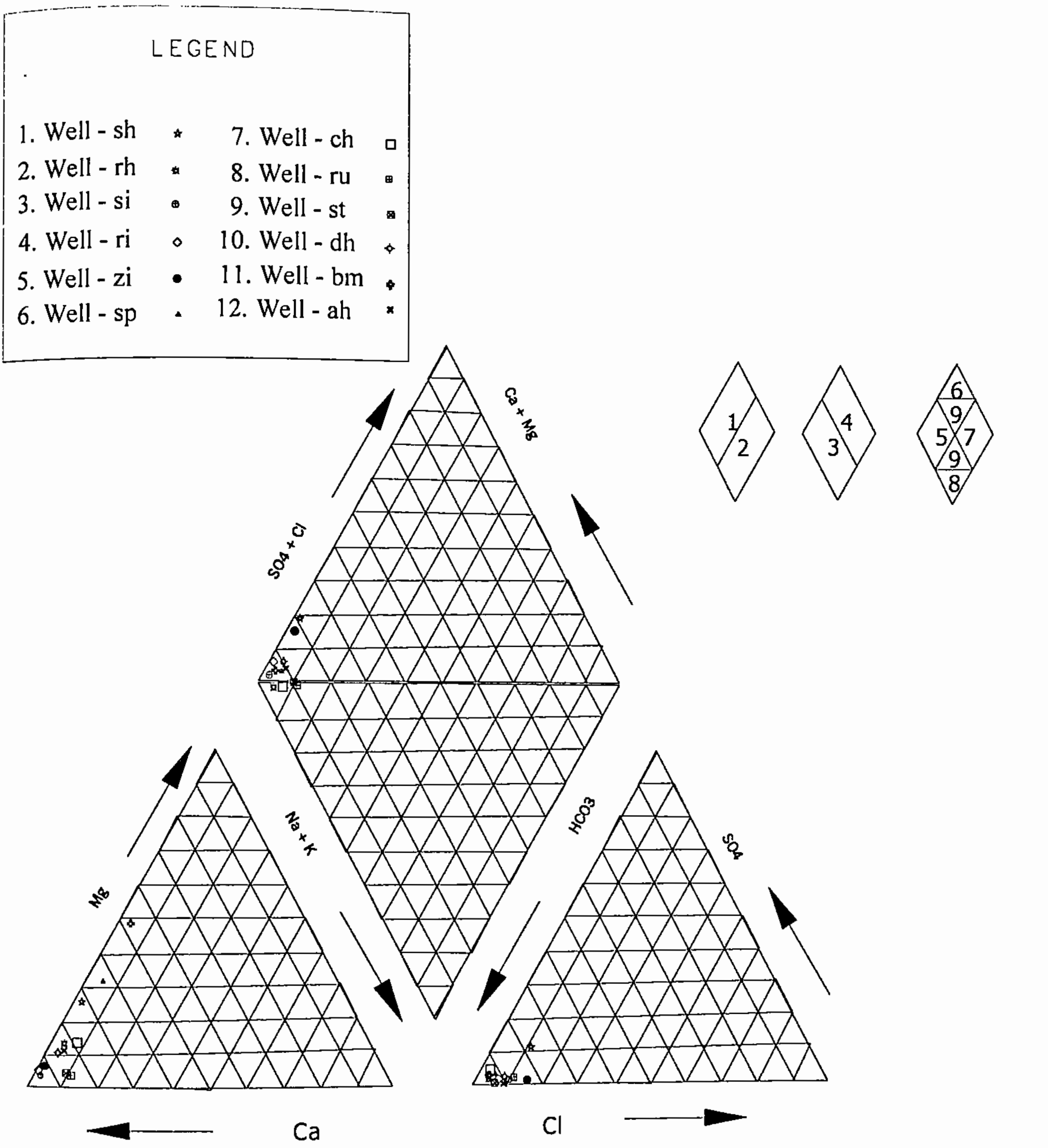


Fig. 5.8: Piper Trilinear Diagram of groundwater of the wells of the study area.

Table-5.10: Distribution of samples in the Piper's Trilinear Diagram.

Field No.	No. of samples	Interpretation (After Lloyd *et al.,* 1985)
1.	**sh, rh, si, ri, zi, sp, ch, ru, st, dh, bm, and ah,**	Alkaline earth exceeds alkalis.
2.	**No**	Alkalis exceed alkaline earth.
3	**sh, rh, si, ri, zi, sp, ch, ru, st, dh, bm, and ah,**	Weak acids exceed strong acids.
4	**No**	Strong acids exceed weak acids.
5.	**sh, rh, si, ri, zi, sp, ch, ru, st, dh, bm, and ah,**	Carbonate hardness (secondary alkalinity) exceeds 50%, that is chemical properties are dominated by alkaline earth and week acids.
6.	No	Non-carbonate hardness (secondary salinity) exceeds 50 %.
7.	No	Non-carbonate alkali (primary salinity) exceeds 50 % that is chemical properties are dominated by alkalis and strong acids; ocean water and many brines plot in this area, near its right hand vertex.
8.	No	Carbonate alkali (primary salinity) exceeds 50 %, here plot the groundwater, which are inordinately soft in proportion to their content of dissolved solids.
9.	No	No cation-anion pair exceeds 50 %.

b) Expanded Durov Diagram:

One of the most important graphical forms, developed by Burden and Mazloum (1965) and Lloyd (1985) which provides a distinct classification of the combination of major cations and anions. It is based on the percentage of major ions expressed as milliequivalent, and the cations and anions together form a total 100 percent. The Expanded Durov diagram provides a better display of hydrochemical types and some processes (Lloyd and Heathcote, 1985). Cations and anions triangles are recognized in this diagram and are separated along the 25 percent axes so that the main field is conveniently divided into nine fields. Significance of these nine fields is illustrated in Fig. 5.9 and in the Table-5.11 followed.

Groundwater samples has fall in the Field-1, which indicates that dominating of HCO_3^- and Ca^{2+} are freshly recharging water in the sandy aquifer of the study area. From the above discussion, it may be concluded that the groundwater of the study area may be classified as of Magnesium-Bicarbonate and Calcium-Bicarbonate types.

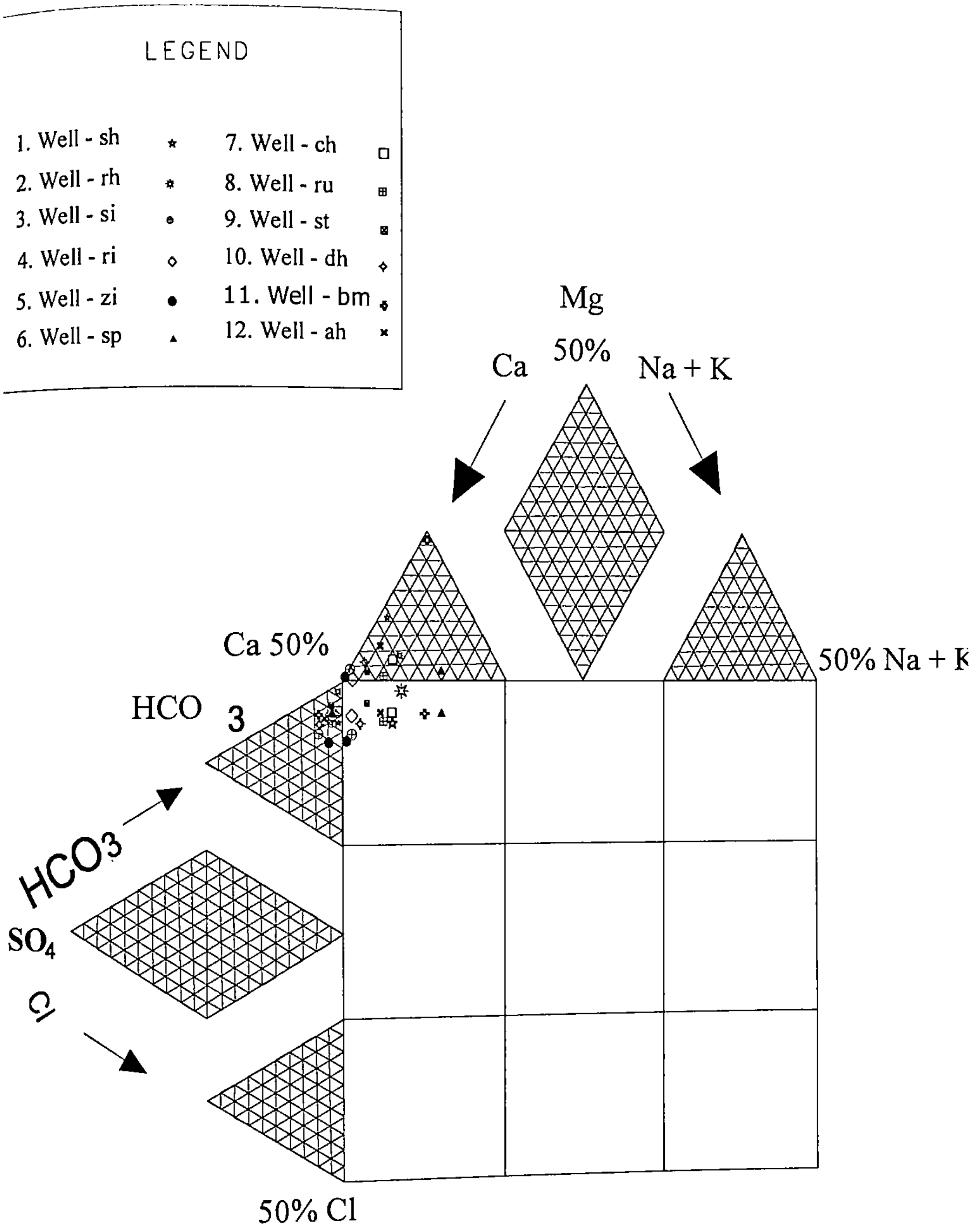


Fig. 5.9: Expanded Durov diagram of groundwater of wells of the study area.

Table–5.11: Distribution of samples in the Expanded Durov Diagram.

Field No.	No. of samples	Interpretation (After , Lloyd et, al . 1985)
1.	**sh, rh, si, ri, zi, sp, ch, ru, st, dh, bm and ah,**	HCO_3^- and Ca^{2+} dominant, frequently indicates recharging waters in the sandy aquifers.
2.	**No**	HCO_3^- dominant and Mg^{2+} dominant or cations indiscriminant with Mg^{2+} dominant or Ca^{2+} and Mg^{2+} important, indicates water often associated with dolomites; where Ca^{2+} and Na^+ are important partial ion exchange may be indicated.
4.	**No**	SO_4^{2-} dominant and anion indiscriminant and Ca^{2+} dominant, Ca^{2+} and SO_4^{2-} dominant frequently indicates a mixed water or a water exhibiting simple dissolution may be indicated.
7.	**No**	Cl^- and Ca^{2+} dominant, indicates the water may result from reverse ion exchange of Na^+ - Cl^- waters.
8.	**No**	Cl^- dominant and no dominant cation indicate that the groundwater may be related to reverse ion exchange of Na^+ - Cl^- waters.

5.4.1.3 The Facies Mapping Approach (Beck, 1961):

To determine the hydrochemical facies from chemical data the facies mapping approach is one of the most important and significant ways. In this system of mapping, the samples are classified according to their facies with two templates for the Piper's trilinear diagram. The chemical analysis data (in meq/L percentage of each cation and anion) are plotted on facies map and described the variation and distribution of hydrochemical facies of groundwater throughout the study area.

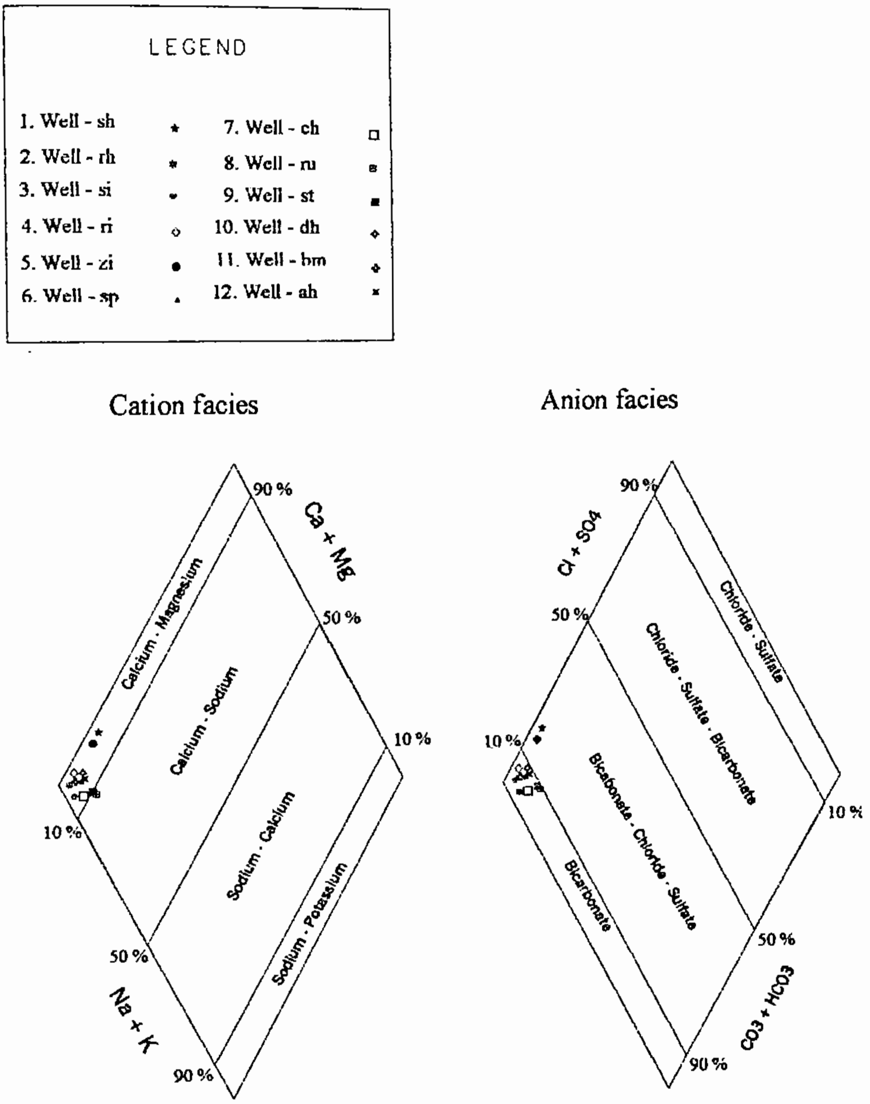


Fig. 5.10 Facies mapping approach of groundwater of the study area.

Cation facies: The groundwater facies of the study area are shown in Fig. 5.10. From this figure, it is observed that all the cation facies of groundwater samples show Calcium-Magnesium to Calcium-Sodium facies.

Anion facies: Among all the samples (12) of groundwater of the study area, only two (2) samples indicate Bicarbonate-Chloride facies and rests (10) indicate Bicarbonate facies.

From the study of hydrochemical facies, it may be concluded that in the groundwater of the study area, alkaline earth predominates over the alkalis. Among the anions, bicarbonate is dominant than chloride (Cl^-) and sulfate (SO_4^{2-}) in the both seasons.

5.5 RELATION OF ARSENIC WITH OTHER DIFFERENT PARAMETERS:

Arsenic (As) concentration was cross-plotted against that of the calcium (Ca), magnesium, potassium, sodium, iron, bicarbonate, chloride and sulphate to find out a relation among them.

Arsenic and Calcium (Ca^+): The cross plots of arsenic against Calcium shows (Fig. 5.11.a) relatively very low negative correlation (R^2= 0.007) with increase of arsenic, calcium decreases.

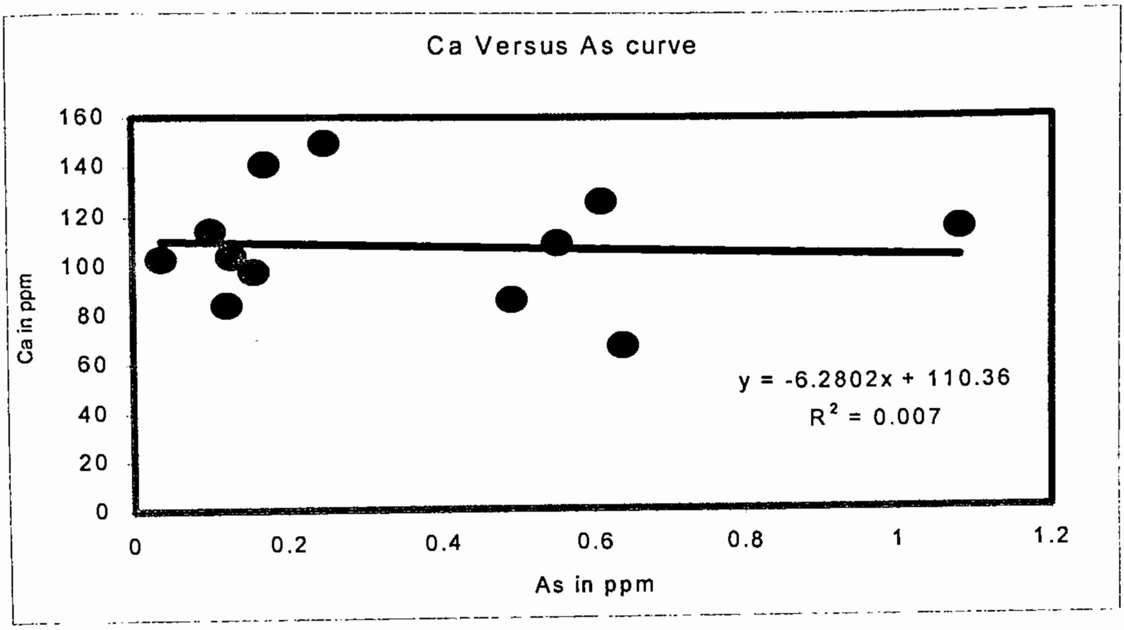


Fig. 5.11.a: Figure showing relation between arsenic concentration and calcium concentration of groundwater of the study area.

Arsenic and Magnesium (Mg^+): The cross plots of arsenic and magnesium shows (Fig. 5.11.b) that the arsenic increases with the increases of magnesium with a very low positive correlation ((R^2= 0.009).

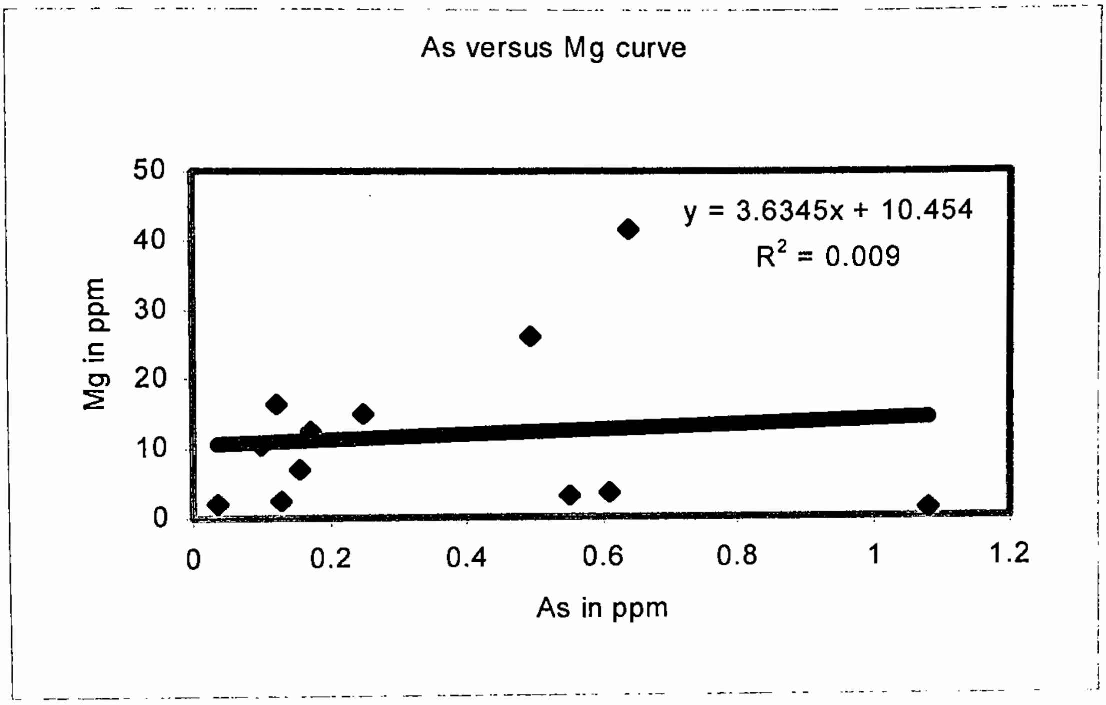


Fig. 5.11.b: Figure showing the relation between arsenic and magnesium concentration of groundwater of the study area.

Arsenic and Sodium (Na^+): Sodium content in groundwater of the study tends to increases with increase of arsenic (Fig. 5.11.c) having a positive correlation (R^2= 0.0185).

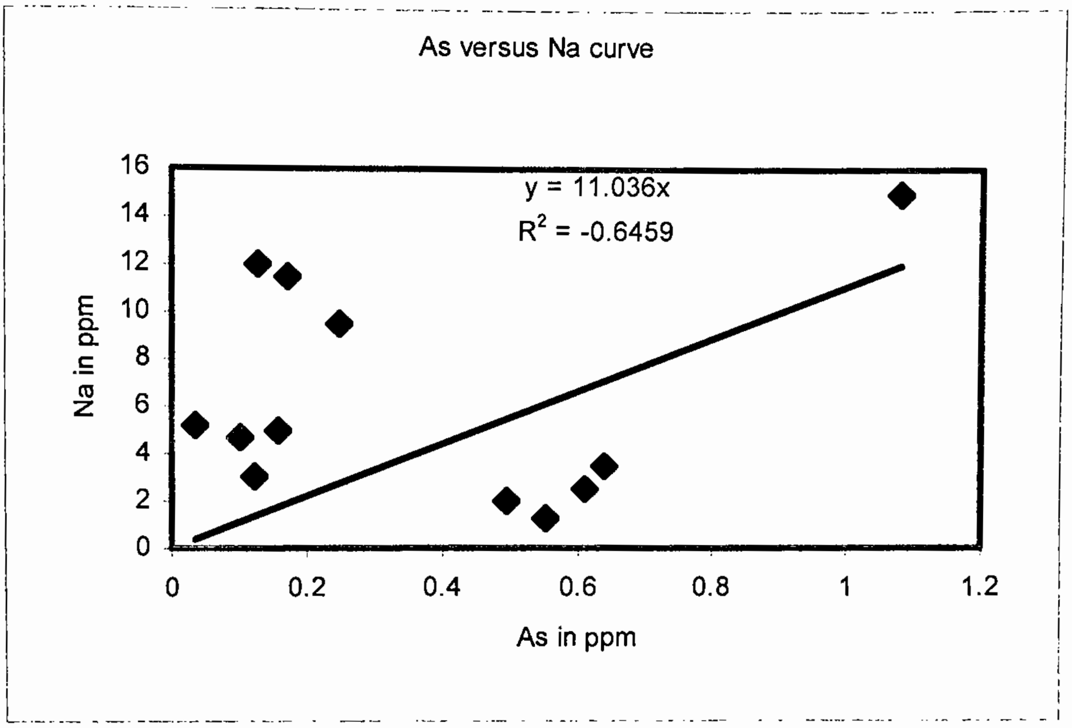


Fig. 5.11.c: Figure showing the relation between the arsenic and sodium concentration of groundwater of the study area.

Arsenic and Potassium (K^+): The cross plots of arsenic against potassium shows (Fig. 5.11.d) a very low negative correlation (R^2= 0.0027). That is, arsenic increases with decrease of potassium.

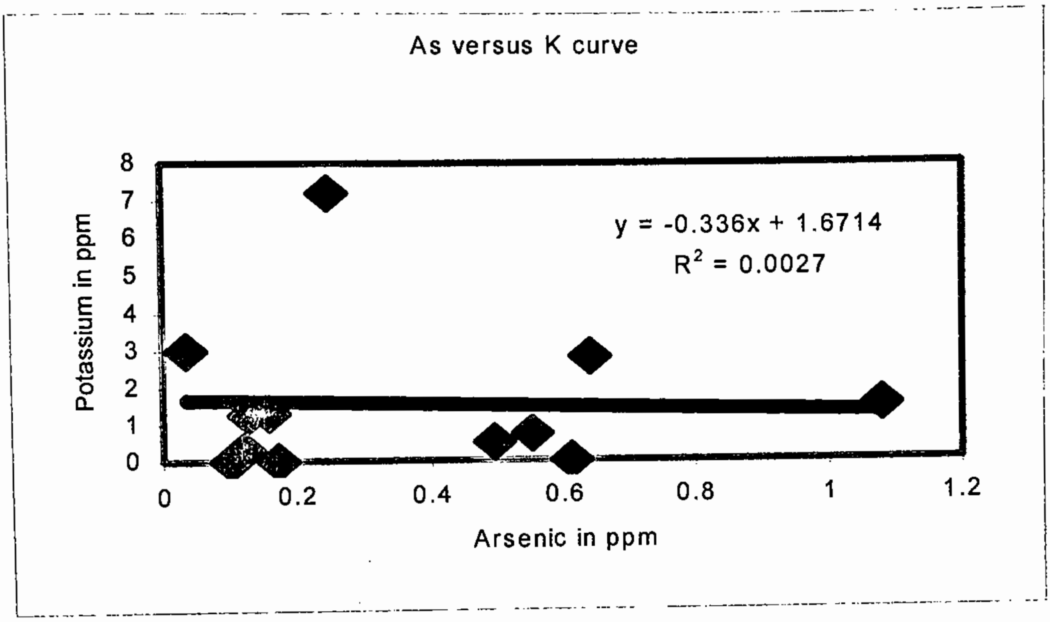


Fig. 5.11.d: Figure showing relation between the arsenic and potassium concentration of groundwater of the study area.

Arsenic and Total Iron (Fe^{total}): The cross plot of arsenic versus total iron shows (Fig. 5.11.e) that arsenic increases with the increase of iron with a positive correlation (R^2= 0.015).

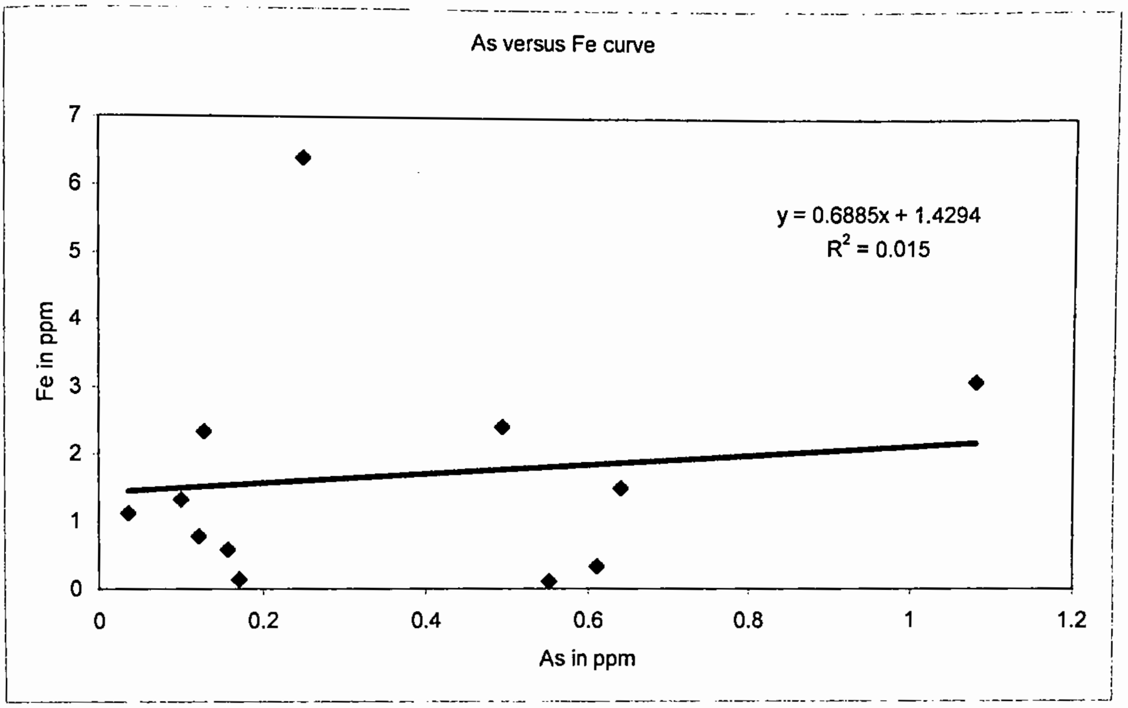


Fig. 5.11.e: Figure showing positive correlation between arsenic and total iron of groundwater of the study area.

Arsenic and Bicarbonate (HCO_3^-): The cross plot of arsenic against bicarbonate shows (Fig. 5.11.f) a very low positive correlation (R^2= 0.0008).

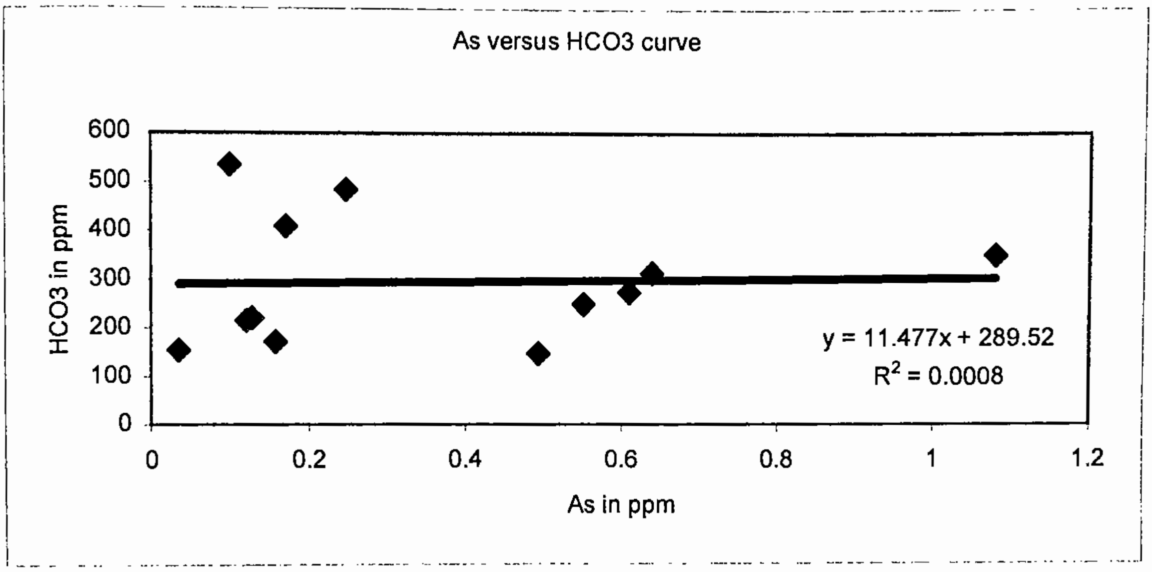


Fig. 5.11.f: Figure showing a low positive correlation between arsenic and bicarbonate of groundwater of the study area.

Arsenic and Chloride (Cl^-): The cross plots of arsenic against the chloride shows (Fig. 5.11.g) a low correlation (R^2= 0.0027).

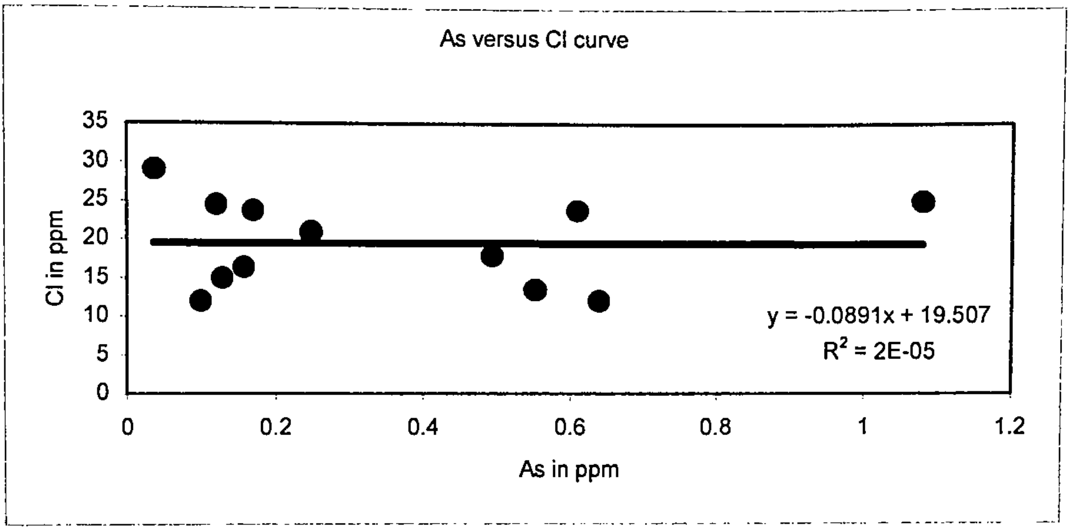


Fig. 5.11.g: Figure showing a parallel correlation between arsenic and chloride of groundwater of the study area.

Arsenic and Nitrate (NO_3^-): Arsenic concentration in groundwater of the study area is increasing with the increases of nitrate (Fig. 5.11.h) with a positive correlation (R^2= 0.0218).

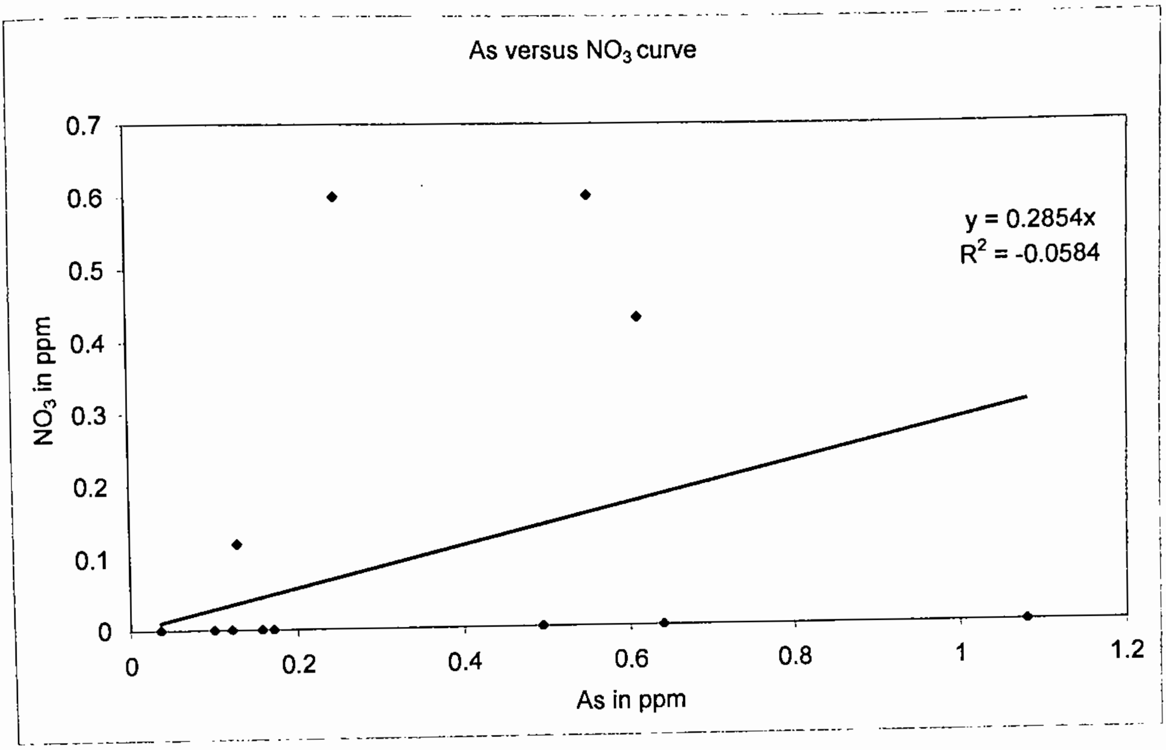


Fig. 5.11.h: Figure showing a positive correlation between arsenic concentration and nitrate concentration of groundwater of the study area.

Arsenic and Sulfate (SO_4^-): The cross plots of arsenic against sulfate shows (Fig. 5.11.i) a relatively strong positive correlation (R^2= 0.6866). That is, arsenic concentration in groundwater of the study area is increasing with the increases of sulfate.

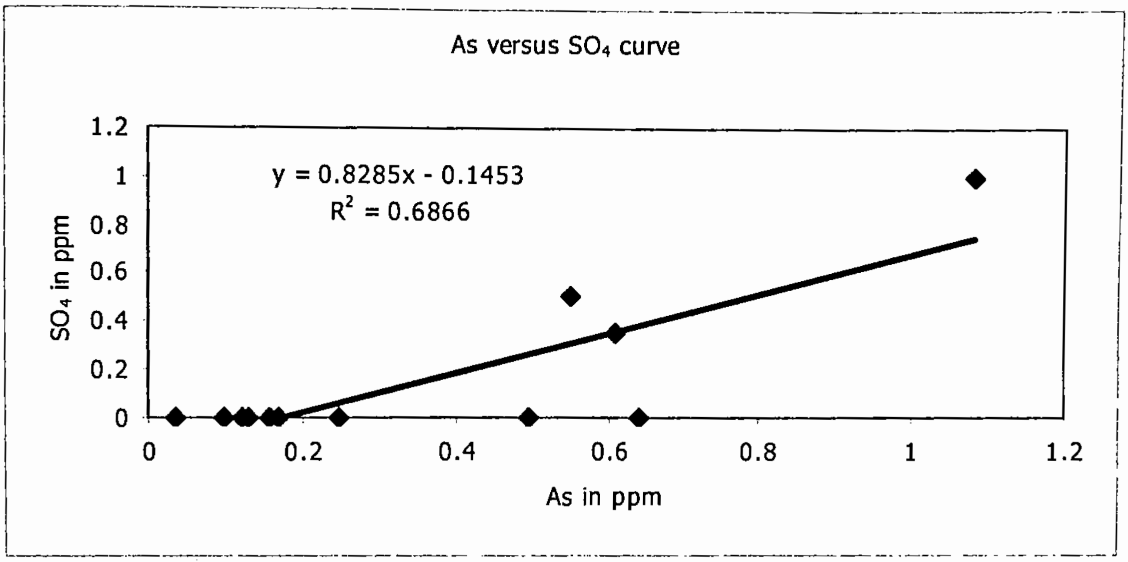


Fig. 5.11.i: Figure showing Arsenic concentration of tube-well water increases with the increase of Sulfate concentration of groundwater of the study area.

Arsenic and pH: The cross plots of arsenic against pH shows (Fig. 5.11.j) a relatively strong positive correlation (R^2= 0.0213). That is, arsenic concentration in groundwater of the study area is increasing pH.

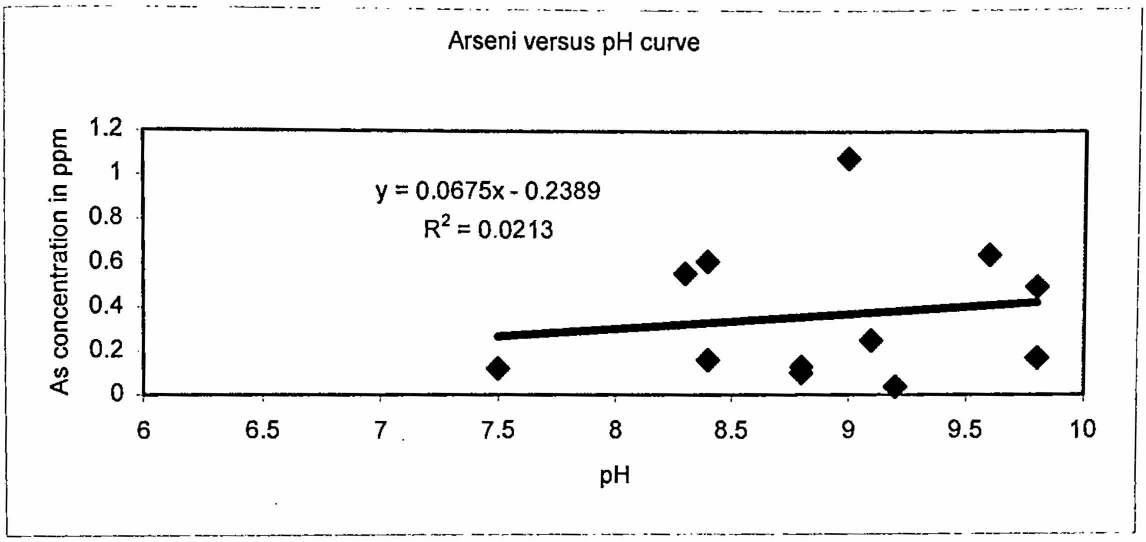


Fig. 5.11.j: Figure showing that Arsenic in tube well water increases with increase of pH of groundwater of the study area.

Total Iron (Fe^{total}) and pH: The cross plots of total iron against pH shows (Fig. 5.11.k) a relatively strong positive correlation (R^2= 0.0885). That is, iron concentration in groundwater of the study area is increasing with the increase of pH.

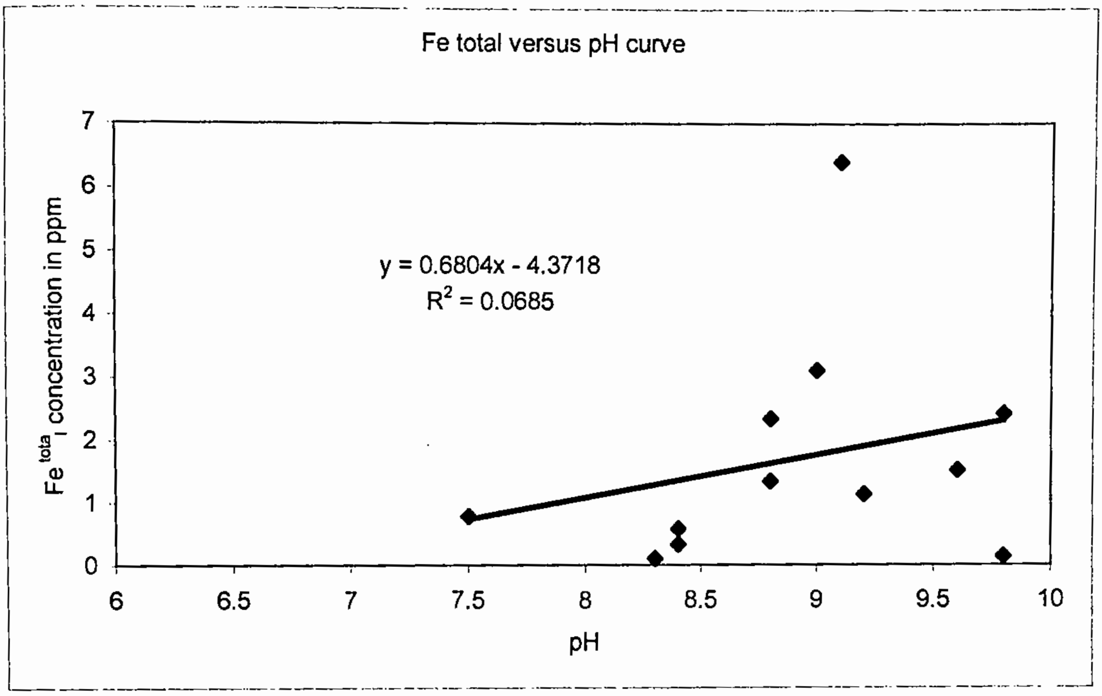


Fig. 5.11.k: Figure showing that Fe ^{total} of tube well water increases with the increase of pH of groundwater of the study area.

CHAPTER-6

SUSTAINABLE MITIGASTION OPTION

- INTRODUCTION
- ARSENIC REMOVAL MECHANISM
- FIELD IMPLEMENTATION
- SLUDGE RECYCLING PROCESS
- SYSTEM'S PERFORMANCE

6.1 INTRODUTION:

Arsenic contaminated groundwater has become a serious health problem in Bangladesh. To mitigate this problem, one needs to supply alternative safe drinking water. In order to provide alternative safe drinking water a number of options have been suggested by different organizations. These can be done either at community or household levels.

1. Arsenic free shallow or deeper tube wells.
2. Surface water purification, e.g., PSF.
3. Rainwater harvesting.
4. Dug wells (arsenic free with purification)

In Bangladesh, in places where most of the tube-wells are not contaminated, they would keep on supplying safe water. In place where water from arsenic-free wells are sufficient to meet the community demand there is no any problem sealing off the affected ones. For areas where arsenic-free wells are not enough, alternative supply of drinking water has to be secured to fulfill additional requirements. For this a choice has to be made between surface waters and groundwater. Use of surface waters poses two difficulties: a) ensuring that treatment of surface water is properly and routinely performed over a long period of time and b) surface waters are not available in many areas in dry season. On the other hand, deep aquifers, mostly free from contamination, are capable of maintaining sustainable supply of the extra water. Therefore, wells in deeper aquifers, properly constructed and protected from contaminated shallow aquifers, should be preferred at this stage. However, deeper aquifers may not be always present, and may be problematic to drill in some areas. Sinking shallow wells in isolated arsenic-free aquifer can also be tried. In absence of arsenic-free groundwater, treated surface water and treated dug well water as well as properly harvested rainwater may be used. In Fig. 6.1, a systematic step - by - step selection of alternative options for mitigation of As contaminated groundwater has been presented. This figure shown where all natural options are not implementable which is a likely situation in many parts of Bangladesh, decontamination of arsenic contaminated groundwater by chemical method is the only alternative left.

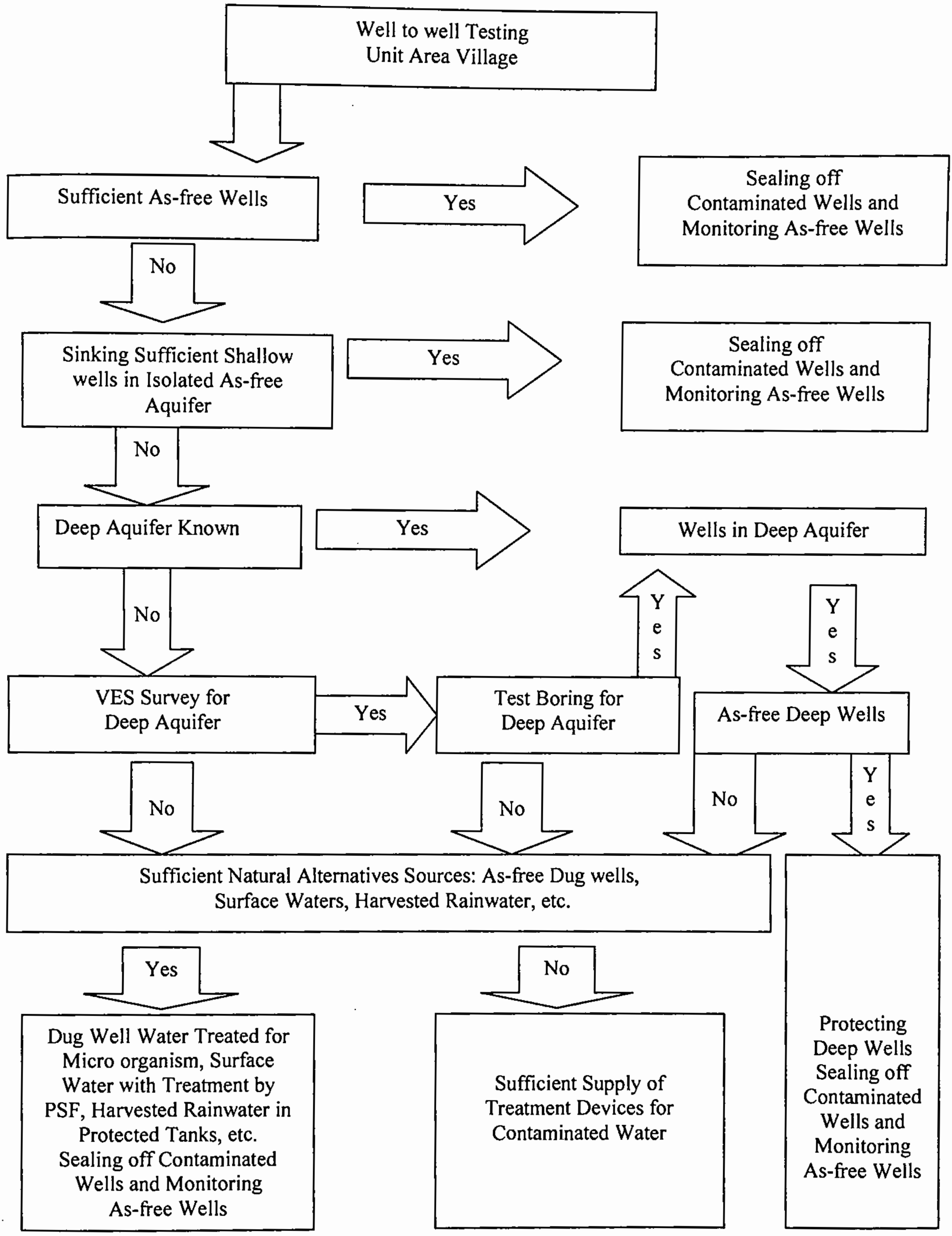


Fig. 6.1: A Scheme for Sustainable Supply of Arsenic-free Water.

In the present study a sustainable chemical mitigation method based on decontaminating arsenic contaminated tube well water has been implemented in Rajarampur, a village of Chapainawabganj in collaboration with AUT New Zealand. The study has installed four units of decontaminating system in the same number of households, which are supplying 60 liters of decontaminated water per day. Of these, two are treating high-contaminated tube well water (0.932 ppm and 0.5 ppm As) while the other two are medium to low (0.254 ppm and > 0.05 ppm As).

6.2 ARSENIC REMOVAL MECHANISM:

Treatment for removal of arsenic is actually adding oxidized ion as ferric oxyhydroxide in water. It makes use of the strong adsorption property of arsenic onto iron oxyhydroxide. These oxides, when added in sufficient quantities, are able to bring the concentrations arsenic in water below the acceptable limit by adsorbing the extra arsenic onto their surfaces. This essentially is the reverse of the chemical process by which arsenic has been released from the sediment and dissolved into the groundwater in reducing conditions in the first place (Ravenscroft *et al.*, 1998). A number of researches have been undertaken to devise a treatment system that can remove arsenic from contaminated water. The mitigation technique employed in the present study is a relatively successful one.

The arsenic removal mechanism is based on the simple process of adsorption of trace elements in water by naturally occurring ferric oxyhydroxide precipitates at near neutral pH's typical of the tube well water. For the arsenic contaminated regions, in general, the level of iron is too low and arsenic level is too high to safely use a method with only natural iron levels. As typically a significant fraction of the arsenic (depending on the individual well chemistry or water chemistry) is not removed, leaving the water still partially contaminated in all but wells with very lowest As/Fe mole ratios. It was decided that while maintaining use of this natural, nontoxic adsorbent of trace element, a ferric oxyhydroxide supplementation method would be used. This would have a sufficient low As/Fe mole ratio to reduce arsenic to <0.05 ppm for practical cycle times.

6.2.1 Technique to Treat Contaminated Tube-Well Water (Adsorption Process):

Adsorption processes have been used for purification of water supplies for a long time. Lowtiz first observed it in solution in 1785. It was applied as a process for removal of color from sugar during refining from the beginning (Hassler, 1974). In American water treatment plants activated charcoal filter were used in the late nineteenth century (Croes, 1883). Large volumes of granulated activated carbon (GAC) were manufactured during First World War for use in gas masks. Powdered activated carbon (PAC) was used by Chicago meat packers in the 1920s to control taste and odor in water supplies contaminated by chlorophenols (Baylis, 1929). The first GAC units for treatment of water supplies were contracted in Hamm, German, in 1929 and Bay City, Michigan, in 1930. PAC was first used in municipal water treatment in New Milford, New Jersey, in 1930; its use become widespread in the next few decades, primarily for taste and odor control. During the mid-1970s, interest in adsorption as a process for removal of organics from drinking water heightened.

At present, the applications of adsorption in water treatment in the United States are predominantly traditional odor control. However, it is increasingly being considered for removal of synthetic organic chemicals, color forming organics, and disinfecting by-products and their naturally occurring precursors. Some inorganic compounds that represent a health hazard such as heavy metals are also removed by adsorption.

Adsorption is the attachment of a solute to the surface of solid or, more generally, the accumulation of solutes in the vicinity of a solid-solution interface. Adsorption mechanisms can be subdivided in to ***physical adsorption, electrostatic adsorption, and chemical adsorption.***

Physical adsorption is the mechanism, where attraction to the surface is due to weak Van der Waals forces. Electrostatic adsorption is the mechanism, where ions in solution are attracted by a surface of the opposite electrical charge. Chemical adsorption is the mechanism of chemical bonding between the solute molecule and one more atoms on the surface of the solid.

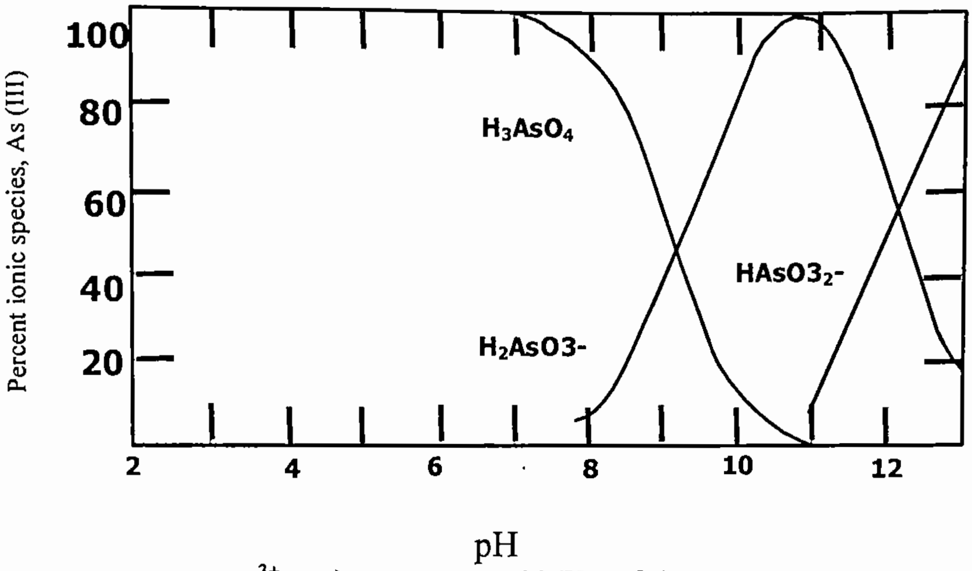
In the present study the arsenic removal mechanism is based on the chemical adsorption mechanism, i.e., chemical bonding of adsorbate to specific surface sites is a acid-base reaction at a factional group. This is the reaction of hydrated metal ions from solution with hydroxide sites on metal oxides:

ROH (aq) + SOH =SOR + H_2O (aq) Where R is metal ion adsorbate and S is metal oxide adsorbent (Park. 1975). In present study R is arsenic and SOH is Ferric oxyhydroxide (Fe-O-OH)

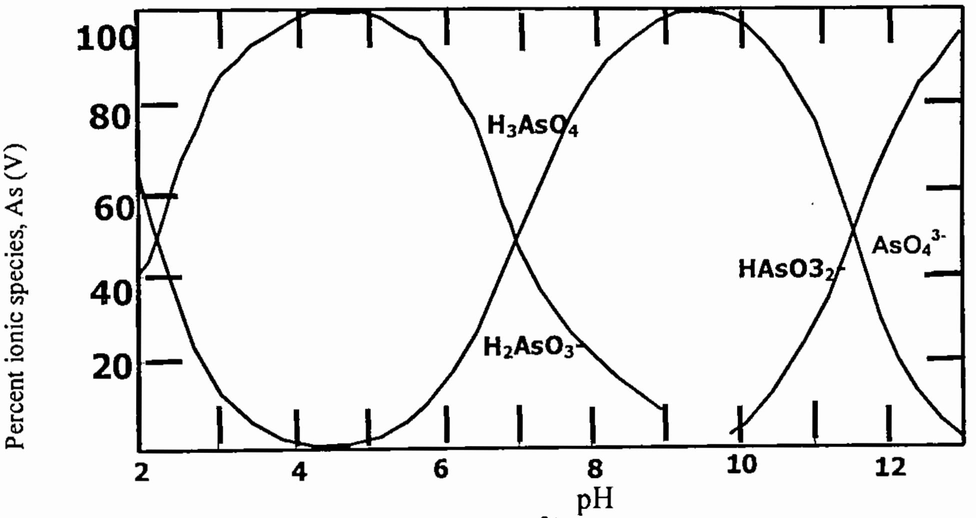
6.3 ARSENIC REMOVAL CHEMISTRY IN ADSORPTION PROCESS:

Arsenic can occur in water in the form of four oxidation states (+5, +3, 0, -3) but only the trivalent and pentavalent states are commonly found in groundwater. The predominance diagram for arsenate, As (III) and arsenite As (V) shows (Fig. 6.2.a) that as function of pH, H_3AsO_3, an undissociated weak acid, is predominant in the pH range of 2-9 (Gupta and Chen, 1980).

Sorg and Logsdon in 1978 reviewed a number of treatment methods of removing arsenic from contaminated water in the light of the above discussed chemistry. Conventional coagulation with iron or aluminum salt is effective for removing greater than 95 percent of As (V) with initial concentrations of roughly 0.1mg/l at pH of 7 or below. Above pH 7, iron coagulation will still remove As (V) effectively, but alum coagulation efficiency drops off. Lime softening is very efficient for As (V) (>95 percent removal) at pH 10.5. These processes are not as successful with As (III). Iron coagulation will remove 50 percent, while alum coagulation will not reduce As (III) levels more than 20 percent. Lime softening above pH 11 can remove up to 80 percent of As (III). Gupta and Chen (1978) showed that equilibrium capacities for As (V) were maximized at pH less than 7, where As (III) removed best at pH less than 9. If As (III) is found to predominate, then pre-oxidation should be considered to be adsorbed both As (III) to As (V).



As^{3+} ⟶ arsenous acid (H_3AsO_4)
As^{3+} ⟶ arsenous acid (H_3AsO_4)



At pH 4-9 As^{3+} mainly as H_3AsO_3; As^{3+} mainly as $H_2AsO_4^-$ and $H_3AsO_5^-$

Fig. 6.2.a: Predominance diagram for As (III) and As (V) as a function of pH (Gupta and Chen. 1978).

It has been shown recently (Raven et al. 1998) that at near neutral pH, arsenate and arsenite will be close to 100% adsorbed on ferrihydrite at low arsenic concentration in the solution (Fig. 6.2.b and Fig. 6.2.c).

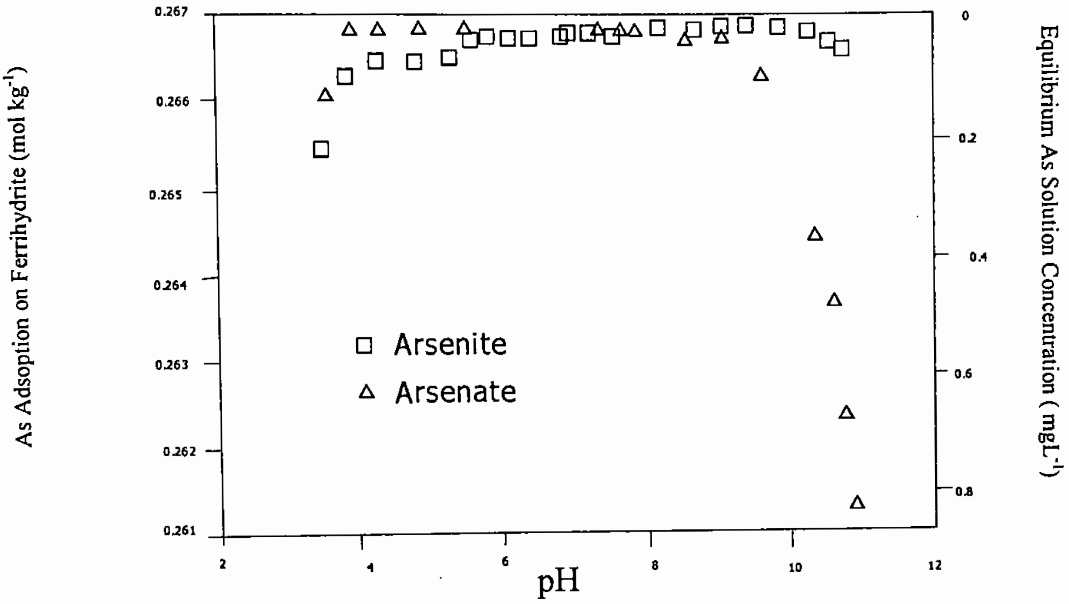


Fig. 6.2.b: Adsorption envelops for the arsenate and arsenite with 2-line ferrihydrate at 0.1 ionic strength following the 0.267 mol AS kg fer^{-1} (Raven *et al.*, 1998).

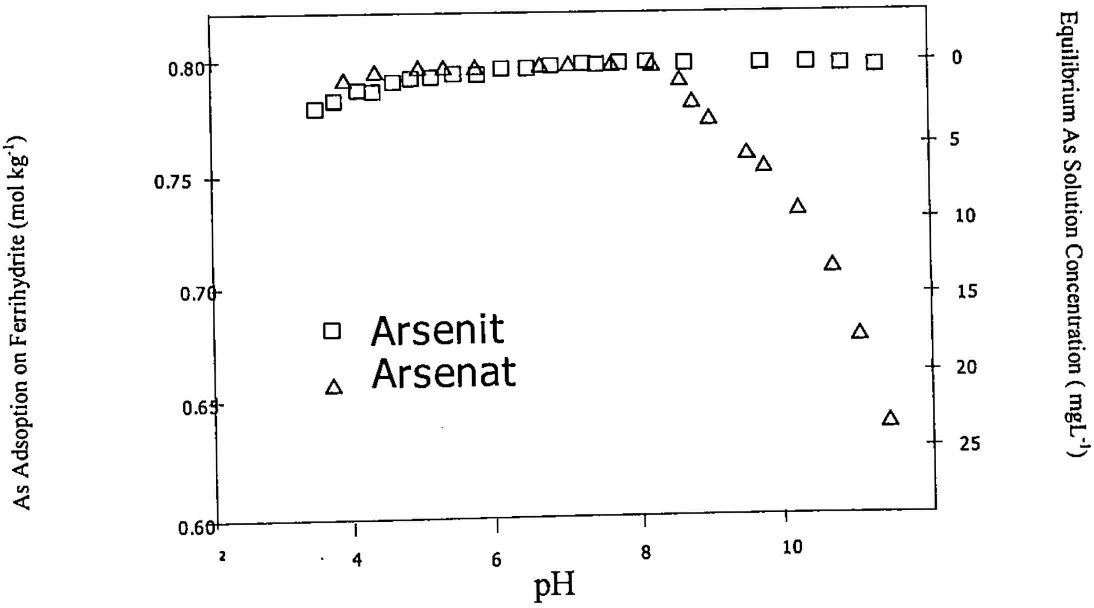


Fig. 6.2.c: Adsorption envelops for the arsenate and arsenite with 2-line ferrihydrate at 0.1 ionic strength following the 0.80 mol AS kg fer^{-1} (Raven *et al.*, 1998).

6.3.1 Laboratory Experiment of Present Study:

In light of above studies in the present study, a different adsorbent ferric oxyhydroxide was used to remove arsenic from contaminated water through adsorption process. Laboratory experimental results consistent with previous studies (Raven et al. 1998) show (Fig. 6.3) that arsenate and arsenite adsorption on ferric oxyhydroxide respectively for 120 minutes. Adsorption was rapid in the first few minutes then continued at a decreased rate. Within 5 minutes for arsenate and 10 minutes for arsenite concentration was less than the Bangladesh standard limit (0.05 ppm) (90 % adsorbed). The laboratory experimental results also show (Fig. 6.4) up to 0.0514 of the As/Fe molar ratio adsorption of total arsenic reached to 100 % within 120 minutes. Consistent with the previous results (Raven et al. 1998), continued increased of the As/Fe molar ratio resulted in the total arsenic adsorption at 0.0678 (1 ppm As, 11 ppm Fe) slower and only 85 % was removed (Fig. 6.4). Arsenic (total) 1 ppm used here a representative of the higher arsenic concentration in the study area.

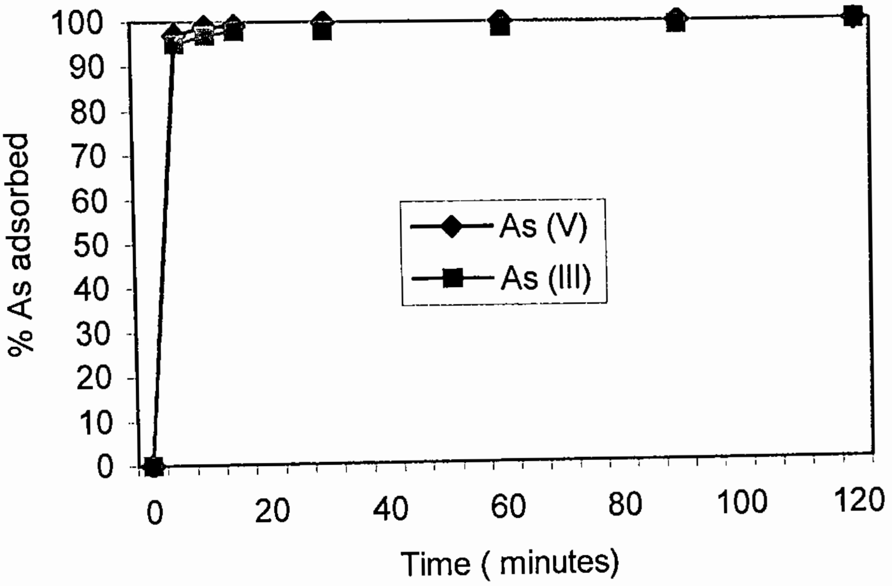


Fig. 6.3: Experimental adsoption of 1ppm arsenate and arsenite on ferric oxyhydroxide suspensions.

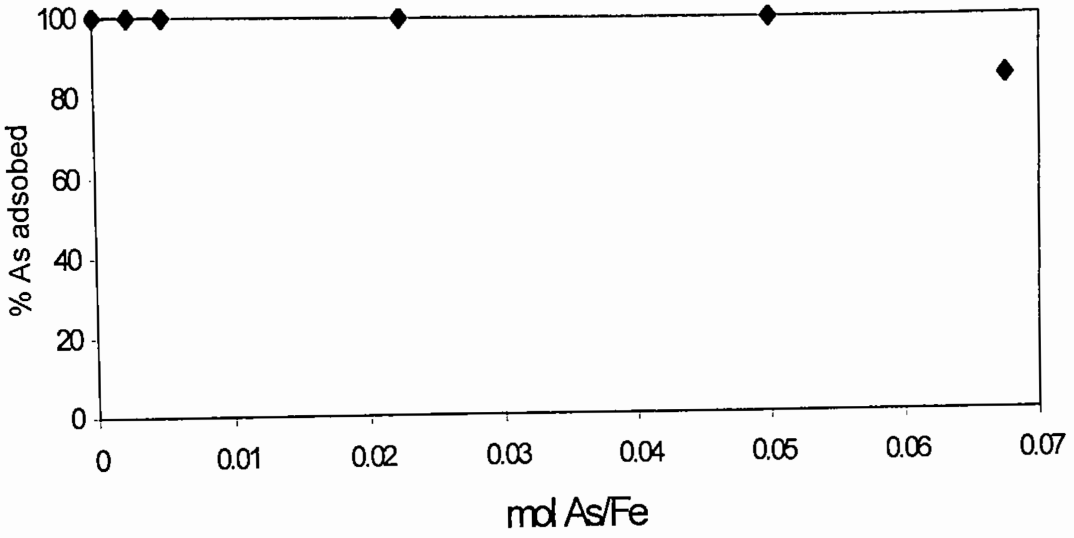


Fig. 6.4: Figure showing adsorption is decreasing with increasing As/Fe molar ratio.

These results indicate ferric oxyhydroxide suspensions with As/Fe molar ratio up to at 0.0514 can remove arsenic from the groundwater of the study area below 0.01 ppm.

6.4 FIELD IMPLEMENTATION:

6.4.1 Decontamination of Arsenic Contaminated Water:

Theory: Ferric oxyhydroxide is the most common neutral active adsorbent of arsenic (heavy metal) at neutral pH in groundwater. To prepare ferric oxyhydroxide 0.1 M ferric chloride hexahydrate ($FeCl_3.6H_2O$) solution is mixed with 0.05 M NaOH solution and stirred for 10 minutes with magnetic stirrer at 2500 rpm.

Apparatus:

- Magnetic Stirrer: Centrifuged at 2500 rpm.
- Electric Balance
- Plastic Container: Capacity 2 litter.
- Plastic Tank (100 liter size) with a tap at 17 cm height from the bottom level

Reagents:

- Ferric Chloride Hexahydred Analytical grade ($FeCl_3.6H_2O$).
- Sodium Hydroxide Anhydrous Food Grade (NaOH).
- Distilled Water

Procedure: The chemical procedure of the system was divided into two steps:

a) Laboratory Preparations:

1. Ferric Chloride Solution (0.1 M/10% solution): This solution is prepared by dissolving 100 gram Ferric Chloride Hexahydrate in 1000 ml distilled water and stirred for 15 minutes with magnetic stirrer.
2. Sodium Hydroxide Solution (0.05 M/5% solution): This was made by dissolving 50 gram Sodium Hydroxide Anhydrous in 1000 ml distilled water stirred for 10 minutes with magnetic stirrer.

b) Field Preparation:

Field preparation can be divided into two steps

1. Preparation of Slurry: This was prepared by mixing both solutions of a) in the plastic tank and stirred for few minutes.
2. Controlling pH: After mixing both solutions in the 60 liter tank, it was filled by tube well water, it is stirred and kept undisturbed for 20 minutes for settling and then water from above the precipitation was siphoned. After three siphons the system reaches normal pH, the fine particles were washed out and the system was ready for use.

Users routinely filled the tanks at night before going to bed and collecting fresh decontaminated water from bottom tap in the next morning. This system was able to supply 60 liter fresh water per day for up to 30 day with initial arsenic contaminated water of >0.5ppm. After up to 30 days cycle the arsenic concentration of the decontaminated water begins rising towards 0.05 ppm (Bangladesh Standard limit) showing that the precipitate becomes exhausted for extraction below this limit.

Designing of Tank:

The mechanical section of the system is tank design. The system was first designed as a single tank (Fig. 6.5) system. However, after few months the design was changed to control the finer particles in the decontaminated water. The system was finally designed as a three-tire tank (Fig. 6.6).

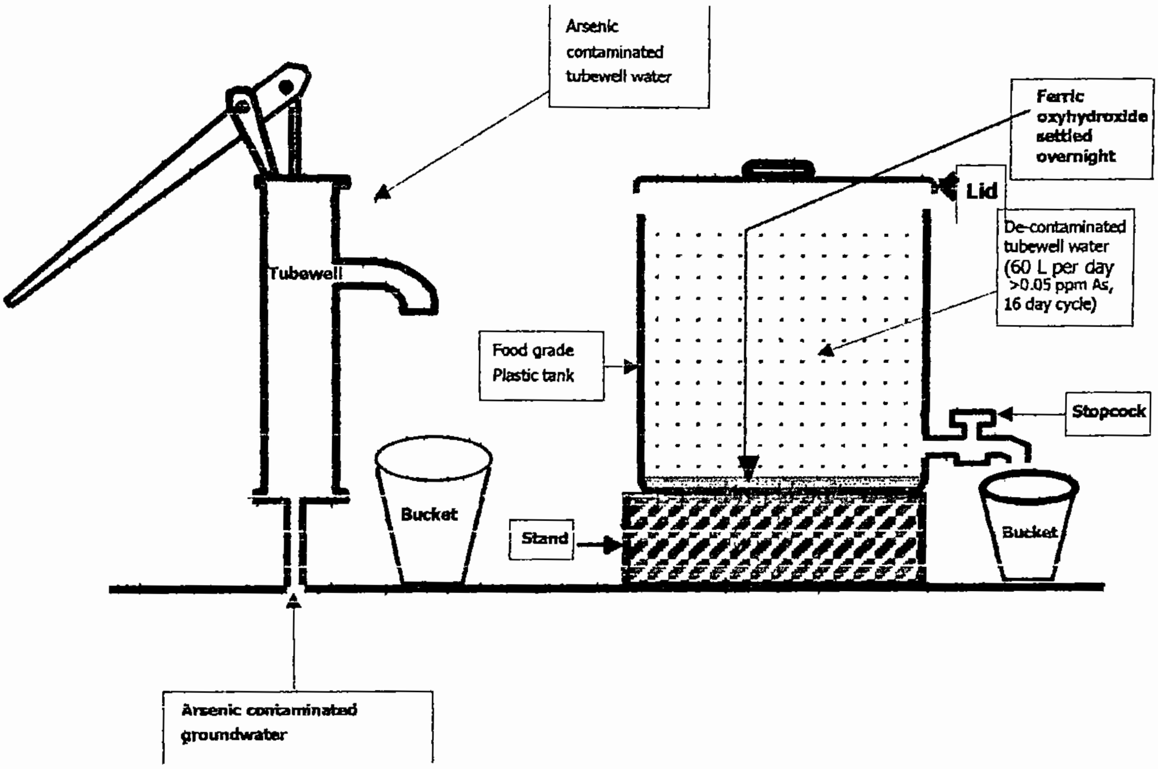


Fig. 6.5: Figure showing single Tank system.

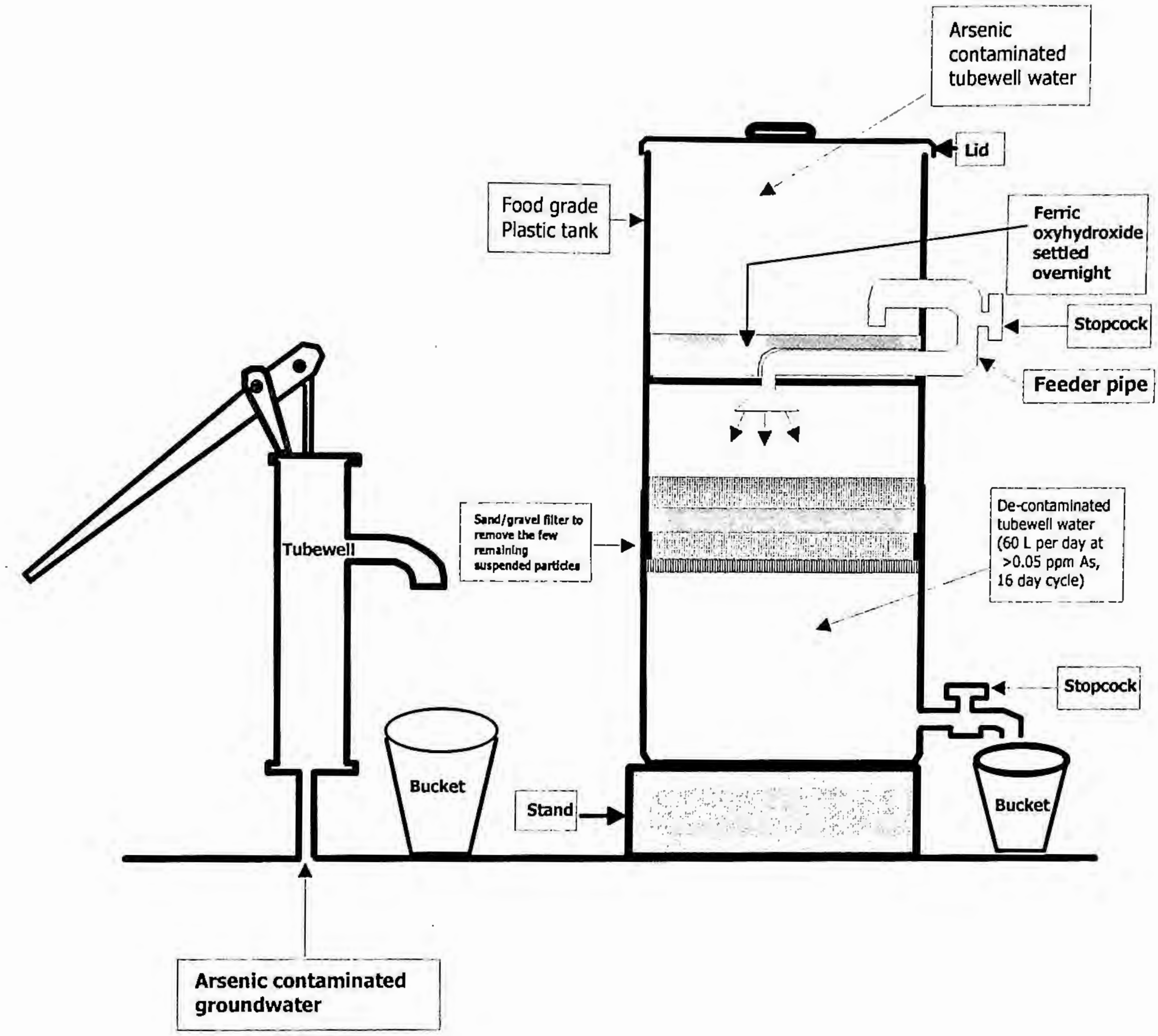


Fig. 6.6: Figure showing three-tire tank system.

Single Tank: In this tank-system, there was no filter media, it is a 100-liter plastic tank with service tap at 17 cm height above the bottom.

Three-Tire Tank: In this system the tank was divided in to three chambers

1. Upper Chamber: This part was use for mixing contaminated water with chemical solution. This chamber was a 60-liter tank with a lid and bypass drainage tube at 17 cm high above the bottom fitted with a stop cork.
2. Middle Chamber: This was a filter chamber. This chamber was consisting of four layers different particles size in a bottom-perforated tank. The bottom layer was 3cm thick gravel layer. The meddle two layers were of each 3 cm thick bed of coarse and medium sand respectively while the top layer was again consisting of gravel.
3. Lower Chamber: The lower chamber is the bottom part of the system, which was a 60-liter reserve tank for the fresh or decontaminated water. It is fitted with a service tap.

6.4.1.1 System Efficiency of the present Study:

Four units of this mitigation system have been used in four families of Rajarampur village of Chapainawabganj. The decontamination curve over the cycles shows that in highly contaminated water (0.932 ppm) the system could continue for 15 days, on the other hand in medium contaminated water (<0.5 ppm) the system would be continue for 30 days. The decontamination curves for tank NA-2 and NA-4 are shown in Fig. 6.7 and Fig. 6.8.

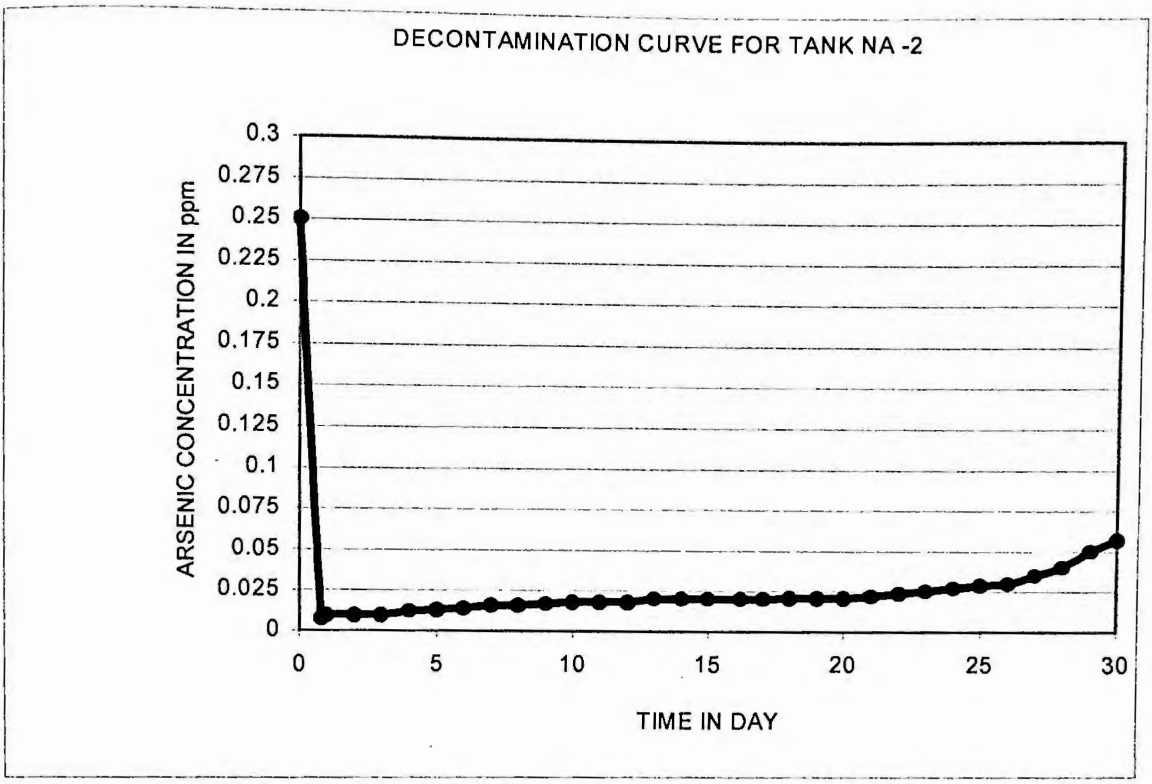


Fig. 6.7: Showing Arsenic decontamination curve for tank NA –2 (a 30 days cycle).

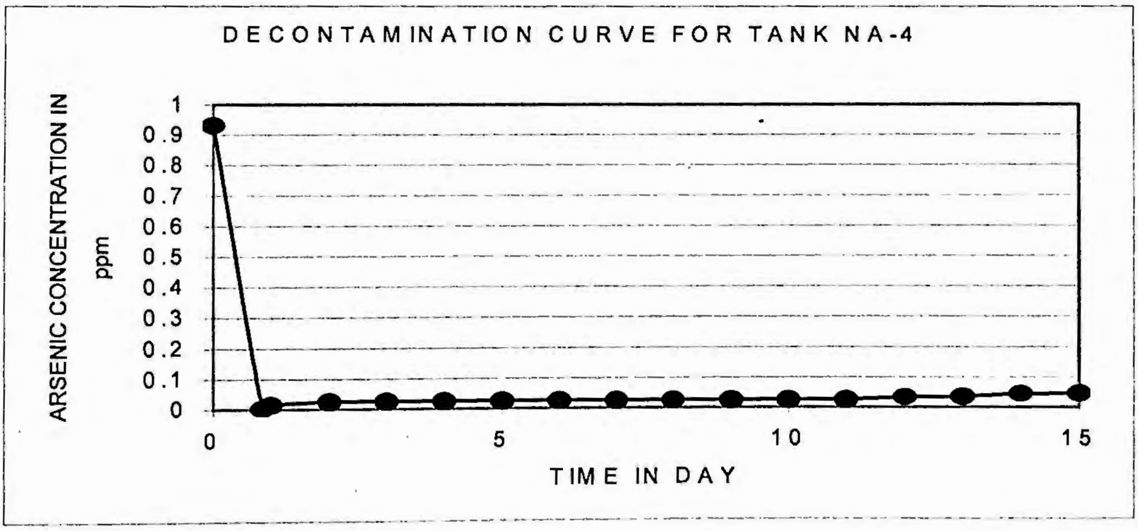


Fig 6.8: Showing Arsenic decontamination curve of tank NA-4 (15 days cycle).

However, in the field results are not quite same as those found in lab at molar As/Fe molar ratio of 0.0514. The reasons that is presence of relatively high concentration of the others ions in natural contaminated water compete for sites with arsenic. If there were no ions other than arsenic the surface area of the amount of ferric oxyhydroxide used would be enough to keep the arsenic below permissible limit for long time. To meet offset the inference from other ions in field the system decreased As/Fe molar ratios have been used i.e., increased the ferric oxyhydroxide.

6.4.2 Sludge Recycling Process:

To make the system sustainable i.e., to reuse exhausted precipitate recycling process was performed. It is a simple technique – the sludge was dissolved with concentrated Hydrochloric acid and then mixed with the high concentrated Sodium hydroxide solution. In this process, the fresh ferric oxyhydroxide was precipitated at the bottom As going into the sodium hydroxide solution (Fig. 6.9.a and Fig. 6.10.a). After draining out the solution from above the precipitate and washing in water, it could be reused for decontaminating arsenic contaminated water again.

The sludge recycling procedure is as follows:

Principle: To recycle the sludge, it was dissolved with concentrated HCl, whereby arsenic was released from the exhausted ferric oxyhydroxide, and then the pH of the resulting brown color solution was raised to leave arsenic-free ferric oxyhydroxide in the solution as precipitates. After a few washes with tap water, fresh Fe-O-OH precipitate with neutral pH was obtained.

Apparatus:

- Magnetic Stirrer
- Electric Balance
- Plastic Tank (20 liter size)

Reagents:

- Hydrochloric Acid Concentrated
- Sodium Hydroxide Solution (5%)
- Collected Sludge

Procedure:

The sludge recycling process was done in several steps:

(1) By putting the sludge in a plastic bucket and began stirring with a magnetic stirrer.

(2) After stirring for a few minutes, concentrated hydrochloride acid was added to the sludge to dilute it completely. When the sludge was completely dissolved in acid, it gives a clear red solution.

(3) Dissolved sludge added slowly to pH ~13 NaOH solution. After 10 minutes, the stirring was stopped and the ferric oxyhydroxide in the solution was started to settle at the bottom of the bucket. It takes 3 hours for complete settling.

(4) Once settled the solution above the precipitate is siphoned and is collected in a plastic container.

(5) The precipitate from step (4) was washed with tap water for 6 times (Fig. 6.10.a). After that, the ferric oxyhydroxide precipitate has been found to be completely arsenic free having normal pH, which was ready for use again for arsenic decontamination.

6.5 SYSTEM'S PERFORMANCE:

Four tanks have been operated in Rajarampur, Chapainawabganj for supplying safe arsenic decontaminated water to the same number of families for two years. Two of these systems have closely monitored for a full cycle. The decontamination curve over the cycle shows that in highly contaminated water (NA-4, 0.932 ppm) the system would complete for 16 days cycle, on the other hand in medium contaminated water (NA-2, >0.25 ppm) the system would supply safe water (<0.05 ppm) for 30 days. The decontamination curves for tank NA-2 and NA-4 are shown in figure (Fig. 6.7 and Fig. 6.8).

From the curve of tank NA-4 it is clear that the tank supplied 60 litter of water per day for 16 days with arsenic contamination below 0.05 ppm. Arsenic concentrations in the daily 60 liter batch of decontaminated water slowly increases from 0.001 ppm on the 1 st to 0.047 ppm on the 16 th day as the ferric oxyhydroxide precipitate becomes more and more saturated (Fig. 6.8).

On the other hand, the decontamination curve of tank NA-2 it is clear that the tank supplied 60 litter of water per day for 30 days with arsenic below 0.05 ppm. Arsenic concentration in each daily 60 litre batch following treatment slowly increased from 0.001 ppm on the 1 st to 0.05 ppm on the 30 th day as the ferric oxyhydroxide become more saturated through the cycle (Fig. 6.7).

The performance of the system when used recycled precipitation shows similar result (Fig.11 and Fig. 6.12).

To see whether the system is pathogen free, BOD test was performed. The BOD value of the tank water indicated that it remained at safe level (BOD 0.4 to 5.7). The rate of flow of water for the system is excellent 30 liter per hour. Taste of the treated water is good and people except it very much as any people can maintain this system.

It is now clear that the system is very simple, efficient, and low-cost and not requiring additional devices or energy supply. It is the most practical mitigation approach for arsenic contamination in some places where natural options do not work.. Moreover, the sludge recycling and reuse of recycled sludge make the system renewable and sustainable.

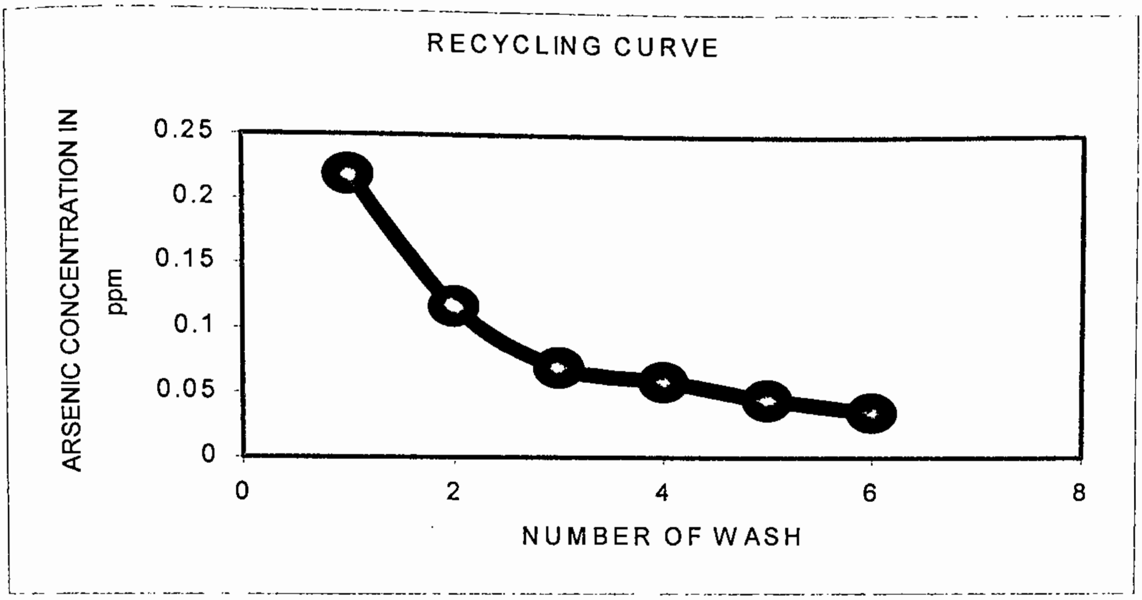


Fig. 6.9.a: Showing sludge recycling curve through sodium hydroxide solution.

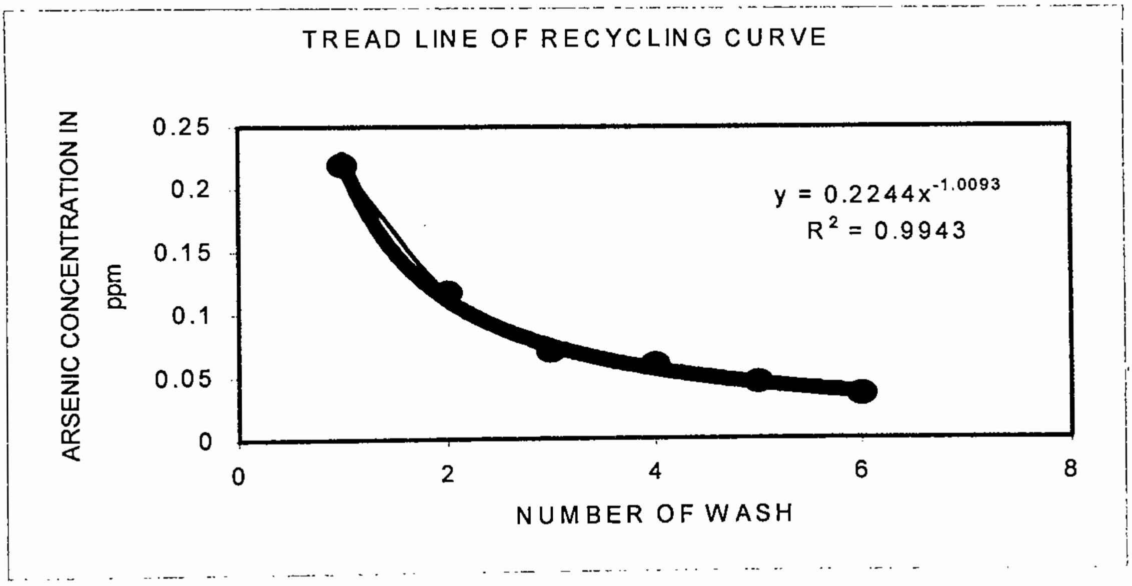


Fig 6.9.b: Showing trend sludge recycling curve through sodium hydroxide solution.

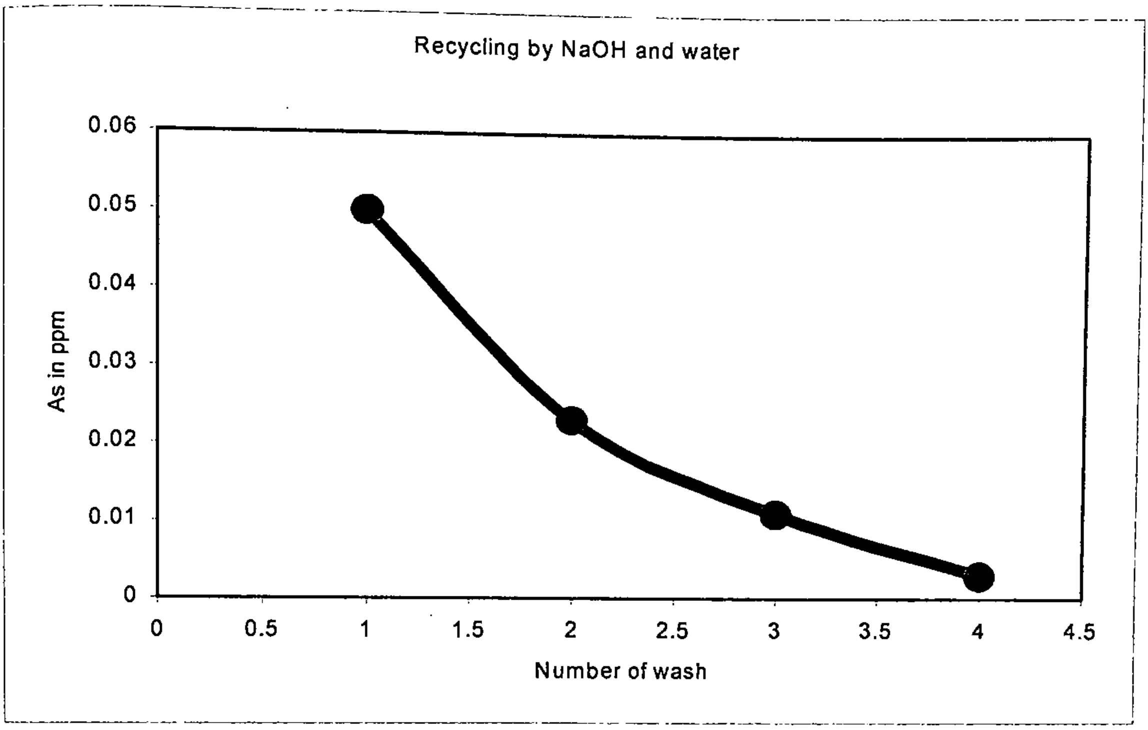


Fig. 6.10.a: Showing Sludge recycling curve by NaOH and water wash.

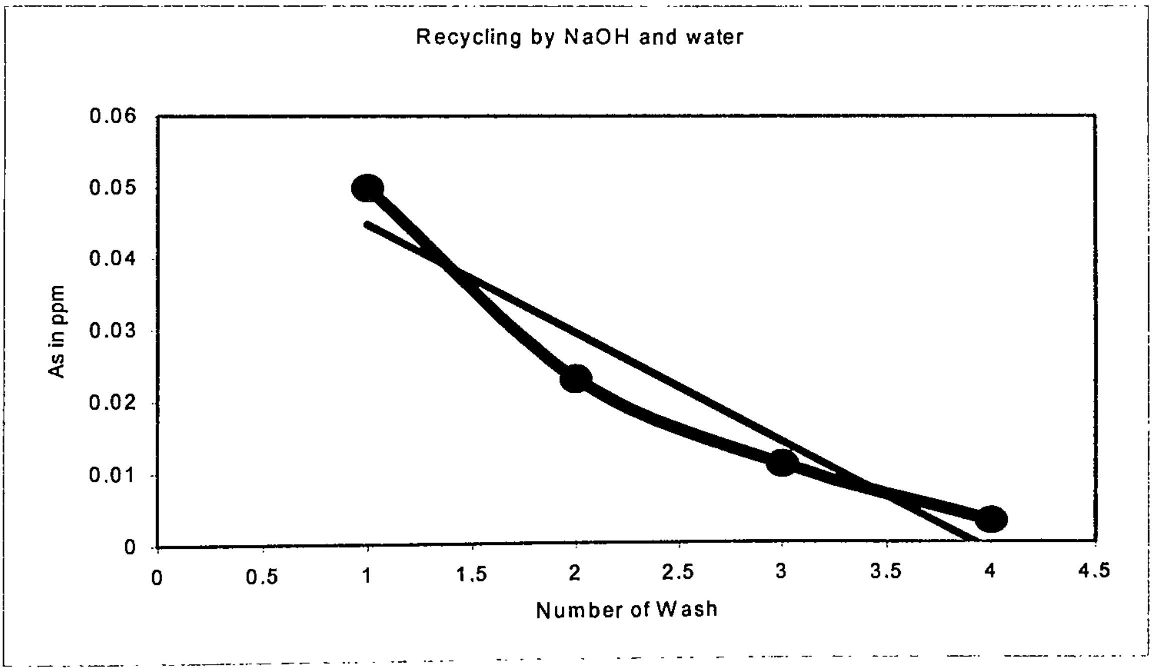


Fig 6.10.b: Showing trend of recycle curve by NaOH and water wash.

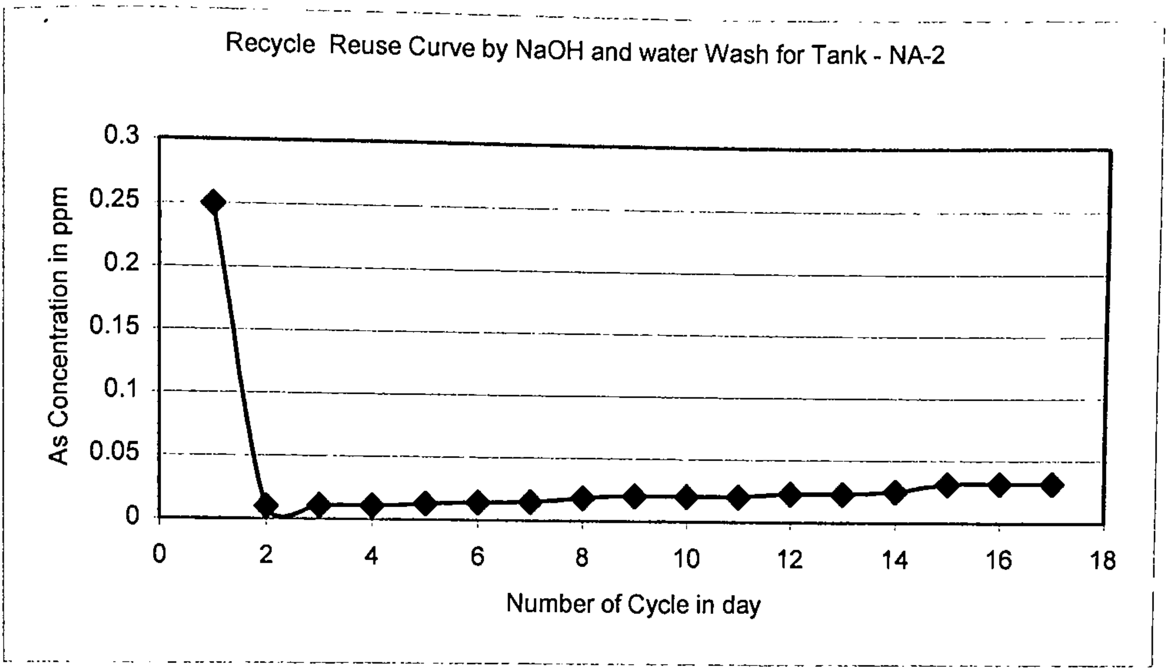


Fig. 6.11: Decontamination curve of Tank NA-2 by recycle reuse of sludge.

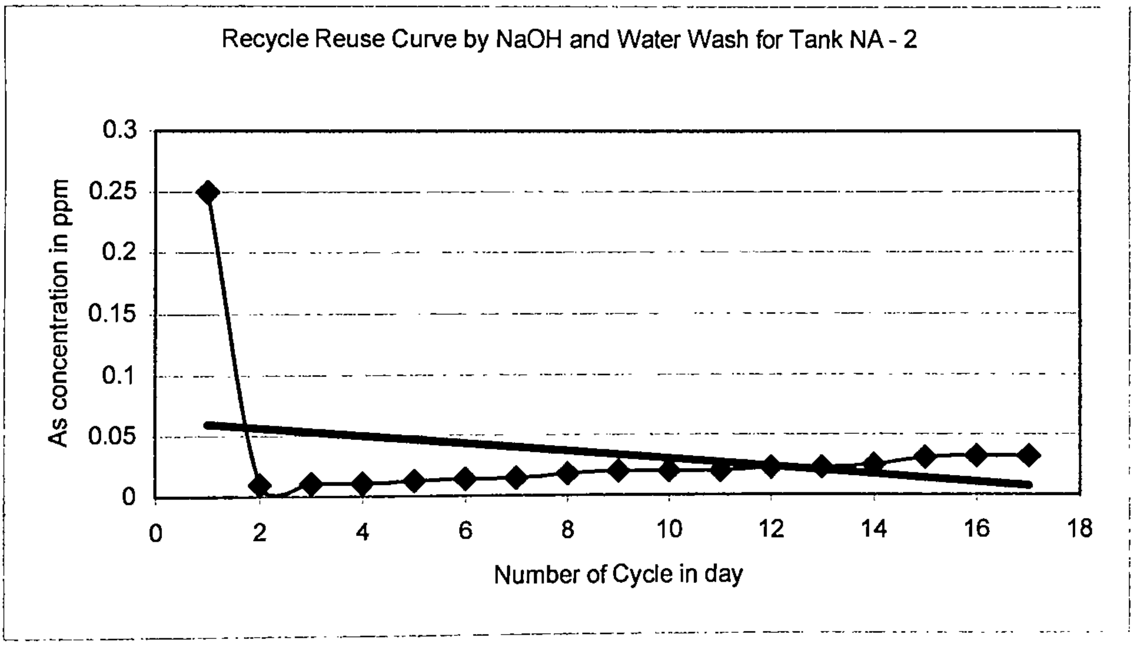


Fig. 6.12: Trend of Decontamination curve by recycle reuse of sludge.

CHAPTER-7

CONCLUSION AND RECOMMENDATIONS

7.1 CONCLUSION:

This work has been undertaken to study the water quality of the study area, specifically focussing on arsenic contamination of groundwater as well as finding a sustainable mitigation option. The findings of the present study integrating lab analyses and field investigations are summarized as follows:

On the basis of regional groundwater development potentiality, the study area is characterized by simple geology comprising of younger alluvium. From the geological cross sections constructed on the basis bore log data of the area, it is inferred that aquifer of study area can be taken as a confined aquifer. The thickness of the upper clay layer is 5 meter to 50 meter and that of the middle sand layer ranged from 30 meter to 120 meter this overlying a clay layer.

Chemical analyses of groundwater of the study area showed that the pH of groundwater ranged from 7.5 to 9.8; EC concentration ranged from 550 μS/cm to 745 μS/cm; TDS concentration ranged from 357.5 ppm to 484.25 ppm. Ca^+ concentration ranged from 67.13 ppm to 150 ppm; Mg^+ concentration ranged from 2 ppm to 41.63 ppm; Na^+ concentration ranged from 1.25 ppm to 15 ppm; K^+ concentration ranged from 0.3 to 7.2 ppm; Fe^{total} concentration ranged from 0.11 ppm to 6.4 ppm; HCO_3^- concentration ranged from 273 ppm to 483 ppm; Cl^- concentration ranged from 12.00 ppm to 23.37 ppm; SO_4^{-2} concentration ranged from 0.00 ppm to 1.00 ppm; NO_3^- concentration ranged from 0.00 ppm to 1.00 ppm and the total hardness concentration ranged from 239.46 ppm to 367.68 ppm.

Most importantly, arsenic concentration ranged from 0.035 ppm to 1.8 ppm which is much higher than the WHO Guide line value (0.01ppm) and as well as Bangladesh standard limit (0.05 ppm).

By the genetic classification, the groundwater of the study area was of "Normal Chloride", "Normal Sulphate" and "Super Carbonate" type water. Based on Total hardness groundwater of the study area is "Very hard".

From the Piper Trilinear Diagram and Expanded Durov Diagram it is apparent that the contaminated groundwater of the study area is Ca-Mg-HCO_3^- type, i.e., mainly recharged waters.

Facies map of the groundwater indicated a Calcium-Magnesium to Calcium-Sodium cation facies and Bicarbonate to Bicabonate-Chloride-Suphate anion facies.

According to drinking water quality standard the groundwater of the study area was harmful for public health as the arsenic concentration exceed the WHO guide line value (0.001 ppm) as well as Bangladesh standard (0.05 ppm). From agriculture and irrigation water quality standard, the groundwater of the study area showed very good quality but presence of arsenic made it unsuitable.

Cross-plots between arsenic and different chemical parameters showed that only arsenic versus sulfate had a relatively strong positive correlation (R^2= 0.6866). The rest, i.e., arsenic versus Calcium (Ca^+), Magnesium (Mg^+), Potassium (K^+), Sodium (Na^+), Iron total (Fe^{total}), Bicarbonate (HCO_3^-), Chloride (Cl^-) and Nitrate (NO_3^-) all showed almost no correlation.

The present study showed that the arsenic contaminated groundwater could be decontaminated through adsorption by ferric oxyhydroxide at neutral pH.

Experimental results in the lab showed that the adsorption of total arsenic reached to 100 % up to 0.0514 of the As/Fe molar ratio. As/Fe molar ratio >0.0514 resulted less arsenic adsorption, e.g., at molar ratio 0.0678, only 85% total arsenic was adsorbed.

The field results also showed that the adsorption of total arsenic reached to 100 % at a decreased As/Fe molar ratios (up to 0.0392 - 0.035), i.e., at increased ferric oxyhydroxide depending on the total ionic concentration. The reason is that the presence of relatively high concentrations of others ions remain in the natural contaminated waters competing for sites with arsenic.

To help make the system sustainable exhausted sludge or precipitate was recycled. In this process the as sludge was dissolved with concentrated hydrochloride acid. Whereby arsenic was released from the exhausted sludge and then the pH of the resulting brown color solution raised to leave the arsenic-free ferric oxyhydroxide at the solution as precipitates. After a few wash with distilled water fresh ferric oxyhydroxide with neutral pH was obtained. The recycled precipitate performed exactly the same as the fresh ones.

This system can supply 60 liters of decontaminated water per day. The efficiency of the system is dependent on the level of As concentration of in the tube-well waters. The system for high level of contamination (0.932 ppm) As/Fe molar ratio of 0.0365 was used and the cycle would run for 15 days. In case of medium concentration (0.25 ppm) 0.0372, As/Fe molar ratio was used and the cycle would last 30 days. At the end of the cycle, the system would produce decontaminated water with As concentration less than Bangladesh Standard. The system performance was exactly the same when the recycle precipitation was used.

The BOD test results showed that it was at safe level (BOD, 0.4-5.9), i.e., safe from pathogen.

Finally, it is clear that the system is very simple, efficient, low-cost and not required additional devices or energy supply. It is the most practical mitigation option for arsenic contamination in localities, where natural options do not work.

7.2 RECOMMENDATIONS:

On the basis of findings and results of the present study, following recommendations have been made to mitigate the arsenic contaminated water in the study area.

- Mitigation option that developed in the present study has shown a good performance so it can be a mitigation option in the study area as well as other parts of Bangladesh where all kind of alternative mitigation options failed by following the step-by-step selection of alternative mitigation options.
- Byproduct of recycle reused of sludge can be used in industrial purpose like in medicine, pesticides, pigment and glass factory.
- Further detail work is recommended to implement the system in large scale, i.e., in community levels.

REFERENCES

Acharyya, S.K., Chakraborty, P., Lahiri, S., Raymahashay, B.C., and Bhowmik, A. (1999) *Arsenic poisoning in Ganges Delta,* Nature, vol. 401, pp. 545.

Acharyya, S.K., Lahiri, S., Raymahashay, B.C. and Bhowmik, A. (2000) *Arsenic toxicity of groundwater in parts of the Bengal basin in India and Bangladesh: the role of Quaternary stratigraphy and Holocene sea-level fluctuation,* Environmental Geology, vol. 39(10), pp. 1127-1138.

Ahmad, S. A. (2000) *Arsenic: Water Contamination and Health Hazard,* 1st ed., p. 7-62.

Alam D., Huq, S.M.I., Rahman, S., Anam, K. (1991) *A Handbook on Chemical Analyses of Soil, Plant and Water,* 1st ed., Ahmed Perveg Shamsuddin Pub., Dhaka.

Alam, M. (1972) *Tectonic Classification of Bengal Basin,* Geol. Soc. Amer. Bulletin, v. 83, p. 519-522.

American Water Works Associates (1971) *Water quality and treatment,* McGraw-Hill, New York, pp. 654.

APHA (1992) *Standard methods for the examination of water and waste-water,* 18th ed. Washington, Amer. Public Health Assoc.

APHA (1995) *Standard methods for the examination of water and waste-water,* 19th ed. Washington, Amer. Public Health Assoc.

ASIA ARSENIC NETWORK (1998) Special Edition on Bangladesh, January 30, pp. 16.

Baitey, S.W. (1966) *Clays and Clay Minerals – Proceedings of the Fourteenth National Conference,* Berkley, California, 1st ed., pp. 35-235.

Bakr, M.A. (1976) *Quaternary geomorphic evolution of the Brahmanbaria-Noakhali area, Comilla and Noakhali Districts, Bangladesh,* Rec. Geol. Surv. Bangladesh, vol. I,2, pp. 5-48.

Bakhtine, M.I. (1966) *Major tectonic features in Pakistan,* II Eastern Province, Science and Industry, vol. 4, pp. 89-100.

Bangladesh Bureau of Statistics (1997) *Statistical Yearbook.*

Beck, W. (1960) *Origin of Hydrochemical facies of groundwater in the Atlantic coastal plain,* Int. Geol. Congress. Copenhagen, p. 87-95.

Beck, W. (1966) *Hydrochemical facies and groundwater flow in northern part of Atlantic coastal Plain,* U. S. G. S., Prof. Paper 498 A., p. 422.

Bhattacharya, B.P. (1972) *Arsenic mineralization in parts of Hazaribagh District, Bihar, West Bengal,* Indian Min., vol. 26, pp. 28-34.

Bhatacharya, A. and Banerjee, S.N. (1979) *Quaternary geology and geomorphology of the Ajoy-Bhagirathi Valley, Birbhum and Murshidabad districts, West Bengal,* Indian Jour. of Earth Sci., vol. 14, pp. 307-320.

Bouwer, H. (1978) *Groundwater Hydrology,* McGraw-Hill Series in Water Resources and Environmental Engineering, New York, USA, p. 480.

Bowell, R. J. (1994) *Sorption of arsenic by iron oxides and oxyhydroxides in soils,* Applied Geochemistry, vol. 9, pp. 279-286.

Bowen, H. J. M. (1997) *Environmental chemistry of the Elements,* Academi Press Inc., London., p. 101.

Brammer, H. (1969) *Soil resources of East Pakistan Soil Survey Dept.* FAO/UNDP Technical Report No. 3.

Brannon, J.M. and Patrick, W.J. (1987) *Fixation, transformation, and mobilization of arsenic in sediments,* Environ. Sci. Technol., vol. 20, pp. 450-459.

British Geological Survey & Mott McDonald Ltd. (UK) (1999) *Groundwater studies for arsenic contamination in Bangladesh,* Main Report.

British Geological Survey (BGS), Dept. For International Development (DFID) and Local Govt. Eng. Dept. (LGED) (2001) *Arsenic contamination of groundwater in Bangladesh,* Natural Environmental Research Council, vol. 2-Final Report.

BWDB (1997) *Groundwater Quality Report,* WSP-97, GWC-II, Dhaka, pp. 2-3.

BWDB (1998) *Report on the compilation of aquifer test,* GWC-II, BWDB.

Calvert, S. E. and Pedersen, T. F. (1993) *Geochemistry of recent oxic and anoxic marine sediments: implication for the geological record,* Marine Geol., vol.113, pp. 67-88.

Chakraborti, D. (1995) *Arsenic contamination in six districts of the West Bengal, India: the background,* Proceedings of the International Conference on Arsenic in Groundwater: Cause, Effect and Remedy, Calcutta, pp. 3.

Cherry, J.A., Shaikh, A.U., Tallman, D.E. and Nicholson, R.V. (1979) *Arsenic species as an indicator of redox conditions in groundwater,* Jour. of Hydrology, vol. 43, pp. 373-392.

Cook, J.M., Edmunds, W.M. and Kinniburgh, D.G. (1989) *Field Techniques in Groundwater Quality Investigations,* Morris B.L. (Ed.), BGS Technical Report, WD/89/56, Hydrogeology series.

Curray, J.R. and Moore, D.G. (1971) *Growth of the Bengal Deep-Sea Fan and denudation in the Himalayas,* Bull. Geol. Soc. Amer., c. 82, pp. 563-572.

Davis, J. and Exley, C. (1992) *Hydrochemical Character of the Main Aquifer Units of* Central and North-Eastern Bangladesh and Possible Toxicity of Groundwater *to Fish and Humans,* Final Report, British Geol. Surv. Technical Report, WD /92/43R.

Davis, S.N. and Dewiest, R.J. M. (1966) *Hydrology,* John Wiley & Sons Inc., New York, p. 463.

De, A. E. (1989) *Environmental Chemistry,* Wiley Eastern Ltd., New Delhi, India, p. 42-43.

De, A.K. (1994) *Environmental Chemistry,* Wiley Eastern Ltd., New Age Int. Ltd., New Delhi, India, p. 229-264.

Department of Environment, Bangladesh (1991) *Environmental Quality Standards for Bangladesh.*

Desikachar, S.V. (1974) *A review of the tectonic and geologic history of Eastern India in term of plate tectonics theory,* Jour. Geol. Soc. India, c. 15, pp. 137-149.

Drever, J.I. (1997) *The Geochemistry of natural waters: surface and groundwater environments,* 3rd ed., Prentice-Hall Inc., New Jersey, p. 69-187.

Doneen, L.D. (1962) *The influence of crop and soil on percolating water,* Proc. 1961 Biennial Conference on groundwater recharge, pp156-163.

Fairbridge, R.W. (1971) *World sea level and climatic changes,* Quaternaria VIII, INQUA, Paris.

Fergusson, J. (1963) *Deltas of the Ganges,* Quaterly Jour. of Geo. Soc. of London, vol. XIX, pp. 274-276.

Fergusson, J.E. (1990) *The Heavy elements: Chemistry, Environmetnal impact and Health Effects,* Pergamman Press, p. 72.

Ferguson, J.F. and Gavis, J. (1972) *A review of the arsenic cycle in natural water,* Water Research, vol. 6, pp. 1259-1276.

Fetter, C.W. (1993) *Contaminant Hydrology,* Prentice-Hall Inc., New Jersey, p. 274-476.

Folk, R.L. (1968) *Petrology of sedimentary rocks,* Austin-Tex, Hemphill, p. 170.

Gale, I.N. and Smedley, P.L. (1989) *Iron in groundwater: a survey of the extent and nature of the problems and methods of removal,* BGS Technical Report, WD/89/29.

Government of the People's Republic of Bangladesh, Ministry of Planning, (2000) *Statistical Yearbook of Bangladesh (2000),* Bureau of Statistics, Statistical Division.

Guha, D.K. (1978) *Tectonic framework and oil and gas prospects of Bangladesh,* Proceedings of the 4th Annual Conference of Geol. Soc. of Bangladesh, pp. 65-76.

Gulledge, J.H. and O' Connor (1973) *Removal of Arsenic (V) from water by adsorption on aluminium and ferric hydroxides,* Jour. of American Water Works Assoc., vol. 65, pp. 548-552.

Gullens, J., Champ, D.R. and Jackson, R.E. (1979) *Chemical modeling in aqueous systems,* Jenne E.A. (Ed.), ACS Symposium Series 93, American Chemical Society, Washington D.C., pp. 81-95.

Guo, T., Delaune, R.D. and Patrick, W.H. Jr. (1997) *The influence of sediment redox chemistry on chemically active forms of arsenic, calcium, chromium and zinc in estuarine sediment,* Environment International, vol. 23, No. 3, pp. 305-316.

Gupta, S. K. and Chen, K.Y. (1978) *Arsenic removal by adsorption,* Research Journal of the Water Pollution Control Federation, vol. 50, pp. 43-506.

Handa, B. K. (1977) *Water Quality Criteria,* Tech Manual No. 4, p. 1-175.

Handa, B. K. (1987) *Nitrate content of groundwater in India,* Fert. News., vol. 32, p. 11-32.

Handa, B. K. (1992) *Status report on groundwater pollution in India,* vol. 1: Pollution of groundwater by potassium in India, pp. 1- 301.

Hassler. J. S. (1974) *Purification with Activated Carbon.* Chemical Publishing. New York.

Hem, J.D. (1970) *Study and interpretation of the chemical characteristics of nature water,* USGS Water Supply Paper 1473, p. 269.

Hem, J.D. (1989) *Study and interpretation of the chemical characteristics of natural water,* 3rd ed., USGS Water Supply Paper 2254, Washington D. C., p. 263.

Holtrop and Keiser (1967) *Some aspects of the stratigraphy and correlation of the Surma Basin Wells,* ECAFE Rpt.

Johnson, D.L. and Pilson, E.Q. (1972) *Spectrophotometric determination of arsenite, arsenate and phosphate in natural waters*, Anal. Chim Acta, 58, pp. 289-299.

Jones, P.H. (1985) *Geology and Groundwater Resources of Bangladesh,* World Bank (Asia division) Report, P.M. Jones Hydrogeology Inc.

Keeny, D.R. (1973) *The nitrogen cycle in sediment water systems*, Jour. of Environ. Quality, vol. 2, pp. 15.

Keller, E.A. (1985) *Environmental Geology*, 4th Ed., CBS Publications, p. 180.

Khan, A.A. (1991) *Tectonics of the Bengal Basin,* Jour. Himalayan Geol., India, vol. 2 (1), pp. 91-101.

Khan, F.H. (1991) *Geology of Bangladesh,* Wiley Eastern Ltd., Ec. ed., New Delhi, India, p. 7-122.

Khan, A.A. and Rahman, T. (1992) *An analysis of the gravity field and tectonic evaluation of north western part of Bangladesh,* Tectonophysics, vol. 206, pp. 301-364.

Khandokar, R.A. (1987) *Origin of elevated Barind-Madhupur area, Bengal Basin, Result of neotectonic activities,* Bangladesh Jour. Geol., vol. 6, pp. 1-10.

Raven, K.P., Jain, A., and Loeppert, R.H. (1998) *Arsenite and Arsenate Adsorption on Ferrihydrite: Kinetics, Equilibrium, and Adsorption Envelopes,* Environmental Science & Technology, vol. 32, no. 3, pp. 344-349.

Kumar, R. (1985) *Fundamentals of historical geology and stratigraphy of India,* Wiley Eastern Ltd., New Delhi, India, p. 254.

Lloyd, J.W. and Heathcote, J.A. (1985) *Natural Inorganic Hydrochemistry in Relation to Groundwater, An introduction,* Claredon Press, Oxford, p. 291.

Maeda, S. (1994) *Biotransformation of arsenic in the Freshwater environment,* Nriagu J.O. (Ed.), Arsenic in environment, Part: Cycling and Characterization, pp. 155-188.

Maher, W.A. (1985) *Arsenic in the marine environment of South Australia,* Craig P.J. & Glocking F. (Ed.), The Biological Alkylation of Heavy Metals, Royal Society of Chemistry, London, pp. 120-126.

Masscheleyn, P.H., Delaune, R.D. and Patrick, W.H. Jr. (1991) *Effect of redox potential and pH on arsenic speciation and solubility in a contaminated soil,* Environ. Sci. Techno., vol. 25, pp. 1414-1419.

Matin, M.A. (1983) *Tectonic map of Bangladesh, present and past,* Bangladesh Jour. Geol., vol. 2, pp. 17-44.

Matthess, G. (1982) *The Properties of Groundwater,* John Wiley and Sons, New York, p. 397.

Mauch, Rezso. (1949) *The Graphic Symbolization of Chemical Composition of Natural Water,* Hydrol. Kozlony, vol. 29.

Mitra, R.N. (1959) *Tectonics of the frontal folded belt of the Tripura-Surma Valley,* Bull. ONGC, vol. 2.

MMI (1993) *Gumti phase II sub-project feasibility study* (Draft final report), Government of the Peoples Republic of Bangladesh.

Monsur (1982) *An Introduction to the Quaternary Geology of Bangladesh,* p. 397.

Moorhouse, W.W. (1985) The study of rocks in thin section, John Wiley and Sons, India.

Morgan, J.P. and McIntire, W.G. (1959) *Quaternary geology of the Bengal Basin, East Pakistan and India,* Geol. Soc. Amer. Bull., vol. 70, pp. 319-342.

Morton, W.H. and Khan, Q. (1979) *Groundwater in the Coastal Zone and offshore islands of Bangladesh,* UNDP/UNCTAD, GWC.

MPO (1978) *The Groundwater resource and its availability for development,* Master Plan Organization Technical Report No. 2, Ministry of Irrigation, Water Development and Flood Control.

Nickson, R. (1997) *Origin and distribution of arsenic in groundwater, central Bangladesh,* Unpublished MSc Thesis, Dept. of Geological Sciences, University College, London, UK.

Nickson, R., McArthur, J., Burgess, W., Kazi, M. H., Ravenscroft, P. and Rahaman, M. (1998) *Arsenic poisoning of Bangladesh groundwater.* Nature vol. 395 pp. 338.

Niyogi, D. (1972) *Quaternary mapping in plains of the West Bengal,* Proceedings of the Geomorphology, Geohydrology and Geotechniques of the lower Ganga Basin, IIT, Kharagpur, West Bengal, India.

Niyogi, D. and Mallick, S. (1973) *Quaternary laterite of West Bengal: its geomorphology, stratigraphy and genesis,* Quaterly Jour. of Min. Met. Society of India, vol. 45, pp. 157-174.

Niyogi, D. (1975) *Quaternary geology of the coastal plain in West Bengal and Orissa,* Indian Jour. of Earth Sci., vol. 2, pp. 51-61.

NRECA (1997) *Report of Study of the Impact of the Bangladesh Rural Electrification Program on Groundwater Quality,* Prepared for Bangladesh Rural Electrification Board, by NRECA International with Personnel Provided by The Johnson Company Inc. USA and ICDDR, B (Dhaka) for USAID.

Onishi, H. and Sandell, E.B. (1955) *Geochemistry of Arsenic,* Geochim. Cosmochim. Acta 7, pp. 1-33.

PARD (1961) *Publication of the Pakistan Academy of Rural Development (*Now BARD, Comilla).

Ravenscroft, P. and Kazi, M.A.(1998) *Regional Hydrogeological control on the Occurrence of Arsenic in Groundwater in the Bengal Basin,* Extended Abstract, International Conference on Arsenic Contamination of Groundwater. Dhaka.

Peterson, M.L. and Carpenter, R. (1986) *Arsenic Distributions in porewaters and sediments of Puget Sound, Lake Washington, The Washington Coast and Scanish inlet,* Geochem. Cosmochim. Acta 50, pp. 353-369.
Pettijohn, F. J. (1975) *Sedimentary Rocks,* 3rd ed., Harper and Row, New York, p. 628.

Piper, A.M. (1944) *A graphic procedure in geochemical interpretation of water analysis,* Trans. Amer. Geophysical Union, vol. 25, pp. 914-928.

Piper, A.M. (1953) *A graphic procedure in geochemical interpretation of water analysis,* USGS Groundwater Note No. 12.

Poddar, B.C., Chakraborty, C., Banerjee, S.N., Chakravarti, P. (1993) *Changing geography and climate of West Bengal since 18,000 b.p.,* Rec. Geo. Sur. of India, vol. 121, pp. 47-53.

Powell, C.McA. (1979) *A speculative tectonic history of Pakistan and surroundings-some constraints from the Indian Ocean,* Farah, A. & De Jong, K. A. (ed.). Geological Survey of Pakistan, pp. 5-24.

Powell, C.McA. (1986) *Continental underplating model for the rise of the Tibetan Plateau,* Earth & Planet. Sci. Lit. vol. 81, pp. 79-94.

Raghunath, H.M. (1990) *Groundwater,* 2nd Ed., Wiley Eastern Ltd., New Delhi, India, p. 345-364.

Rahman, A.K.M.M. and Kazi, A.I. (2000) *Methods to Measure Arsenic in Water,* Jour. of Science, Technology and Development, BCSIR, Dhaka, vol. 1(1), pp. 145-153.

RainWater, F. H. and Thatcher, L.L. (1960) *Methods for collection and analysis of water Samples,* USGS WSP. 14, Washington D. C., p. 93-301.

Raju, A.T.R. (1968) *Geologic evaluation of Assam and Cambay Tertiary basins of India,* Amer. Ass. Petrol. Geol. Bull.,vol. 52, pp. 2422-2437.

Reimann, K.U. (1993) *Geology of Bangladesh,* Gebrüder Borntraeger, Berlin-Stuttgart, p. 17-91.

Sakata, M. (1987) Relationship between adsorption of Arsenic (III) and Boron by Soil and soil properties, Environ. Sci. Technol., Vol. 21, pp. 1126-130.

Sampei, Y., Matsumoto, E., Kamei, T. and Tokuoka, T. (1997) *Sulfur and organic carbon relationship in sediments from coastal brackish lakes in the Shimane Peninsula district, southwest Japan,* Geochem. Jour., vol. 31, pp. 245-262.

Schoeller (1962) *Les eaux souterraines,* Masson & Cie, Paris, p. 642.

Sengupta, S. (1966) *Geological and Geophysical Studies in Western part of Bengal Basin, India*, Amer. Ass. Petrol. Geol. Bull. vol. 50., pp. 1001-1017.

Shahidul, M.I. and Tooley, M.J. (1999) *Coastal and sea-level changes during the Holocene in Bangladesh,* Quaternary International 55, pp. 61-75.

Stiff, H.A. (Jr) (1951) *The Interpretation of Chemical Water Analysis by means of Patterns,* J. Petrol. Tech. Report. 15.

Stumm, W. and Morgan, J.J. (1981) Aquatic Chemistry, 2nd ed., John Wiley & Sons, U.S.A., p. 70.

Talukdar, S.A. (1997) *Studies of Analytical Chemistry in Drinking Water Quality and Arsenic Calamity in Groundwater of Bangladesh.*

Todd, D.K. (1980) *Groundwater Hydrology,* 2nd ed., John Wiley & Sons, New York, p. 535.

UNDP (1982) *The Hydrogeological Conditions of Bangladesh,* United Nations Development Programme, DP / UN / BGD-74-009/1.

Umitsu, M. (1993) *Late Quaternary sedimentary environments and landforms in the Ganges delta,* Sediment Geol., vol. 83, pp. 177-186.

U.S. Department of Agriculture (USDA) (1955) *Water: The 1955 Yearbook of Agriculture,* p. 751.

Water Aid Bangladesh (2000) *Arsenic 2000, an over view of the arsenic issue in Bangladesh,* Draft Final report.

Wilcox, L.V. (1955) *Classification and Use of Irrigation Water,* USDA Circ. 969, Washington D.C., p. 19.

World Health Organization (1984) *Guidelines for Drinking Water Quality,* W. H. O., Geneva.

World Health Organization (1993) *Guidelines for Drinking Water Quality,* W. H. O., Geneva.

World Health Organization (2001) *United Nations Synthesis Report on Arsenic in Drinking Water,* Arsenic UN Rep. 1, pp. 1-45.

Xu, H., Allard, B. and Grimvall, A. (1988) *Influence of pH and organic substances on the adsorption of Arsenic (V) on geologic materials*, Water, Air, Soil polluts. vol. 40, pp. 293-306.

Yan-chu, H. (1994) *Arsenic Distribution in Soils,* Nriagu J.D. (Ed.), Arsenic in the environment, Part 1: Cycling and Characterization, pp. 17-50.

ANNEXURE

Annexure-1: Result of Chemical analysis of water samples of the study area.

Sl.no	Tube well code	pH	EC in µS/cm	TDS in ppm	Ca in ppm	Ca in meq/l	Mg in ppm	Mg in meq/l	Na in ppm	Na in meq/l	K in ppm	K in meq/l	Fe^{total} in ppm	Fe^{total} in meq/l	Total Cation in ppm
1	SH	7.5	550	357.5	84	3.7716	16.41	1.3503789	3.01	0.130935	0.3	0.007677	0.78	0.0452166	5.3058075
2	RH	8.8	660	429	114	5.1186	10.5	0.864045	4.7	0.20445	0	0	1.38	0.0799986	6.2670936
3	SI	8.4	625	406.25	126	5.6574	3.5	0.288015	2.5	0.10875	0	0	0.33	0.0191301	6.0732951
4	RI	8.3	620	403	109	4.8941	3	0.24687	1.25	0.054375	0.73	0.018681	0.11	0.0063767	5.2204024
5	ZI	9.2	730	474.5	103	4.6247	2	0.16458	5.2	0.2262	3	0.07677	1.13	0.0655061	5.1577561
6	SP	9.8	745	484.25	86	3.8614	26	2.13954	2	0.087	0.5	0.012795	2.41	0.1397077	6.2404427
7	CH	9.1	680	442	150	6.735	15	1.23435	9.5	0.41325	7.2	0.184248	6.4	0.371008	8.937856
8	RU	9	700	455	115	5.1635	1.25	0.1028625	15	0.6525	1.5	0.038385	3.1	0.179707	6.1369545
9	ST	8.8	675	438.75	104	4.6696	2.5	0.205725	12	0.522	1.27	0.032499	2.33	0.1350701	5.5648944
10	DH	8.4	630	409.5	98	4.4002	7	0.57603	5	0.2175	1.3	0.033267	0.58	0.0336226	5.2606196
11	BM	9.6	725	471.25	67.13	3.014137	41.63	3.4257327	3.5	0.15225	2.8	0.071652	1.5	0.086955	6.7507267
12	AH	9.8	740	481	141	6.3309	12.43	1.0228647	11.5	0.50025	0	0	0.14	0.0081158	7.8621305

(Continued)

Annexure-1: Result of Chemical analysis of water samples of the study area.

Sl.no	Tube well code	HCO_3 in ppm	HCO_3 in meq/l	Cl in ppm	Cl in meq/l	SO_4 in ppm	SO_4 in meq/l	NO_3 in ppm	NO_3 in meq/l	Total Anion in ppm	As in ppm	Total ion	TCI-TAI
1	SH	290	4.7531	24.5	0.691145	0	0	0	0	5.444245	0.121	10.75005	-0.13844
2	RH	435	7.12965	12	0.33852	0	0	0	0	7.46817	0.1	13.73526	-1.20108
3	SI	333	5.45787	23.7	0.668577	0.43	0.008944	0.35	0.0057645	6.1411555	0.611	12.21445	-0.06786
4	RI	305	4.99895	13.5	0.380835	0.6	0.01248	0.5	0.008235	5.4005	0.552	10.6209	-0.1801
5	ZI	254	4.16306	29	0.81809	0	0	0	0	4.98115	0.035	10.13891	0.176606
6	SP	349	5.72011	17.8	0.502138	0	0	0	0	6.222248	0.494	12.46269	0.018195
7	CH	483	7.91637	21	0.59241	0.6	0.01248	0	0	8.52126	0.248	17.45912	0.416596
8	RU	350	5.7365	25	0.70525	0	0	1	0.01647	6.45822	1.08	12.59517	-0.32127
9	ST	321	5.26119	15	0.42315	0.12	0.002496	0	0	5.686836	0.128	11.25173	-0.12194
10	DH	273	4.47447	16.5	0.465465	0	0	0	0	4.939935	0.157	10.20055	0.320685
11	BM	353	5.78567	12	0.33852	0	0	0	0	6.12419	0.64	12.87492	0.626537
12	AH	409	6.70351	23.7	0.668577	0	0	0	0	7.372087	0.171	15.23422	0.490044

(Continued)

Annexure-1: Result of Chemical analysis of water samples of the study area.

Sl.no	Tube well code	TCI-TAI	Ionic Balance	Total Hardness mg/l	RC in ppm	SAR	Permeablity Index	sqr HCO3	Na%
1	SH	-0.13844	-1.28778441	256.098945	0.368879	0.081824	43.55482177	2.18	2.612458
2	RH	-1.20108	-8.74447288	299.13225	-1.147005	0.118255	45.86575825	2.67	3.262278
3	SI	-0.06786	-0.55557472	297.27075	0.487545	0.063082	40.25409534	2.336	1.790626
4	RI	-0.1801	-1.69569019	257.0485	0.14202	0.03392	43.85437797	2.235	1.399427
5	ZI	0.176606	1.741865427	239.464	0.62622	0.146203	43.9377116	2.04	5.874066
6	SP	0.018195	0.145993353	300.047	0.28083	0.050219	39.70872131	2.391	1.599165
7	CH	0.416596	2.3861231	398.4675	0.05298	0.20702	36.0964643	2.813	6.685026
8	RU	-0.32127	-2.55070305	263.318125	-0.47014	0.402252	49.83742343	2.406	11.25778
9	ST	-0.12194	-1.08375864	243.76625	-0.38586	0.334335	50.58496708	2.293	9.964238
10	DH	0.320685	3.14379573	248.8115	0.50176	0.137932	44.33888358	2.115	4.766872
11	BM	0.626537	4.866335951	321.993485	0.6542	0.084869	37.88110693	2.405	3.31671
12	AH	0.490044	3.216729051	367.688235	0.650255	0.260957	39.29278457	2.589	6.362779

Annexure-2: Results of mitigated water and recycled sludge analysis

Results of Mitigation by fresh ferric oxyhydroxide				Results of Sludge Recycling	
Tank NA-2		Tank NA-4		Recycled Sludge by Sodium hydroxide solution wash	
Number of cycle in day	As concentration in ppm	Number of cycle in day	As concentration in ppm	Number of wash	As concentration remain in sludge in ppm
0	0.25	0	0.932	1	0.219
0.8	0.008	0.85	0.001	2	0.117
1	0.01	1	0.015	3	0.07
2	0.01	2	0.025	4	0.059
3	0.01	3	0.025	5	0.045
4	0.012	4	0.025	6	0.035
5	0.013	5	0.025		
6	0.014	6	0.025		
7	0.016	7	0.025		
8	0.016	8	0.025		
9	0.017	9	0.025		
10	0.018	10	0.025		
11	0.018	11	0.025		
12	0.018	12	0.032		
13	0.02	13	0.034		
14	0.02	14	0.043		
15	0.02	15	0.045		
16	0.02				
17	0.02				
18	0.021				
19	0.021				
20	0.021				
21	0.022				
22	0.024				
23	0.025				
24	0.027				
25	0.029				
26	0.03				
27	0.035				
28	0.04				
29	0.05				
30	0.057				

Annexure-2: Results of mitigated water and recycled sludge analysis

Results of Mitigation by recycled ferric oxyhydroxide				Results of Sludge Recycling	
Tank NA-2		Tank NA-4		Recycled Sludge by Sodium hydroxide solution and water wash	
Number of cycle in day	As concentration in ppm	Number of cycle in day	As concentration in ppm	Number of wash	As concentration remain in sludge in ppm
1	0.25	1	0.06	1	0.05
2	0.01	2	0.045	2	0.023
3	0.011	3	0.009	3	0.011
4	0.011	4	0.019	4	0.003
5	0.013	5	0.02		
6	0.014	6	0.022		
7	0.015	7	0.026		
8	0.018	8	0.029		
9	0.02	9	0.035		
10	0.02	10	0.038		
11	0.02	11	0.041		
12	0.023	12	0.045		
13	0.023	13	0.055		
14	0.025	14			
15	0.031	15	0.164		
16	0.032				
17	0.032				