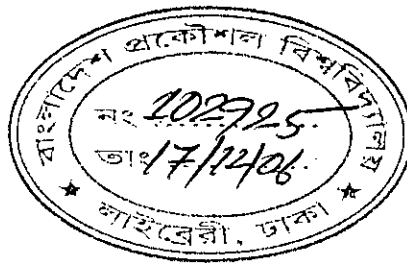


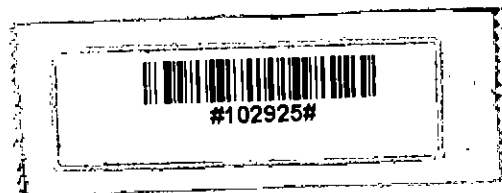
SHORT-TERM AND LONG-TERM LEACHING OF ARSENIC  
FROM WASTES OF ARSENIC REMOVAL SYSTEMS

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DHAKA

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**SHORT-TERM AND LONG-TERM LEACHING OF ARSENIC  
FROM WASTES OF ARSENIC REMOVAL SYSTEMS**

BY  
**MD. KAMRUZZAMAN**

A thesis submitted to the Department of Civil Engineering of Bangladesh  
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of

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SEPTEMBER 2006

**SHORT-TERM AND LONG-TERM LEACHING OF ARSENIC  
FROM WASTES OF ARSENIC REMOVAL SYSTEMS**

CERTIFICATE OF APPROVAL

We hereby recommended that the thesis titled "Short-Term and Long-Term Leaching of Arsenic from Wastes of Arsenic Removal Systems" submitted by Md. Kamruzzaman, Roll No. 100104149(F) be accepted as fulfilling this part of the requirements for the degree of Master of Science in Civil Engineering.

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---

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Signature of Candidate

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## ABSTRACT

Arsenic contamination of groundwater in the alluvial aquifer underlying Bangladesh has been recognized as a major problem of catastrophic proportions. Millions of people are exposed to high levels of arsenic from drinking tubewell water and thousands are suffering from arsenic poisoning but little is known about the fate and transport of arsenic in the environment. In Bangladesh, a number of arsenic removal technologies (both for household and community use) have been developed for getting arsenic-free water. Majority of these technologies are based on either coagulation-coprecipitation (e.g., using alum and ferric chloride) or adsorptive filtration (e.g., using activated alumina, iron coated sand, granular ferric hydroxide, etc.) techniques. Besides, some devices use ion exchange and membrane filtration techniques. All the arsenic removal units generate some form of arsenic-rich wastes, primarily in the form of slurry containing coagulated flocs of alum or iron salt (from coagulation based units), or spent adsorption/ion-exchange media (from filtration based units). In the absence of any clear guidance for safe disposal of wastes, indiscriminate disposal of these spent media or sludge is likely to contaminate the surface water and groundwater sources, as a result of leaching of arsenic from these wastes.

In this study short-term leaching characteristics of arsenic-rich wastes have been evaluated through Toxicity Characteristic Leaching Procedure (TCLP). For majority of the slurry samples, leaching of arsenic expressed as percent of initial arsenic present is found to be negligible. The arsenic content in the TCLP extract for slurry waste samples varied from 0.011 to 1.255 mg/l which is within the range of acceptable limit. In the case of waste samples from spent media, leaching of arsenic expressed as percent of initial arsenic present was also found to be very low. The arsenic content in the TCLP extract for spent media samples varied from 0.172 to 0.654 mg/kg of spent media. The TCLP results confirm that the slurry waste samples and solid waste samples from different arsenic removal units are not "hazardous" as defined by the United States Environmental Protection Agency (USEPA).

Column experiments were carried out with spent media samples from “Shapla filters” in order to evaluate the long-term leaching characteristics of the waste. For column experiment, the initial arsenic concentration of the spent filter media was 38.8 mg/kg, and at the end of the experiment, 35.3 % of arsenic was found to have leached out with distilled water; leaching was 28.1 %, 27.4 %, 25.4 %, and 22.7 % with groundwater, rainwater, pond water and extraction fluid #1 (TCLP extraction fluid), respectively. About 1564 bed volume of distilled water, 1750 bed volume of groundwater, 1658 bed volume of rainwater, 1720 bed volume of pond water and 1929 bed volume of extraction fluid#1 was passed through the respective columns before the arsenic concentration in the leachate reached below the method detection limit (MDL). Distilled water showed highest leaching, followed by groundwater, rainwater, pond water and finally the extraction fluid #1. Thus, long-term leaching is much greater than the short-term leaching. Short-term leaching was found to be less than 2% of initial arsenic content, whereas long-term leaching (column leaching) was found to be between 22.7 % and 35.3 %. It takes a maximum of four and a half months for the surface bound arsenic to leach out to a level below the MDL.

Extensive research work should be undertaken in order to investigate the mobility of arsenic. It is essential to create awareness among the users of different arsenic removal units about the disposal of waste materials and sludge generated from the units. Potential management options for waste disposal must also be considered prior to distribution of the treatment systems. The protocol for management of sludge generation from the arsenic removal units is currently being developed. It is expected that this study will help the process of protocol development.



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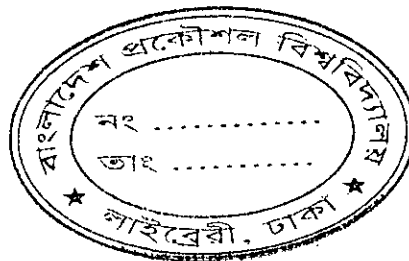
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## LIST OF ABBREVIATIONS

- AAS = Atomic Absorption Spectrophotometer  
ARU = Arsenic Removal Unit  
BGS = British Geological Survey  
BTU = Bucket Treatment Unit  
BUET = Bangladesh University of Engineering and Technology  
DPHE = Department of Public Health Engineering  
GoB = Government of Bangladesh  
MDL = Method Detection Limit  
NGO = Non-government Organization  
SHTW = Shallow Hand Tube Well  
STAR = Stevens Technology for Arsenic Removal  
TCLP = Toxicity Characteristic Leaching Procedure  
TW = Tube Well  
UNU = United Nations University  
USEPA = United States Environmental Protection Agency.  
ZHE = Zero Headspace Extractor

# CHAPTER - 1

## INTRODUCTION



### 1.1 GENERAL

Arsenic occurs widely in the alluvial aquifers of the southern part of Bengal Basin in West Bengal and southern Bangladesh, beneath the floodplains of the Ganges, Brahmaputra and Meghna rivers (Burgess et. al, 2001). Arsenic contamination of ground water in the alluvial aquifer underlying Bangladesh has been recognized as a major problem of catastrophic proportions. Millions of people are exposed to high levels of arsenic from drinking tube well water and thousands are suffering from arsenic poisoning but little is known about the fate and transport of arsenic in the environment.

South and Southeast Asia are heavily polluted and contain approximately 25% of the world's population (Jacks and Bhattacharya, 2001). A look at the population density shows that the delta areas carry the heaviest loads of habitation. In 20 countries in different parts of the world, ground water arsenic contamination and suffering of people has been reported (Chakrabarti et. al, 2001). Out of these, major calamities are in Asia. In Asia, the arsenic contamination scenario in Bangladesh, both in terms of magnitude and human exposure, is the worst followed by West Bengal in India, Peoples Republic of China including Inner Mongolia and Taiwan.

The poor people of this country have been facing a variety of natural disasters like severe flood, drought, cyclone, tidal storm, famine, diseases etc. for a long time. Nothing has disrupted their life so severely. But arsenic contamination appears as a catastrophic disaster to them. Arsenic in ground water and its fate and transport in the environment have become a matter of great concern in Bangladesh. An estimated 268 upazillas out of 465 have been affected with significantly high concentrations of arsenic (Ali et. al, 2003). In Bangladesh, tube well water extracted from shallow aquifers is the primary source of drinking / cooking water for most of its population. It



is also estimated that about 77 million people are at risk of arsenic poisoning (Badruzzaman, 2003). Arsenic contamination may cause skin lesions and cancer of the bladder, kidney, lung and skin along with cardiovascular problems. It may be the largest mass poisoning in the history. The scale of arsenic disaster in Bangladesh is beyond the accidents at Bhopal, India in 1984 and Chernobyl, Ukraine in 1986.

In the early 1970's nearly one quarter of a million children died each year in Bangladesh and West Bengal from water borne diseases (Badruzzaman, 2003). In the context of very high prevalence of diarrhoeal diseases in Bangladesh, bacteriological quality received priority as a criterion for drinking water supply. Groundwater is free from pathogenic microorganism and available in adequate quantities in shallow aquifers, permitting development of cost effective water supply systems for scattered rural population. Groundwater abstracted by shallow tube wells was found to be the best option for rural water supply and as a result, a large number of tube wells have been drilled during the last 30 years to provide reliable, pathogen-free drinking water. At present, an estimated 11 to 12 million hand-tube wells constitute the backbone of the rural water supply in Bangladesh (Ali et. al, 2003). The country achieved a remarkable success by providing 97% of the rural population with tubewell water. Unfortunately, when rural people have developed the habit of drinking tubewell water, being aware of its importance to avoid diarrhoeal diseases, arsenic in excess of acceptable limits has been found in tube well water in many parts of Bangladesh.

Arsenic has been called the King of poisons and is found in drinking water spot wise all over the world. In Bangladesh, arsenic in groundwater was first detected in late 1993 at Barogharia union of Chapai Nawabganj district bordering the West Bengal district of India by the Department of Public Health Engineering (DPHE). Since then high levels of arsenic have been found in 61 out of 64 administrative districts of the country (Ali et. al, 2003). The southern, central and north-eastern regions of Bangladesh have been most severely affected by arsenic contamination of shallow tube well water.

A number of studies have been conducted to develop suitable techniques to treat arsenic laden groundwater. Most of these are aimed at developing household and small community level units. Although removal of arsenic from drinking water is

possible through highly sophisticated treatment methods, they are often expensive and are only applicable at a centralized treatment plants used in a distribution network (Badruzzaman, 2003). At present, the Government of Bangladesh (GoB), the Non-Government organizations (NGOs), the donor agencies, private entrepreneurs, etc. are promoting locally and internationally developed household and community level arsenic removal units. The treatment alternatives currently being studied and promoted by different Government and Non-government organizations, Donor agencies and Private entrepreneur include:

- Passive sedimentation followed by filtration
- Filtration through sand column
- Filtration through activated alumina column
- Alum coagulation followed by filtration
- Ferric chloride coagulation followed by filtration
- Filtration through iron coated sand bed, brick chips
- Filtration through granular ferric hydroxide.

All the arsenic removal units generate some form of arsenic-rich wastes, because almost all the materials used for filtration get clogged after prolonged use. Some of these units may be regenerated by washing with water or other reagents. However, after certain time the filter column has to be discarded. These spent filter media are likely to contain very high level of arsenic following continuous accumulation. Also, some of the arsenic removal units generate liquid sludge containing high level of arsenic associated with iron flocs. In the absence of any clear guidance for safe disposal of wastes generated from arsenic removal units, such wastes are often disposed of in the open environment. Indiscriminate disposal of these spent media or sludge is likely to contaminate the surface water sources or may leach arsenic, which may be transported to the underlying aquifer. Concerns have been raised regarding safe disposal of these wastes and possible contamination of environment from arsenic present in the wastes. However, there is only limited data on the qualities and characteristics of these wastes (e.g., Hamel and Zinia, 2001, Badruzzaman, 2003, Islam et. al, 2003) and possible mobilization of arsenic from these wastes.

## 1.2 OBJECTIVES OF RESEARCH

Almost all the arsenic removal units generate some form of arsenic-rich wastes. The sludge generated from coagulation based arsenic removal units and the filter media used in filtration based arsenic removal units are likely to contain very high level of arsenic following continuous accumulation. Arsenic may leach out from these wastes after they are disposed of. The major objectives of the study are:

- a. To estimate the short-term leachable arsenic in the wastes generated from filtration based arsenic removal units through Toxicity Characteristic Leaching Procedure (TCLP) developed and followed by the USEPA.
- b. To estimate the short-term leachable arsenic in the wastes generated from coagulation based arsenic removal units through Toxicity Characteristic Leaching Procedure (TCLP) developed and followed by the USEPA.
- c. To estimate the long-term leachable arsenic in the wastes generated from filtration based arsenic removal units through Column Experiment.
- d. To compare short-term (through TCLP) and long-term (through Column experiment) leaching of arsenic from wastes generated from filtration based arsenic removal units.

Results of this study would contribute to the understanding of leaching characteristics, both short-term and long-term, of arsenic from the wastes generated from different ARUs under varying disposal conditions. This would also give a guideline whether the disposal of arsenic-rich wastes generated from different ARUs in the open environment is safe or not. Efforts would be made to assess the time period required by the wastes to be completely stabilized after leaching.

### 1.3 SCOPE OF THE STUDY

In the context of prevalence of high concentration of arsenic in tube well water, a wide range of technologies have been tried in Bangladesh for the removal of arsenic from drinking water. Almost all the technologies generate some form of arsenic-rich wastes, which most of the time are disposed of in the open environment. Indiscriminate disposal of these wastes may cause surface water pollution through the mobilization of arsenic from the wastes. The present study focuses on mobilization of arsenic from filter media used or sludge generated in various arsenic removal units being practiced in Bangladesh. The research gives emphasis on two types of leaching namely, short-term and long-term leaching characteristics of arsenic from the arsenic rich wastes through carrying out the Toxicity Characteristic Leaching Procedure (TCLP) for short-term leaching and column experiment for long-term leaching. A comparison between the short-term and long-term leaching of arsenic from the wastes was attempted in this study. In addition, an assessment of the time required for the waste to be completely stabilized after long-term leaching of arsenic was estimated following long-term leaching.

### 1.4 RESEARCH METHODOLOGY

In order to achieve the mentioned research objectives, initial approach was literature review to strengthen the knowledge background in order to proceed with the task. Samples were collected from filter media used in and sludge generated from various arsenic removal units installed at different places of the country. Then the collected samples were digested and analyzed in the laboratory for total arsenic concentration. Toxicity Characteristic Leaching Procedure (TCLP) was performed, following the USEPA method 1311 (USEPA, 1992), on both solid and slurry sample to know the short-term leaching characteristics of the wastes. Experimental set up for column experiment was developed and column experiments were conducted with the filter media collected from 'Shapla' filter using five different types of fluids in order to know the long-term leaching characteristics of the wastes under varying disposal conditions. Thereafter, a comparison is made between the short-term and long-term leaching of arsenic from the wastes.

## 1.5 ORGANIZATION OF THE THESIS

The whole study has been represented in five distinct Chapters. Chapter 1 gives a general introduction of the arsenic problems including background information and the present status of arsenic in Bangladesh. The chapter also includes the scope, objectives and methodology of the study. Chapter 2 titled "Literature Review" presents a brief overview of arsenic chemistry. In Chapter 3, short-term leaching characteristics of the samples collected from different types of arsenic removal units are presented. The results of TCLP performed on various semi-solid and solid samples collected from different ARUs are described elaborately in this Chapter. The main findings of this study are presented in Chapter 4. This Chapter provides a brief overview of long-term leaching characteristics of the waste sample collected from filtration based arsenic removal unit named 'Shapla' filter. In this chapter, the ins and outs of column experiment, experimental design, experimental setup and analysis of column experiment results are described. Finally, a mass balance analysis is performed. Concluding remarks and recommendations came at the concluding Chapter. References and Appendices are placed at the end to support my work.

## CHAPTER - 2

### LITERATURE REVIEW

#### 2.1 INTRODUCTION

Arsenic is a naturally occurring element. Pure arsenic is a gray metal, which is usually found in the environment combined with other elements such as oxygen, sulfur and iron. Arsenic may be found in organic form when it is combined with carbon and hydrogen. Sometimes arsenic occurs naturally in the soil, from where it leaches into groundwater. Sometimes it may be found in effluents of different industries. This chapter presents a review of literature concerning occurrence, source, chemistry, uses and health effects of arsenic and its behavior in the environment.

Through the process of earth's materialization, the mantle was formed to contain the toxic metals in small quantities and in a way that does not affect our biosphere to any large extent. The toxic metals occurred only spot wise and mainly immobilized in geological formations. This allows for groundwater to migrate through the deep soil without dissolution at too high concentration levels. Like that, rainwater can pass through multiple geological layers of varied chemical compositions and contents of potentially toxic compounds. Yet it most often comes out in springs as fresh, enriched with tasty and healthy minerals and free of pathogenic micro-organism and toxic substances. There is no doubt that this immobilization of toxic components in the geosphere has been of significant importance for the development and survival of the biosphere as we know it today.

Like most of the toxic metals, arsenic occurs immobilized in the geosphere. However, arsenic is not a typical metal. It is also called metalloid, exhibiting metallic as well as non-metallic characters and corresponding chemical processes. It is due to this arsenic chemistry that mankind has developed the multiple uses and anthropogenic pollution. It is also due to this arsenic chemistry that arsenic is immobilized naturally to water bodies. Thus, arsenic is extremely toxic even carcinogenic and understanding of at

least some of the arsenic chemistry may be most essential for the avoidance and the remediation of its environmental health problems, seriously faced in Bangladesh.

## 2.2 ARSENIC IN THE ENVIRONMENT

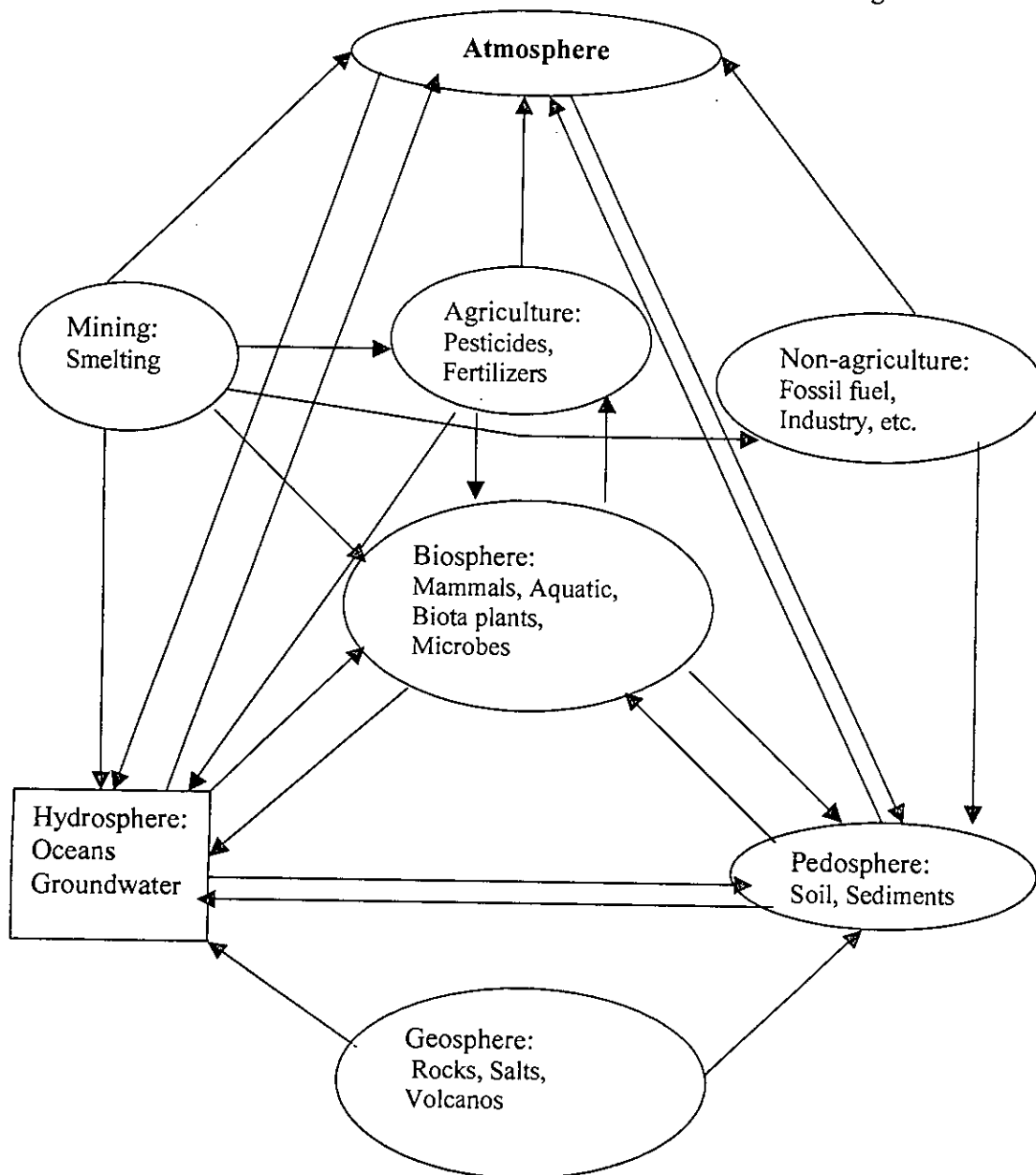
Arsenic is the 20<sup>th</sup> most abundant element in the earth's crust and the 12<sup>th</sup> most abundant element in the biosphere, where it is said to be an essential element at least for some animal species, but not for human. Arsenic is the king of poisons and has plagued human beings since the days of antiquity. As a carcinogen, it has been well known since early times. In Asia, arsenic is both a cause of large-scale environmental contamination and a serious health-hazard. Arsenic is a toxic chemical and may pollute air, soil, sediments and water causing health hazards to both human and animal's life. Arsenic is found to occur in nature as mineral form which, by way of erosion and deposition, soil may be contaminated. Table 2.1 shows the approximate environmental concentration levels of arsenic and human exposure through the air, food and water.

**Table 2.1: Approximate environmental concentration levels of arsenic and human exposure through the air, food and water (Data from WHO, 1996).**

Medium	Concentration	Daily Intake	Daily exposure	Remarks
Air	0.4-30 ng/m <sup>3</sup>	20m <sup>3</sup>	0.01-0.6µg	May be much higher in industrial areas
Food	0.4-120µg/kg	1kg	0.4-120µg	70% is organic As and 25% is inorganic As
Water, Generally	1-2µg/L	2 L	2-4µg	Mainly inorganic As(III) most toxic
Water, up to	12000µg/L	2 L	24000µg	Causing endemic illnesses

At high concentrations (76 mg arsenite), arsenic can be lethal to human body. Arsenic is a dietary constituent and is present in many foods such as meat, fish, poultry, grain and cereals.

Arsenic is found in everywhere in the environment. It is found in atmosphere, biosphere, hydrosphere, pedosphere and geosphere and transferred from one to another by natural processes or human activities such as mining, agriculture, industrial processes etc. The environmental cycle of arsenic is shown in Figure 2.1.



**Figure 2.1: The environmental cycle of arsenic (after Bhumbra and Keefer, 1994)**

Arsenic is mainly found in the form of its mineral compounds and widely distributed in air, water, soils, rocks and earth crust. It may be seen that rocks and minerals are the main reservoirs of arsenic, which is mobilized in the other media of the



environment by natural weathering processes, biological activity, volcanic eruption and anthropogenic activities.

## 2.3 USE OF ARSENIC

### 2.3.1 Historical Uses

The use of arsenic is recorded 2000-3000 years ago in the orient. Orpiment and realgar are occasionally cited in Akkadian texts as ingredients of paints and for ornamental or cosmetic purposes (Forbes, 1964). The yellow sulfide of arsenic was known to the classical painters as aurpigmentum and was a common ingredient in most of the colors in the Middle Ages for painting, and also for writing and in imitation of gold (Thompson, 1956). Arsenic bronzes were made by the Egyptians, who used it with copper and tin in making metal mirrors (Derry and Williams, 1961). Arsenic is cited in the first treatises on glasses as on the fluxing ingredients in glass manufacture (Nriagu, 1994). Its effects are produced by crystallization during the cooling of the glass (Singer et al., 1957).

The main uses arsenic compounds in antiquity were pharmaceutical and medicinal. At the beginning of the sixteenth century, the revolutionary Paracelsus designated arsenic, along with opium, mercury, lead and copper sulfate as part of the modern pharmacopoeia (Hunter, 1978). Some arsenic compounds, mainly arsenate of potash, which was prepared by fusing the trioxide with saltpeter, seemed to be greatly favored as a medicine by Paracelsus, who named it arsenicum fixum (Meyer, 1975).

Until the nineteenth century, arsenic ( $As_2O_3$ ) was the preferred poison of most homicidal practitioners, to the point where laws were passed against possession of it (Emsley, 1985). Despite this, Flower's solution (1% potassium arsenate, discovered in 1786) became the most widely used medication for a variety of illness for 150 years (Frost, 1984). Donovan's solution (arsenic iodide) and devalagin's solution (arsenic trichloride) were also recommended to treat rheumatism, arthritis, asthma, malaria, trypanosome infections, tuberculosis and diabetes (Leonard, 1991). Several poisoning cases have been reported from the historical use of arsenical pigments for coloring

artificial flowers, toys, wallpaper, and wrapping papers (Nriagu, 1994). A vast literature exists regarding the hypothesis that arsenic poisoning was the cause of Napoleon's death, due to its presence in the green pigments of the wallpaper (Jones, 1982; Richardson, 1974).

### 2.3.2 Modern Uses of Arsenic

Elemental arsenic has few uses, one of which is to impart more nearly spherical shape in the manufacture of lead shot. It is also used in certain alloys to increase strength at elevated temperatures, in bronzing and in pyrotechniques. E-Pure arsenic elements are used for hollow cathode lamp's filament in arsenic analysis. Arsenic compounds are used as components of pesticides and preservatives of electric poles and other wood, leather and like as shown below in Table 2.2.

**Table 2.2: Principal modern uses of arsenic compounds (Azcue & Mrgagu, 1994)**

Sector	Uses
Agriculture	Pesticides, insecticides, defoliants, wood preservatives, debarking trees, soil steriliant and disinfectant.
Livestock	Feed additives, disease prevention (swine dysentery, heart worm infections), cattle and sheep dips, algaecides
Medicine	Antisyphylitic, drugs, treatment of trypanosomiasis, amebiasis and sleeping sickness.
Electricity	Solar cells, optoelectronic devices, semiconductor applications, light-emitting diodes in digital instruments.
Industry	Glassware, electro-photography, catalysts, pyrotechnics, antifouling paints, dyes, soaps, ceramics, pharmaceutical substances.
Metallurgy	Alloys (automotive body solder and radiators), battery plates as hardening agents.

## 2.4 SOURCES OF ARSENIC

### 2.4.1 Natural Sources of Arsenic

Arsenic is a component of more than 245 minerals (Fredrick et al. 1994). These are mostly ores containing sulfide, along with copper, nickel, lead, cobalt or other metals. The most important ores are arsenopyrites or mispickel ( $\text{FeS}$ ), realger ( $\text{As}_4\text{S}_4$ ), orpiment ( $\text{As}_2\text{S}_3$ ), Ioellignite ( $\text{FeAs}_2$ ), nicolite ( $\text{NiAs}$ ), cobalt glance ( $\text{CoAsS}$ ), Gersdroffite ( $\text{NiAsS}$ ) and smaltite ( $\text{CoAs}_2$ ). Within these minerals, arsenopyrite is probably the most common mineral in the environment. Table 2.3 shows some naturally occurring minerals containing arsenic.

**Table 2.3: Naturally occurring minerals containing arsenic (NRCC, 1978)**

Mineral	Chemical Formula	Mineral	Chemical Formula
Arsenite	As	Mutite	$\text{Pb}_5(\text{PO}_4, \text{AsO}_4)\text{Cl}$
Antimony arsenide	AsSb	Nicollite	$\text{NiAsS}$
Arsenopyrite	$\text{FeAsS}$	Orpiment	$\text{As}_2\text{S}_3$
Arsenogentite	$\text{Ag}_3\text{As}$	Olivenite	$\text{Cu}_2(\text{AsO}_4)\text{OH}$
Arsenolite	$\text{As}_2\text{O}_3$	Proustite	$\text{Ag}_2\text{AsS}_3$
Adamite	$\text{Zn}_2\text{AsO}_4(\text{OH})$	Pearcite	$\text{Ag}_{16}\text{As}_2\text{S}_{12}$
Annabergite	$\text{N}_{13}(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$	Pharmacosiderite	$\text{Fe}_3(\text{AsO}_4)_2\text{OH}_3$
Beaudanite	$\text{PbFe}_3(\text{AsO}_4)\text{SO}_4$	Realgar	AsS
Cobaltite	$\text{CoAsS}$	Rathite	$\text{Pb}_3\text{As}_5\text{S}_{10}$
Domeykite	Cu-As	Scorodite	$(\text{FeAl})\text{AsO}_4 \cdot 2\text{H}_2\text{O}$
Energite	$\text{Cu}_3\text{AsS}_4$	Smaltite	$(\text{Co}, \text{Ni})\text{As}_x$
Erythrite	$\text{Co}_3\text{AsO}_4 \cdot 8\text{H}_2\text{O}$	Safflorite	$(\text{Co}, \text{Fe})\text{As}_2$
Gersdorffite	$\text{CoAsS}$	Skutteridite	$(\text{Co}, \text{Ni})\text{As}_x$
Galucodote	$(\text{Co}, \text{Fe})\text{As}$	Sperrylite	$\text{PtAs}_2$
Jordanite	$(\text{Pb}, \text{Ti})_{13}\text{As}_7\text{S}_{23}$	Shloanthite	$(\text{Ni}, \text{Co})\text{As}_{3-x}$
Loellingite	$\text{FeAs}_2$	Tennantite	$\text{Cu}_{12}\text{As}_4\text{S}_{13}$

Arsenic and its compounds are mobile in the environment. Weathering of rocks converts arsenic sulfides to arsenic trioxide, which enters the arsenic as dust or by dissolution in rain, rivers or groundwater (Clifford and Zhang, 1993). Volatile forms of arsenic e.g. arsine ( $\text{AsH}_3$ ) and trimethyl arsine ( $\text{CH}_3\text{As}$ ) enter the atmosphere from

land and water, are returned by rain and atmospheric fallout. The oxidized forms of arsenic are converted back to sulfides by anaerobic processes occurring on land and water sediments (Tamaki, 1992). The concentrations of arsenic in natural reservoir with respect to soils have been shown in Table 2.4. Soils and oceans are the remaining major reservoirs that have much more inherent arsenic than do biota (plants, animals, man and microbes) and the atmosphere. The average concentration of arsenic in soils of the world is 7.2 ppm (Anonymous, 1978). Arsenic in the natural environment occurs in soils at an average concentration of about 5 to 6 ppm, but this varies among geographic regions (Peterson et al. 1981).

**Table 2.4: Ratios of arsenic concentrations in natural reservoir with respect to soil (Mackenzie et al. 1979)**

Reservoirs	Ratio with respect to soil
Rocks and Minerals	25,000
Oceans	4
Soils	1
Biota (Plant, animals, microbes)	0.0005
Atmosphere	0.000001

#### 2.4.2 Anthropogenic Sources

Recent estimates have placed the ratio of natural to anthropogenic inputs of arsenic at 60:40 (Chilvers et al. 1985). The global production rates of arsenic compounds, determined in a recent survey are shown in Table 2.5.

**Table 2.5: Production rates of the main arsenical compounds (Alloway, 1990)**

Compound	Production (tons As/year)
Herbicides	8,000
Cotton desiccant	12,000
Wood preservatives	16,000

The anthropogenic influence on the level of arsenic in soils depends on the human activity, the distance from the pollution sources, and the pollution dispersion pattern (Yan-Chu, 1994). Arsenic may accumulate in soil through use of arsenical pesticides, application of fertilizers, irrigation, dusts from the burning fuels, and disposal of industrial and animal wastes (Sandberg and Allen, 1975). It is a natural contaminant in lead, zinc, gold and copper ores and can be released during the smelting process (Creelious et al. 1974; ragaini et al. 1977; O'toole et al. 1971; rosehart and Lee, 1973). The stack dust and flue gases from smelters often contaminate soils with arsenic downwind from the operation (Creelcious et al. 1974; Ragaini et al. 1977). Arsenic is also commonly associated with phosphate minerals, in an average concentration of 7.7 ppb (Alloway, 1990).

#### **2.4.3 Geological Sources of Arsenic in Bangladesh**

Although the source and reason of arsenic contamination of groundwater in Bangladesh is said to be geological, extensive studies have not yet been conducted. However, having much geological similarity with West Bengal of India where most of the arsenic contaminated areas are in the region of alluvial formation and it has been recognized that the arsenic is of geological similarity origin, in Bangladesh similar problem may exist in the region of alluvial land. The studies carried out in West Bengal clearly indicated that in the region of alluvial sediment there is existence of pyrite and this pyrite is rich in arsenic. Due to heavy groundwater withdrawal and fluctuation of water table from pre-monsoon and also due to thousands of boreholes, the underground aquifer is aerated and the pyrite decomposes. The acid released due to this decomposition leaches out arsenic from pyrite. This may however, be one of the causes for arsenic contamination in Bangladesh. But there are many areas in south of Bangladesh where water levels remains always at high level and there is no irrigation from groundwater, the presence of arsenic in groundwater are also identified. However, it may be confirmed that the contamination of arsenic in groundwater is originated from the geological sources.

Previously a number of anthropogenic explanations had been made for the occurrence of arsenic in groundwater. While it is possible that some may explain isolated cases of

arsenic contamination, none of the anthropogenic explanations can account for the regional extent of ground water contamination in West Bengal and Bangladesh. There is no doubt that the source of arsenic is of geological in nature. The arsenic content of alluvial sediments in Bangladesh is usually in the range 2-10 mg/kg; only slightly greater than typical sediments (2-6mg/kg). However, it appears that an unusually large proportion of arsenic is present in a potentially soluble form. The high groundwater arsenic concentrations are associated with the gray sands rather than the brown sands.

The groundwater arsenic problem in Bangladesh arises because of an unfortunate combination of three factors:

- ❖ a source of arsenic (arsenic is present in aquifer sediments)
- ❖ mobilization (arsenic is released from the sediments to the groundwater)
- ❖ transport (arsenic is flushed away in the natural groundwater circulation)

## 2.5 CHEMISTRY OF ARSENIC

### 2.5.1 Properties of Arsenic

Arsenic is a chemical element in the nitrogen family (group VA of the periodic table), existing in both grey and yellow crystalline forms. Although some forms of arsenic are metal-like, it is best classified as metalloid and non-metal. It can be manufactured in three allotropic forms, the yellow ( $\alpha$ ) form, the black ( $\beta$ ) form and the steel grey ( $\gamma$ ) form. These have different physical properties. The cubic  $\alpha$ - form is made by condensing the vapor at very low temperatures; its metastable is soluble in  $CS_2$  and consists of tetrahedral  $As_4$  units. The black  $\beta$ - polymorph is iso-structural with black phosphorous (II), also metastable. Both of these modifications revert to the stable  $\gamma$  form, grey or metallic, rhombohedral arsenic, on heating or exposure to light. Gray or metallic arsenic, which is more stable and more common than the softer yellow form, is very brittle, tarnishes in air and sublimates when heated at  $610^{\circ}C$ , i.e., it passes directly into vapor form without melting and reverts to the crystalline solid without liquefying upon cooling the vapor (Encyclopaedia Britannica, 1994). Apart from the

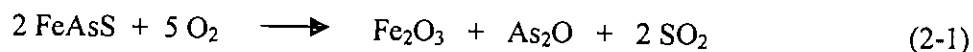
elementary arsenic, where the oxidation state by definition is 0, arsenic is stable in its states +5,+3 and -3. Some important properties of arsenic are listed in Table 2.6.

**Table 2.6: Properties of arsenic (Encyclopedia Britannica, 1994)**

Parameter	Value
Atomic number	33
Atomic weight	74.92158
Melting point (gray form)	814 <sup>0</sup> C at 36 atm
Boiling point	616 <sup>0</sup> C (sublimes)
Density (gray form)	5.73 g/cm <sup>3</sup> at 14 <sup>0</sup> C
Density (yellow form)	2.03 g/cm <sup>3</sup> at 18 <sup>0</sup> C
Specific gravity ( $\alpha$ , $\beta$ , $\gamma$ )	2.026, 4.700, 5.727
Latent heat of fusion	27,740 J/(mol-K)
Latent heat of sublimation	31,974 J/(mol-K)
Oxidation number	-3,0,+3,+5
Electronic configuration	1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup> 3s <sup>2</sup> 3p <sup>6</sup> 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>3</sup> (2-8-18-5)
Electrical resistivity	33.3 $\mu$ ohm cm (273 K)
Crystal system (grey form)	Hexagonal (rhombohedral)
Lattice constant at 26 <sup>0</sup> C	a = 0.376 nm, c = 1.0548 nm
Covalent radius	121 pm
Ionic radius (As <sup>+3</sup> )	69 pm
Metallic radius	139 pm
Hardness (Mohs' scale)	3.5

### 2.5.2 Principal Compounds of Arsenic

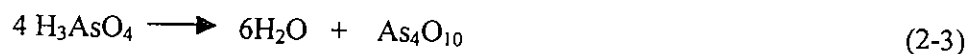
Because arsenic has a range of oxidation states from -3 to +5, it can form a variety of different kinds of compounds. Among the most important commercial compounds are oxides, the principal forms of which are arsenious oxide (As<sub>2</sub>O<sub>3</sub>) and arsenic pentoxide (As<sub>2</sub>O<sub>5</sub>). Arsenious oxide commonly known as white oxide is the material most widely used for the synthesis of arsenic compounds. It is produced as a by-product of the nonferrous metal industry, primarily from the smelting of copper ores. Naturally occurring metal arsenide's realgar and orpiment also convert to the trivalent oxide when roasted in air. The formation of the trioxide by the roasting of a sulfide ore is illustrated in Eq. (2-1).



Elemental arsenic undergoes reaction with oxygen to yield the trioxide as follows:



The trioxide is moderately soluble in water, but dissolves easily in aqueous alkali to produce a solution of arsenic,  $\text{AsO}_4^{3-}$ . It is slightly soluble in polar organic solvents such as alcohols and ethers and insoluble in benzene. The most useful reagent for the synthesis of pentoxide ( $\text{As}_2\text{O}_5$ ) is concentrated nitric acid. The reaction between elemental arsenic and nitric acid gives  $\text{H}_3\text{AsO}_4$ . The controlled dehydration of this acid (Eq.3) gives the pentoxide.



Hypochlorous, hydrochloric and perchloric acids also oxidize the metal or  $\text{As}_2\text{O}_3$  to the pentavalent state. Arsenic pentoxide dissolves readily in water to produce arsenic acid,  $\text{H}_3\text{AsO}_4$ . Arsine ( $\text{AsH}_3$ ) is the best known of the hydrides of arsenic. It is a colorless poisonous gas composed of arsenic and hydrogen. The gas also called arsenic hydride is produced by the hydrolysis of metal arsenides and by the reduction by metals (e.g. zinc) of arsenic compounds in acidic solutions. Other hydrides of arsenic are diarsine ( $\text{As}_2\text{H}_4$ ), diarsine hydride ( $\text{As}_2\text{H}_2$ ), and polymeric diarsine monohydride ( $\text{As}_2\text{H}$ )<sub>x</sub>.

Arsenic pentoxide, the anhydride of arsenic acid ( $\text{H}_3\text{AsO}_4$ ) is very soluble in cold water and dissolves to form a solution of arsenic acid. The free acid can be obtained as a hydrate,  $\text{H}_3\text{AsO}_4 \cdot 0.5 \text{H}_2\text{O}$ , by the evaporation of a cold aqueous solution. Arsenic trioxide is the anhydride of arsenious acid. The solubility of arsenic trioxide in water at  $25^\circ\text{C}$  is 21.6 g/L. The rate of dissolution of trioxide in water is painstakingly slow, sometimes requiring up to 50 h of continuous agitation. The solubility of arsenic trioxide increases greatly and occurs much more rapidly in both acid and alkaline media, Metal salts containing orthoarsenate ( $\text{AsO}_4^{3-}$ ), monohydroarsenate ( $\text{HAsO}_4^{2-}$ ), and dihydrogen arsenate ( $\text{H}_2\text{AsO}_4^-$ ) are known. Diarsenic disulfide ( $\text{As}_2\text{S}_2$ ), but more properly written as  $\text{As}_4\text{S}_4$ , exists in nature as mineral realgar.  $\text{As}_2\text{S}_4$  is normally prepared as an impure material and must be purified by sublimation under an atmosphere of  $\text{CO}_2$ . Diarsenic trisulfide ( $\text{As}_2\text{S}_3$ ), found in nature in orpiment, has been referred to as yellow arsenic sulfide. Diarsenic pentasulfide ( $\text{As}_2\text{S}_5$ ), has been described as brownish-yellow, glassy, amorphous, and highly refractive. When suspended in water and heated, it decomposes into the thermodynamically more stable



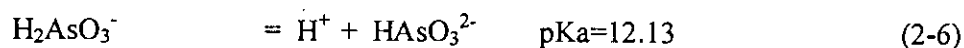
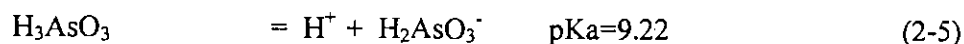
As<sub>2</sub>S<sub>3</sub> and free sulfur. Two binary As-P compounds have been reported. They are As<sub>2</sub>P and AsP. Diarsenic phosphide is black and lustrous and turns brown on exposure to air. AsP is described as a lustrous and red brown powder.

Arsenic also forms numerous organic compounds, as for example, tetramethyldiarsine [(CH<sub>3</sub>)<sub>2</sub>As-As(CH<sub>3</sub>)<sub>2</sub>], used in preparing the common desiccant cacodylic acid. Several complex organic compounds of arsenic have been employed in the treatment of certain diseases, such as amebic dysentery, caused by microorganism. Some of the most important compounds and species of arsenic are shown in Table 2.7. Figure 2.2 (Dahi, 1997) shows a qualitative scale indicating that the toxicity of arsenic compounds varies to a large extent depending upon their chemical form.

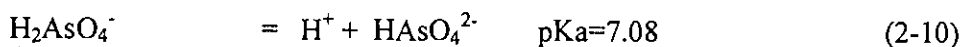
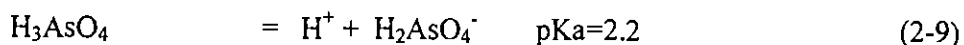
### 2.5.3 Acid-Base Reaction

Apart from the elementary arsenic with oxidation state 0, arsenic is stable in the oxidation states of +5, +3, and -3 (see Table 2.6), but generally found in water only in the trivalent and pentavalent states. The oxides of both As (III) and As(V) are soluble in water. The dissolution implies direct reaction with water, hydration, where the oxides behave like non-metals and exhibit acidic character. Arsenic (III) forms arsenious also called arsonic acid. Arsenic (V) forms the arsenic acid, also called arsinic acid. The two acids dissociate to form respectively arsenite and arsenate ions as shown in the following reactions.

Arsenious Acid Dissociation:

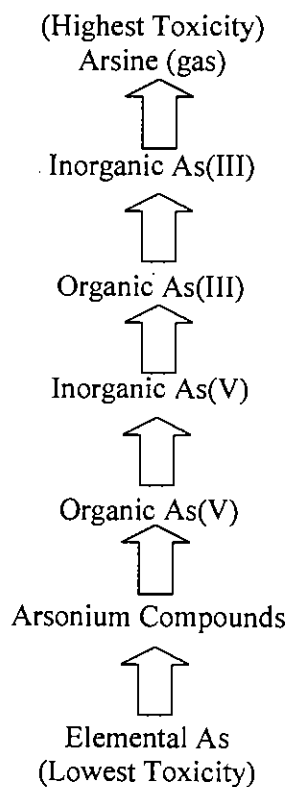


Arsenic Acid Dissociation:



**Table 2.7: Arsenic species and their environmental importance in water**

Compounds	Example	Environmental significance/ Dominant pH region
Arsine Oxidation state: -3	As <sup>3-</sup>	Minor importance [Most toxic As species]
Elemental Arsenic Oxidation state: 0	As	Minor importance [Least toxic As species]
Trivalent Arsenic Oxidation state: +3	As(III)	Dominant under anaerobic condition [10 times more toxic than As(V)]
Arsenite, Inorganic	H <sub>3</sub> AsO <sub>3</sub> H <sub>2</sub> AsO <sub>3</sub> <sup>1-</sup> HAsO <sub>3</sub> <sup>2-</sup> AsO <sub>3</sub> <sup>3-</sup>	pH = 0 – 9 pH = 10 – 12 pH = 13 pH = 14 Important
Methylated As(III) MMAs(III) DMAs(III) TMAs(III) Organo-As(III)	CH <sub>3</sub> As(III)O <sub>2</sub> <sup>2-</sup> (CH <sub>3</sub> ) <sub>2</sub> As(III)O <sup>1-</sup> (CH <sub>3</sub> ) <sub>3</sub> As(III)	Minor importance [Less toxic than inorganic As(III)]
Pentavalent Arsenic Oxidation state: +5		Dominant under aerobic condition [10 times less toxic than As(III)]
Arsenate, Inorganic	H <sub>3</sub> AsO <sub>4</sub> H <sub>2</sub> AsO <sub>4</sub> <sup>1-</sup> HAsO <sub>4</sub> <sup>2-</sup> AsO <sub>4</sub> <sup>3-</sup>	pH = 0 – 2 pH = 3 – 6 pH = 7 - 11 pH = 12 - 14 Important
Methylated As(V) MMAs(V) DMAs(V) TMAs(V) Organo-As(V)	CH <sub>3</sub> As(V)O <sub>3</sub> <sup>2-</sup> (CH <sub>3</sub> ) <sub>2</sub> As(V)O <sub>2</sub> <sup>1-</sup> (CH <sub>3</sub> ) <sub>3</sub> As(V)O	Minor importance [Less toxic than inorganic As(V)]



**Figure 2.2: Arsenic toxicity scale (Dahi, 1997)**

Figure 2.3 shows the predominance diagram of arsenic species as a function of pH. From figure 2.3 it is seen that arsenic acid is stronger than arsenious acid. Within the range of natural waters (particularly groundwater), where pH is usually between 6 to 9, the trivalent inorganic arsenic is found as non-dissociated arsenious acid ( $H_3AsO_3$ ); while the pentavalent arsenic is primarily found as the ionized dihydrogen arsenate ( $H_2AsO_4^-$ ) and mono-hydrogen arsenate ( $HAsO_4^{2-}$ ). The relatively more mobile monomethylated and dimethylated forms are observed in ocean and lake waters, but seldom in groundwater.

As most treatment processes are more capable to remove ions, the trivalent arsenic is more difficult to remove from the water than the pentavalent (Kartinen and Martin, 1995). Probably this ionization of arsenic (V) is also important for the fate of arsenic in the human body. The reduced toxicity of the arsenic (V) may be, to a large extent, due to its ionization, which enables easier control of its intracellular transportation (Dahi, 1997).

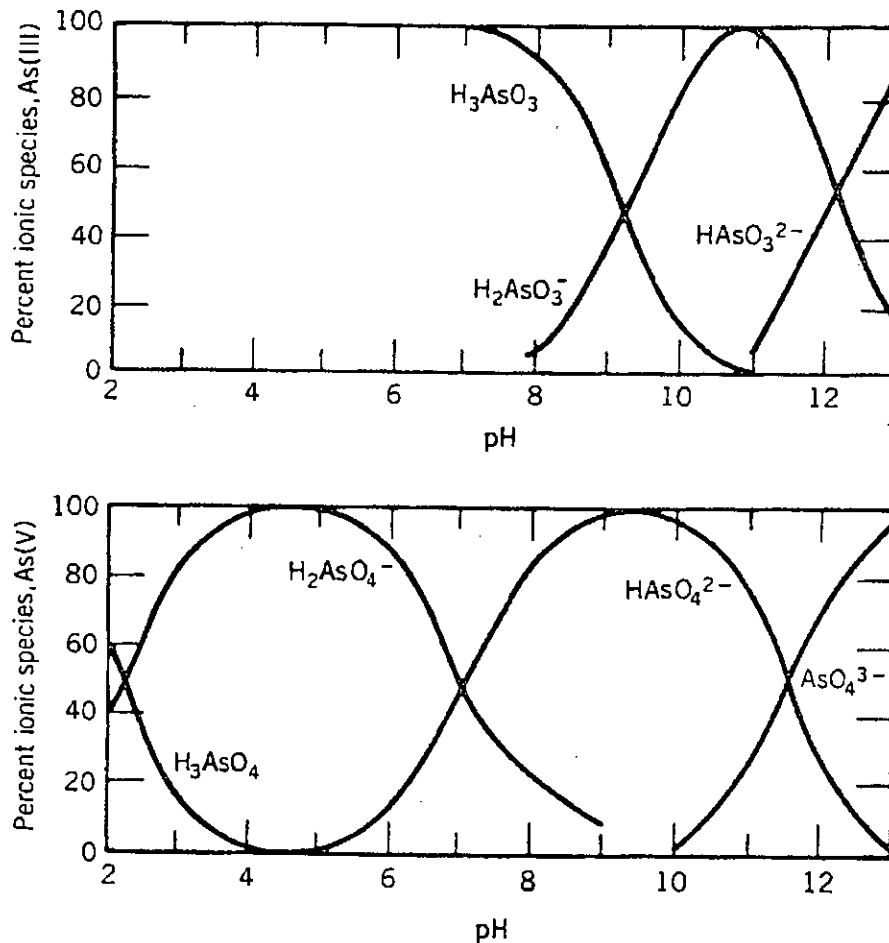


Figure 2.3: Predominance diagram of As(III) and As(V) as a function of pH (Montgomery, 1985)

#### 2.5.4 Redox Reaction

Arsenic is a redox sensitive element. Arsenate [As(V)] and Arsenite [As(III)] are common oxidation states of arsenic in water. The mobility of arsenic is controlled, in large part, by the oxidation-reduction (redox) transformations. The valence in which arsenic exists is related to both pH and the redox potentials,  $Eh$ . The hypothetical electron activity at equilibrium,  $pE$ , is used interchangeably with  $Eh$ . These parameters are related by  $pE = (F/2.3 RT) Eh$ , where  $T$  is the absolute temperature and  $F$  &  $R$  are the Faraday and Gas constants, respectively. Thus at  $25^{\circ}C$ ,  $2.3 RT/F =$

0.059 V and  $pE = Eh/0.059$ . The equation linking arsenic speciation to pH and  $pE$  are readily available, but Eh versus pH diagrams (Fig. 2.4), are the most concise way of presenting this information.

The Eh-pH diagram for arsenic (total concentration  $10^{-5}$  mol/L) in a system including oxygen,  $H_2O$  and sulfur (total concentration  $10^{-3}$  mol/L) is shown in Fig. 2.4. The diagram represents equilibrium conditions of arsenic under various redox potentials. Well-aerated surface waters would tend to induce high Eh values, therefore, any arsenic present should be in the arsenate [As(V)] form. Mildly reducing conditions, such as can be found in groundwater, should produce arsenite [As(III)]. By determining the pH and Eh of water, it is possible to determine which species of arsenic will be prevalent.

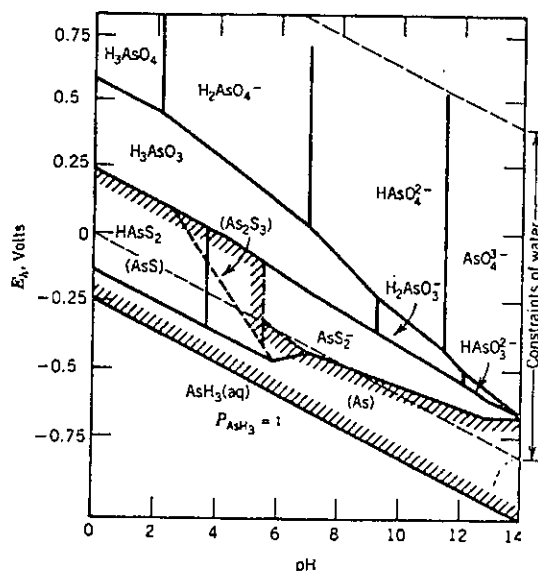


Figure 2.4: The Eh-pH diagram for As at  $25^{\circ}C$  and 1 atm with total arsenic  $10^{-5}$  M and total sulfur  $10^{-3}$  M. Solid species are enclosed in parenthesis in cross-hatched area, which indicates solubility less than  $10^{-5.3}$  M (Montgomery, 1985)

### 2.5.5 Oxidation Reaction

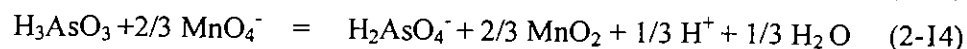
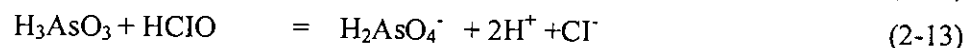
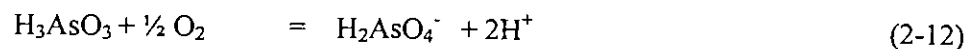
As stated earlier, arsenate is dominant in oxygenated water, while arsenite is dominant in non-oxygenated water. Although thermodynamics can provide an accurate

prediction of possible changes in a given non-equilibrium conditions, they give no insight to the rate at which those changes will occur. While As(III) and As(V) acid-base reactions can be assumed to occur instantaneously, changes between oxidation states require indeterminate time periods in natural waters. For instance, the conversion of As(III) to As(V) in oxygenated water is thermodynamically favored, yet the transformation takes days, weeks or months depending on the specific conditions. The reduction of As(V) to As(III) is similarly kinetically constrained. This is the reason why arsenic (V) can be found in some anoxic waters (Dahi, 1997). This process is however also known to be facilitated through catalysis and bacterial mediation.

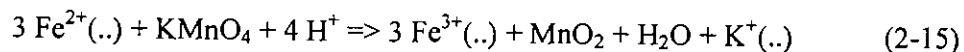
In strongly acidic or alkaline solutions, the presence of copper salts, carbon, certain catalysts and higher temperatures can increase the arsenic oxidation rate (Ferguson and Gavis, 1972). Catalytic oxidation can be achieved by powered active carbon and dissolved oxygen in stirred reactions. The rate of oxidation can be described by the first-order equation.

The effective removal of arsenic from water requires the complete oxidation of As(III), especially if the drinking water standard is low. There are various means of oxidation available, but in drinking water treatment there are important considerations such as the limited list of safe chemicals, the residuals of oxidants, oxidation by-products and the oxidation of other inorganic and organic compounds. In the oxidation processes with dosing of chemicals, effective oxidants are free chlorine, hypochlorite, ozone, permanganate, and hydrogen peroxide/ $\text{Fe}^{2+}$  (Fenton's reagent), but not the chloramines (Frank and Clifford, 1986). These oxidants can directly transform As(III) to As(V) in the absence of oxygen. Chlorine is widely used for oxidation purpose, but may lead to chlorinated by-products, namely trihalomethenes (THMs), from reactions with natural organic matter. Ozone, widely used in surface water treatment for oxidation and disinfection, is quite effective but is not feasible for a specific application with As(III) oxidation. The most feasible oxidants are potassium permanganate and Fenton's reagent ( $\text{H}_2\text{O}_2/\text{Fe}^{2+}$ ). Permanganate oxidizes As(III), Ferrous and manganese ions specifically and quickly. Chlorine and permanganate are able to oxidize As(III) to As(V) within a very short time, e.g., half an hour or even few minutes (Dahi, 1997).

Arsenious acid oxidations by most common oxidants are shown in the following reactions (Dahi, 1997):



Possible reaction with ferrous iron and permanganate is given bellow:



### 2.5.6 Adsorption-Desorption

Adsorption-desorption reactions are very important in determining the mobility of arsenic in nature as well as its removal in many treatment systems. Attachment of arsenic to an iron oxide surface is an example of an adsorption reaction. The reverse of this reaction, arsenic becoming detached from such a surface is an example of desorption. Both arsenate and arsenite adsorb to surfaces of a wide range of solids including iron, aluminum and manganese oxides (e.g., iron oxyhydroxides), and clay minerals.

The strong adsorption characteristics of arsenic has been utilized in its removal from water by coagulation using alum, lime or ferric salts, where arsenic is removed primarily by adsorption onto solid flocs (e.g., aluminum hydroxide or ferric hydroxide) and subsequent precipitation. Arsenate is much more strongly adsorbed and removed than arsenite. Ferric salts have been found to be more effective in removing arsenic than alum on a weight basis and effective over a wider pH range. The strong adsorption of arsenic onto hydrous iron, aluminum and other solids has also been utilized in removing arsenic using a wide range of solid sorption media. These include activated alumina, iron coated sand, granular ferric hydroxide, and a wide range of other materials. Besides arsenic, a number of other ions present in natural water (e.g., phosphate, silicate, sulfate) also have strong affinity for solid surfaces and presence of high concentrations of these ions can reduce removal efficiency of arsenic in adsorption-based treatment systems.

Adsorption-desorption of arsenic onto iron oxide surfaces are important controlling reactions in the subsurface because iron oxides are widespread in the hydro-geologic environment as coatings on other solids, and because arsenate adsorbs strongly to iron oxide surfaces in acidic and near-neutral pH conditions. Desorption of arsenate is favored at higher (i.e., alkaline) pH values. The pH dependence of arsenate adsorption-desorption appears to be related to the change in net charge on iron-oxide surface with pH. The net charge on iron oxide surface changes from positive to negative as pH increases above the "zero-point-of-charge" (pH at which net surface charge is zero). The "zero-point-of-charge" is about 7.7 for goethite (crystalline iron oxide) and about 8.0 for ferrihydrite (amorphous iron oxide). Thus as pH increases above about 8, the net negative surface charge on iron oxides can repel the negatively charged ions such as arsenate. Compared to arsenate, arsenite is less strongly adsorbed by iron oxides. Arsenate and arsenite adsorption-desorption reactions onto other common surfaces are less well characterized.

In Bangladesh arsenic-rich iron oxyhydroxides present in aquifer materials appear to be the primary source of arsenic in groundwater. In the subsurface environment, adsorption-desorption of arsenic onto iron oxyhydroxides is an important mechanism controlling its mobility. As noted earlier, presence of ligands, which may compete with arsenic for adsorption sites on iron oxyhydroxides, e.g., phosphate, silicate and sulfate can also influence the mobility of arsenic in the subsurface, if present in large enough concentrations. Besides oxyanions of molybdenum, selenium and vanadium can also compete with arsenic for adsorption sites.

As a result of pH dependence of arsenic adsorption, changes in groundwater pH can promote adsorption or desorption of arsenic. Similarly, redox reactions can control aqueous arsenic concentration by their effect on arsenic speciation and hence on adsorption-desorption reactions. For example reduction of arsenate to arsenite can promote arsenic mobility because arsenite is less strongly adsorbed than arsenate. It should be noted that in nature bacteria often mediate oxidation-reduction reactions. Finally, structural changes in solid phases at the atomic level can also affect arsenic adsorption-desorption (USGS, 1999). For example, conversion of amorphous ferrihydrite to crystalline goethite may occur gradually over time (Dzombak and Morel, 1990) and this can be accompanied by a decrease in adsorption site density.



This reduction in site density may result in desorption of adsorbed arsenic. Structural changes in other solid phases may also affect arsenic mobility (USGS, 1999).

### 2.5.6.1 Adsorption-Desorption Reactions

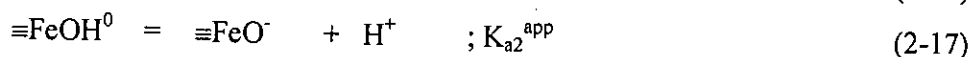
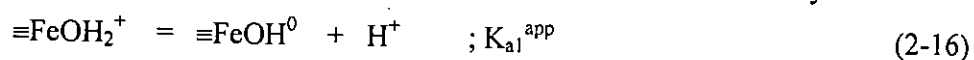
Adsorption-desorption reactions on solid surfaces are usually modeled using surface complexation approach. The fundamental concepts upon which all surface complexation models are based are as follows (Dzombak and Morel, 1990):

- ❖ Sorption on oxides takes place at specific coordination sites.
- ❖ Sorption reactions on oxides can be described quantitatively via mass law equation.
- ❖ Surface charge (on oxides) results from the sorption reactions themselves.

The effect of surface charge on sorption can be taken into account by applying a correction factor derived from the theory to mass law constants for surface reactions.

A number of surface complexation models (SCMs) are available which basically differ in their description of the electrostatic component of sorption. Some important surface complexation models include: (i) constant capacitance model, (ii) diffuse layer model, (iii) triple-layer model, and (iv) generalized two-layer model.

According to the two-layer model, surface ionization reactions resulting in development of surface charge on iron oxide surfaces can be described by:



Here,  $K_{a1}^{\text{app}}$  and  $K_{a2}^{\text{app}}$  are "apparent" equilibrium constants, because they include surface charge effect and hence are dependent on extent of surface ionization. The mass law equations for the above reactions in terms of apparent equilibrium constants can be written as follows:

$$K_{a1}^{\text{app}} = (\equiv\text{FeOH}^0) (\text{H}^+) / (\equiv\text{FeOH}_2^+) \quad (2-18)$$

$$K_{a2}^{\text{app}} = (\equiv\text{FeO}^-) (\text{H}^+) / (\equiv\text{FeOH}^0) \quad (2-19)$$

Although it is impossible to separate experimentally the chemical and electrical contributions to total sorption energy (Dzombak and Morel, 1990), in SCMs these two

are separated theoretically in order to obtain a specific (i.e., chemical) interaction term that does not vary with surface charge. A variable electrostatic interaction term is then added, resulting in a model that accounts for observed variations in effective mass law constants for sorption reactions. For the two layer model (Dzombak and Morel, 1990), we can write:

$$K^{app} = K^{int} \exp(-\Delta ZF\Psi/RT) \quad (2-20)$$

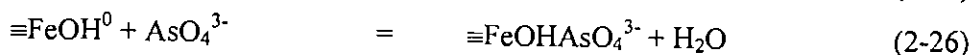
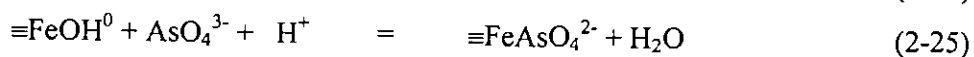
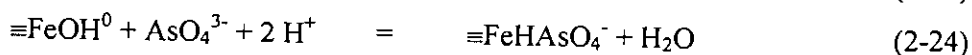
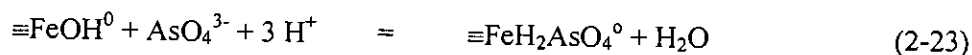
where,  $K^{int}$  is the intrinsic equilibrium constant that does not depend on surface charge, and  $K^{app}$  is the apparent equilibrium constant. Here  $\Psi$  is the surface potential,  $\Delta Z$  is the change in charge of surface species due to sorption reaction, and the exponential term [ $\exp(-\Delta ZF\Psi/RT)$ ] is commonly referred to as electrostatic or coulombic correction factor. Thus the mass law equations given by Eqs. 2-18 and 2-19 can be written as:

$$K_{a1}^{int} \exp(F\Psi/RT) = (\equiv\text{FeOH}^0)(\text{H}^+) / (\equiv\text{FeOH}_2^+) \quad (2-21)$$

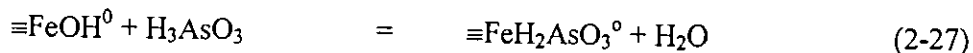
$$K_{a2}^{int} \exp(F\Psi/RT) = (\equiv\text{FeO}^-)(\text{H}^+) / (\equiv\text{FeOH}^0) \quad (2-22)$$

Fitting of the model to experimental data enables determination of intrinsic equilibrium constants for surface reactions. Adsorption-desorption reactions of arsenate and arsenite on hydrous ferric oxide modeled using the generalized two-layer model (Dzombak and Morel, 1990) is shown by the following reactions:

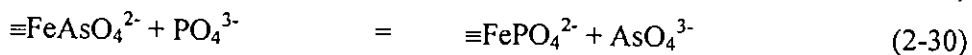
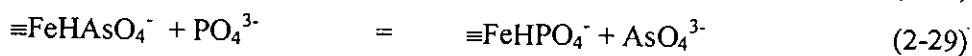
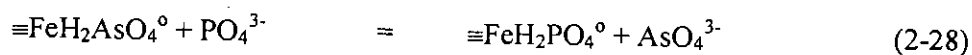
Arsenate Adsorption:



Arsenite Adsorption:



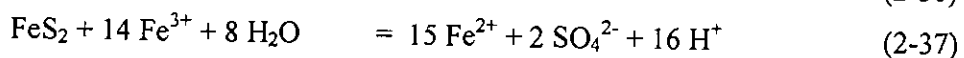
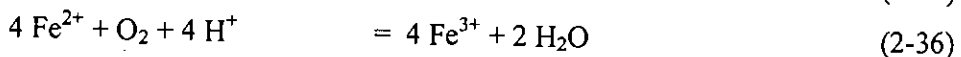
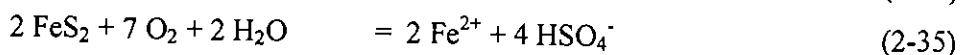
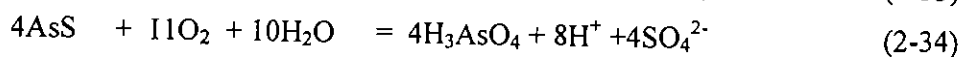
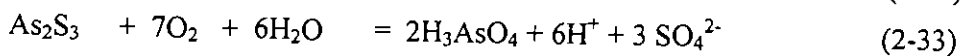
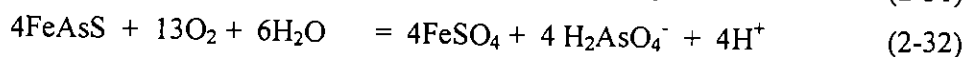
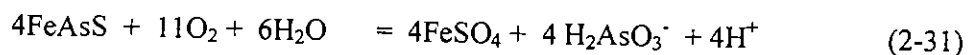
Possible desorption of arsenate in the presence of phosphate ions are shown by the following reactions:



### 2.5.7 Precipitation and Dissolution Reactions

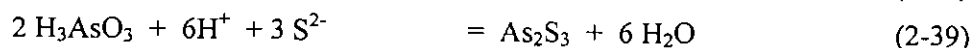
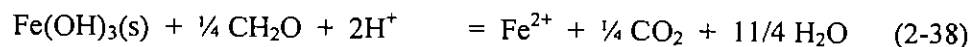
Precipitation-dissolution reactions are important mechanisms controlling mobility of arsenic in the subsurface. Arsenic contained within solid phases, either as a primary structural component of arsenic bearing minerals (e.g., arsenopyrite) or an impurity in any of a variety of solid phases (e.g., pyrite), is released to groundwater when these solid phases dissolve. Similarly, arsenic is removed from groundwater when solid phases containing arsenic precipitate from aqueous phase. As an example, because arsenic often coprecipitates with iron oxide, iron oxides may act as an arsenic source (case of dissolution) or a sink (case of precipitation) for groundwater (USGS, 1999). Besides, solid phase dissolution will contribute not only arsenic contained within that phase, but also any arsenic adsorbed to the solid-phase surface. In Bangladesh, reductive dissolution iron oxyhydroxides and consequent release of adsorbed arsenic could be an important mechanism of arsenic mobilization in the subsurface.

Oxidative dissolution reactions (Bhumba and Keefer, 1994) of arsenopyrite ( $\text{FeAsS}$ ) (Eq. 2-31 & 32), Orpiment ( $\text{As}_2\text{S}_3$ ), (Eq. 2-33) and Reagler ( $\text{AsS}$ ) (Eq. 2-34) are shown below. Oxidative dissolution of pyrite ( $\text{FeS}_2$ ) is shown in Eq. 2-35,36 & 37 (Chowdhury et al., 1998).



The interplay of redox reactions and solid phase precipitation and dissolution may be particularly important with regard to aqueous arsenic and solid-phase iron oxides and sulfide minerals (USGS, 1999). High concentrations of arsenic often are associated with iron oxides and sulfide minerals. Iron oxides frequently dissolve under reducing conditions (e.g., in the presence of organic matter, as shown in Eq. 2-38), but often precipitate under oxidizing conditions. Sulfide minerals generally are unstable under

oxidizing conditions, but may precipitate under reducing conditions (e.g., precipitation of  $\text{As}_2\text{S}_3$ , as shown in Eq. 2-39). Thus, as a result of redox sensitive nature of iron oxides and sulfide minerals, transfer of large amounts of arsenic between these solid phases and neighboring water may result from redox-facilitated precipitation and dissolution reactions (USGS, 1999).



Precipitation of arsenic has been utilized in the removal of arsenic from water. The insolubility of certain inorganic arsenic (V) compounds is the basis of many hydrometallurgical arsenic removal processes (Robins et al., 2001). The most common methods of removing arsenic from aqueous systems are by precipitation as arsenic (III) sulfide, calcium arsenate, or ferric arsenate. The sulfide  $\text{As}_2\text{S}_3$  has its lowest solubility as pH 4, but this solubility is significantly higher than has been generally accepted (Robins et al., 2001). A number of calcium arsenates [e.g.,  $\text{Ca}_3(\text{AsO}_4)_2$ ] can be precipitated from As(V) solutions by lime addition to high pH. Arsenic (V) can also be precipitated from process solutions below about pH 2 with Fe(III) to form ferric arsenate,  $\text{FeAsO}_4 \cdot 2\text{H}_2\text{O}$ . Other solids of interest include ferrous arsenate [ $\text{Fe}_3(\text{AsO}_4)_2 \cdot x\text{H}_2\text{O}$ ], calcium-arsenate-phosphate [ $\text{Ca}_{10}(\text{AsO}_4)_6(\text{PO}_4)_6(\text{OH})_2$ ], and ferric sulfide [ $\text{Fe}_2\text{S}_2$ ]. Some other metal arsenates, such as those of Fe(II), Zn(II), Cu(II) and Pb(II) are less soluble and more stable in the neutral pH region than calcium arsenates and ferric arsenate, but these have not been seriously considered as disposal forms (Robins et al., 2001). Barium (II) arsenate was proposed to as being an extremely insoluble arsenate, but this was shown to be incorrect. More complex compounds, such as the apatite structured calcium phosphate-arsenate have recently been demonstrated to be of low solubility and of appropriate stability for disposal considerations. Ferric arsenite sulfate is also of recent interest and may prove to be useful in stabilizing arsenic (III) (Robins et al., 2001). A number of mixed oxidation state materials [both Fe(II)-Fe(III) and As(III)-As(V)] are currently being studied (Robins et al., 2001).

## 2.6 ARSENIC IN SOIL

In uncontaminated soils, average arsenic concentration varies from about 5 to 6 mg/kg, but this varies among geographic regions. However, significantly high arsenic concentrations have been found in agricultural soil irrigated with arsenic contaminated groundwater. Concentrations as high as 51 mg/kg and 83 mg/kg have been reported in soils of Faridpur and Comilla districts, respectively of Bangladesh (Ullah, 1998). A concentration varying from 1.5 to 19 mg/kg showing higher concentration in the top layers of soil has been found in Samta village in Jessore (Kubota, 1998).

### 2.6.1 Chemical Forms of Arsenic in Soils

The chemical forms of arsenic in soil have been illustrated in Figure 2.5 (Bhumba and Keefer, 1994). The reactions and processes involved in the transformation of different forms of arsenic include oxidation, reduction, adsorption dissolution, precipitation and volatilization. Bacteria and fungi play important roles in chemical transformation of arsenic to volatile arsine gases, which are extremely toxic. Limited data suggest presence of both As(III) and As(V) as well as organic arsenic in agricultural soil and the processes of transformation/bio-transformation of arsenic are not clearly understood. Soil components that contribute to arsenic sorption and retention include oxides of Al, Fe and Mn, soil mineralogy, and organic matter.

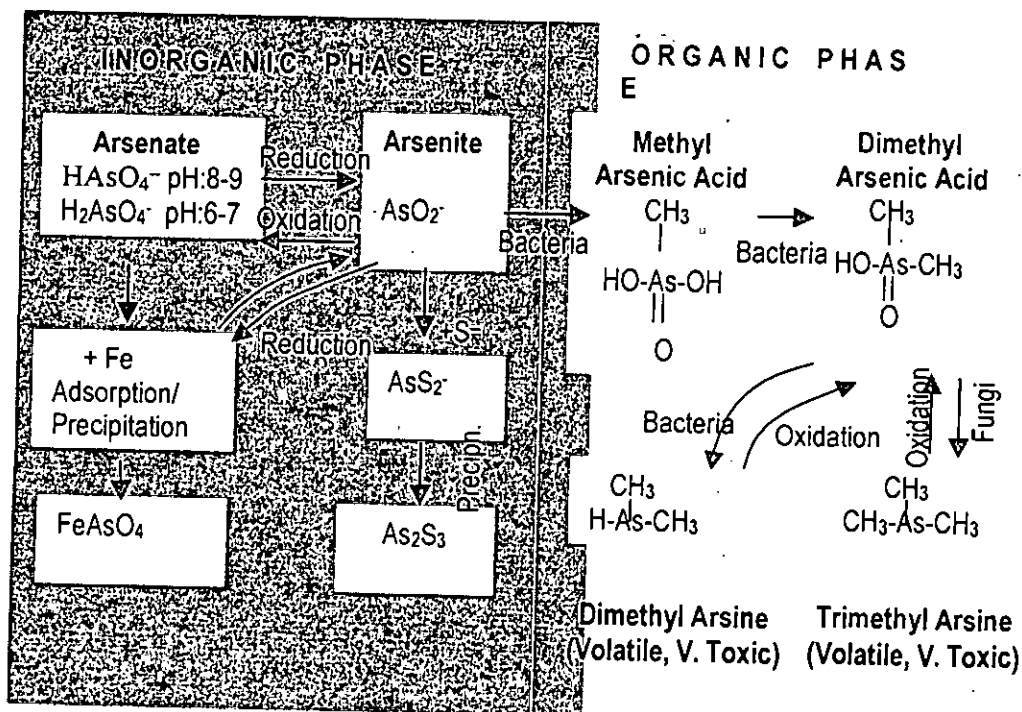


Figure 2.5: Chemical forms of arsenic and their transformations in soils (Bhumba and Keefer, 1994)

## 2.7 ARSENIC IN ATMOSPHERE

Arsenic is widely distributed in nature. It enters into the atmosphere from natural sources that include volcanic activity, wind, erosion, sea spray, forest fires and low temperature volatilization (Cullen & Kenneth, 1989). Smelting operation and fossil fuel combustion contribute anthropogenic sources of arsenic (Eldestein, 1985). These inputs are balanced by removal process such as dry deposition rainfall (Cullen & Kenneth, 1989). Most anthropogenic emissions, such as smelting operation and fossil fuel combustion, consist of  $\text{As}_2\text{O}_3$  (Pacyna, 1987). It was suggested that sea spray would mainly contribute arsenate (Andreae, 1980) – the dominant species in water. However, arsenic speciation studies of rain and snow samples suggest that the ratio of inorganic oxidation states is not reflective of the arsenic source but is governed instead by redox changes in the atmospheric environment (Andreae, 1980). Using the lower arsenic content of rain, it is determined that 75% of the yearly global emissions of arsenic to the atmosphere were from pollution sources (Walsh et al., 1979).

On a global basis, 65% of airborne arsenic is derived from the smelting of base metal ores. Because arsenite, the main component of smelter flue dust, is volatile, a large fraction of the arsenic in the ores is often vented to the atmosphere. It has been estimated that the Ronnskar smelter in northern Sweden used to release 50-115 tonnes of arsenic per year, a gold smelter in Yellowknife, Canada released 19-2600 tonnes of arsenic per year, and the emission from the ASARCO smelter in Tacoma, Washington was about 7-152 tonnes. A pyrite roasting plant in Barreiro/Seixal, Portugal has been known to release 1000-2000 tonnes of arsenic annually to the atmosphere (Nriagu & Pacyna, 1988).

It has been estimated that coal combustion contributes about 11% of the arsenic emission to the atmosphere. The coal burning type of arsenic poisoning is caused by the domestic combustion of coal containing high levels of arsenic (90-2100 mg/kg). The coal is burned inside the home in open pits for daily cooking and corn drying. These practices result in high arsenic concentration in indoor air and arsenic accumulation on the corn. In southern China, these practices resulted in air arsenic concentration as high as 0.04-0.13 mg/m<sup>3</sup>, i.e. 10-40 times higher than the standard. The water-arsenic concentration in that area was less than 0.005 mg/L. The arsenic content in the contaminated corn was in range from 1.5-110 mg/kg, which was 2-15 times higher than the proposed maximum limit value of 0.7 mg/kg (Ren, 1993).

Most of the arsenic in the air is in the form of particulate matter (Cullen and Kenneth, 1989). Less than 10% is present in the vapor phase or on particles small than 0.2 µm (Walsh, 1987; Mackenzie et al., 1979). Analysis of these solids has revealed that they are often considerably enriched (10-1000 times) in arsenic in comparison to the continental crust (Mackenzie et al., 1979).

## **2.8 METHYLATION REACTIONS**

Arsenic taken by mammals is subject to either direct excretion, direct accumulation in some parts of the body (e.g., nails, hair and skin tissue), or to biotransformation in the form of methylation. Besides microbial processes has also been utilized in the bioremediation of arsenic contaminated soils.

Humans are exposed to arsenic mostly in the forms of arsenate/arsenite and organic arsenosugars/arsenobetaines and marine products. The inorganic forms are more toxic than organic forms. Methylation seems to be most important pathway of biotransformation of inorganic arsenic. The inorganic forms are metabolized by consecutive reduction and methylation reactions in humans and mammals to dimethylated arsenic (DMA) (see Figure 2.6), which is excreted into urine (Suzuki, 2002). The toxicity of arsenite is highly dependent on animal species, which in turn depends on the differences in the metabolism shown in Figure 2.6. The methylation process leading to DMA was believed to be the detoxification pathway, but recent studies document it as toxification pathway (Suzuki, 2002). Research works are being carried out to better understand these processes.

Several fungi and bacterial species have been demonstrated to methylate inorganic arsenic by an initially reducing arsenate fraction to arsenite, which then is methylated and released to the environment (Kartinen and Martin 1995). However, the concentration of methylated arsenic in the natural waters, whether ground or surface, is normally low. This is because the methylated arsenic is taken up by the biota where it undergoes metabolic conversion into organic arsenical. Compounds like arsenobetaine and arsenocholine, can thus be found in fish and crustaceans. These compounds do not have any toxicological significance. Upon consumption by man they are directly excreted through urine without any biotransformation (Vahter, 1994).

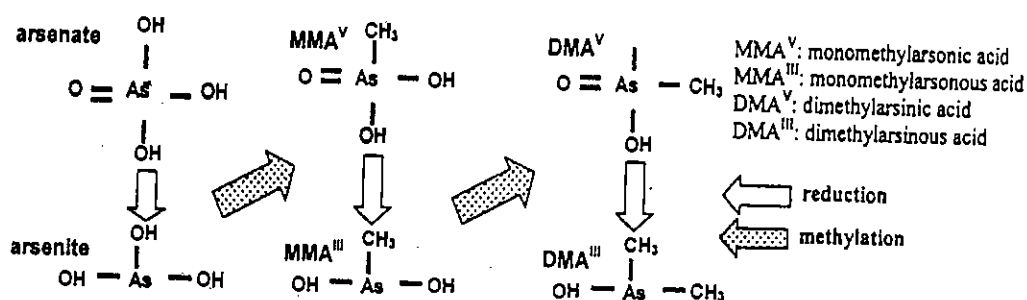


Figure 2.6: Reduction and methylation reactions in the metabolism of arsenic (Suzuki, 2002)



## **2.9 HEALTH EFFECT OF ARSENIC**

### **2.9.1 Introduction**

Arsenic is called the king of all poisons. The fatal dose of arsenic is 125 mg. It means, one will die following acute poisoning if he or she takes such extent of arsenic. Arsenic is four times more poisonous than mercury. The fatal dose of mercury is 500 mg. Arsenic enters in the human bodies through respiration from the air and through mouth from food and drink. The effect of arsenic after it entered by breathing or meals and drinks depends on the amount and physio-chemical states.

### **2.9.2 Toxicity of Arsenic**

According to consumption of arsenic in human bodies, its toxicity can be divided in three categories:

- ❖ Acute toxicity
- ❖ Sub-acute toxicity
- ❖ Chronic toxicity

Chronic toxicity was observed in arsenic polluted area in Bangladesh.

#### **2.9.2.1 Acute Toxicity**

Acute arsenic poisoning in human being is usually homicidal, suicidal or accidental. Smallest recorded fatal dose is about 130 mg and death occurs after a fatal dose in 12 to 48 hours and symptoms appear within half an hour. Patient first of all complains of a feeling of faintness, nausea and severe burning pain in the throat and stomach with increased salivation, intense thirst and severe vomiting are constant symptoms. There may be severe cramps in calf muscles. Skin becomes cold and clammy, face becomes cyanosed, eyes are shrunken and pulse is feeble, irregular and frequent. The respiration becomes laboured and lastly convulsion and coma precede death.

### **2.9.2.2 Sub-acute Toxicity**

This is a condition where arsenic is administered in a small dose at repeated interval. The symptoms are at first dyspepsia, cough and tingling in the throat, then vomiting and purging with abdominal pain and tenesmus with foul tongue, dry and congested throat and a feeling of depression and languor. The motion is bloody. The symptoms of neuritis are pronounced. Severe cramps on the muscles which are tender on pressure. Patient become restless and cannot sleep, ultimately collapse sets in and results in death.

### **2.9.2.3 Chronic Toxicity**

The clinical manifestation due to chronic arsenic toxicity develop very insidiously after six months to two years or more depending on the amount of arsenic intake. Chronic toxicity of arsenic is in terms of the organ and system affected, the skin, nervous system, liver, cardiovascular system and respiratory tract. Long-term effects of arsenic poisoning lead to malignancy.

### **2.9.3 Health Effects and Symptoms**

In a population drinking arsenic contaminated water, a great variety of specific as well as non-specific symptoms may be observed. Table 2.8 lists some of the effects of arsenic reported to be due to exposure through drinking water.

**Table 2.8: Toxicological effects due exposure to high arsenic concentration in drinking water (WHO, 1996, Khan, 1997)**

Effect	Symptoms	Remarks
Blackfoot Disease Arsenical dermatosis	Dermal lesion, Peripheral neuropathy Keratosiis, Hyperkeratosis, Hyperpigmentaion	May necessitate operation
None specific	Nausea, Abdominal Pain, Diarrhoea, Vomiting, Conjunctivitis, Oedema.	Mainly due to acute intoxication
Pregnancy disorders	Spontaneous abortions, miscarriages	-
Heart Disease	Coarctations of aorta, Cardiovascular disturb.	Among children
Cancer	Bladder, Kidney, Skin & Lungs, Liver & Colon	-
Mortality	-	Mainly due to cancer

## 2.10 ARSENIC CONTAMINATION IN BANGLADESH

Presence of high concentrations of arsenic in tubewell water in excess of acceptable limit has become a major concern in Bangladesh. Arsenic contamination of groundwater was first detected in Bangladesh in 1993 by DPHE in Chapai Nawabganj in the far west of Bangladesh in a region adjacent to an area of West Bengal which has been found to be extensively contaminated since 1988. Extensive contamination in Bangladesh was confirmed in 1995 when additional surveys showed contamination of shallow and deep tubewells across much of southern and central Bangladesh. At the same time, cases of chronic arsenicosis were being recognized by health professionals.

The oldest known analyses in groundwater were for three municipal tubewells in Dhaka city in 1990. All were below detection limits, and did not attract attention. Recent analyses have confirmed the absence of arsenic contamination in Dhaka city. Since 1995, data pointing to the extensive contamination of Bangladesh groundwater have been collected by a large number of organizations. Extensive arsenic surveys carried out by Dhaka Community Hospital in association with in 1997 to 1999 were crucial in raising public awareness to the extent of contamination (DCH, 2000). These involved the analysis of water samples collected from homes of arsenic affected

patients and confirmed the seriousness of arsenic problem. Classic symptoms of chronic arsenic exposure were becoming increasingly apparent and Bangladesh patients visited West Bengal in order to seek a 'cure' for their illness.

There have been numerous reports of arsenic problem in the ground water sources in various part of Bangladesh with severe condition prevailing in the south, south west, north western and central zones. However until now, the ground water in the north-western zone of Bangladesh is relatively free of arsenic.

The numbers of patients showing symptoms of arsenic toxicity are increasing, as results from studies are available. The population exposed to arsenic contamination in excess of 50 ppb in Bangladesh Standard by the contaminated tubewells has been estimated as 29.05 million people. Department of Public Health Engineering, British Geological Survey and Mott MacDonald Ltd (MML) in Phase-1 studies estimated that the population exposed to arsenic contamination would lie in the range 185 - 22.7 million (DPHE, BGS, and MML, 1999). However, the BGS-DPHE studies finally gave two estimates of population exposure based on projected population of 125.5 million in 1999 (BGS and DPHE, 2001). The estimates of total population exposed to arsenic concentration above 50 and 10 ppb using kriging method were 35.2 million and 56.7 million respectively. Based on upazila statistics the exposure levels to arsenic concentration exceeding 50 and 10 ppb were 28.1 million and 46.4 million respectively. School of Environmental Studies, Jadavpur University (SOES, JU), Calcutta and Dhaka Community Hospital (DCH), Dhaka estimated that the populations exposed to above 50 and 10 ppb in 43 districts in Bangladesh were 25 million and 51 million respectively (SOES and DCH, 2000).

### **2.11 AN OVERVIEW: LEACHING OF ARSENIC FROM WASTES**

Adsorption-desorption reactions are very important in determining the mobility of arsenic in wastes of many treatment systems. Attachment of arsenic to an iron oxide surface is an example of an adsorption reaction. The reverse of this reaction, arsenic becoming detached from such a surface is an example of desorption. Desorption of arsenate is favored at higher (i.e., alkaline) pH values. The pH dependence of arsenate

adsorption-desorption appears to be related to the change in net charge on iron-oxide surface with pH. The net charge on iron oxide surface changes from positive to negative as pH increases above the "zero-point-of-charge" (pH at which net surface charge is zero). The "zero-point-of-charge" is about 7.7 for goethite (crystalline iron oxide) and about 8.0 for ferrihydrite (amorphous iron oxide). Thus as pH increases above about 8, the net negative surface charge on iron oxides can repel the negatively charged ions such as arsenate.

As a result of pH dependence of arsenic desorption, changes in groundwater pH can promote desorption of arsenic. Structural changes in solid phases at the atomic level can also affect arsenic adsorption-desorption (USGS, 1999). For example, conversion of amorphous ferrihydrite to crystalline goethite may occur gradually over time (Dzombak and Morel, 1990) and this can be accompanied by a decrease in adsorption site density. This reduction in site density may result in desorption of adsorbed arsenic. Structural changes in other solid phases may also affect arsenic mobility (USGS, 1999).

## CHAPTER - 3

### SHORT-TERM LEACHING OF ARSENIC

#### 3.1 INTRODUCTION

The arsenic crisis of Bangladesh has led to a massive poisoning of groundwater and disruption of public health. A large number of initiatives have been taken and different technologies have been developed in Bangladesh for arsenic removal from groundwater since 1993 when arsenic in groundwater was first detected in the district of Chapai Nawabganj. A number of studies (Badruzzaman, 2003) have been conducted to develop suitable techniques to treat arsenic laden groundwater. Most of these are aimed at developing household and small community level units. Although removal of arsenic from drinking water is possible through highly sophisticated treatment methods, they are often expensive and are only applicable at a centralized treatment plants used in a distribution network (Badruzzaman, 2003). At present, the Government of Bangladesh (GoB), the Non-Government organizations (NGOs), the donor agencies, private entrepreneurs, etc. are promoting locally and internationally developed household and community level arsenic removal units.

All the arsenic removal units generate some form of arsenic-rich wastes, because almost all the materials used for filtration get clogged after prolonged use. Some of these units may be regenerated by washing with water or other reagents. However, after certain time the filter column has to be discarded. These spent filter media are likely to contain very high level of arsenic following continuous accumulation. Also, some of the arsenic removal units generate liquid sludge containing high level of arsenic associated with iron flocs. In the absence of any clear guidance for safe disposal of wastes generated from arsenic removal units, such wastes are often disposed in the open environment. Indiscriminate disposal of these spent media or sludge is likely to contaminate the surface water sources or may leach arsenic, which may be transported to the underlying aquifer. Concerns have been raised regarding safe disposal of these wastes and possible contamination of environment from arsenic present in the wastes. However, there is only limited data on the qualities and

characteristics of these wastes (e.g., Hamel and Zinia, 2001, Badruzzaman, 2003, Islam et. al, 2003) and possible mobilization of arsenic from these wastes. This Chapter focuses on determining whether the present disposal methods of sludge generated and spent filter media are safe and arsenic does not return to the nature and consequently contaminates the environment.

## **3.2 ASPECTS OF LEACHING**

### **3.2.1 Short-term Leaching of Arsenic**

Leaching of arsenic indicates the relative stability of arsenic associated with wastes generated from different arsenic removal units. Short-term leaching is determined following TCLP. Usually, this test is used to evaluate the leaching potential of the solid waste disposed in landfill sites. This procedure involves an aggressive acetic acid leaching at a lower pH following  $18 \pm 2$  hours agitation at a speed of  $30 \pm 2$  rpm. In this process arsenic rich wastes are stimulated and leaching occurs within a very short period of time. So, this type of leaching is termed as short-term leaching. These tests may not provide quantitative leach rates expected under disposal conditions but instead provide the relative reactivity of different waste products under similar conditions.

### **3.2.2 Leaching Test Options**

There are two aspects that can be considered for leaching test of arsenic waste:

- Screening for reactivity of different waste types; and
- Kinetic leach testing of a waste under expected disposal conditions

The reactivity of a particular waste, defined as the leachability of arsenic from the waste, may be dependent on the particular technology in question. Simple screening level leach tests can be conducted on the waste products to assess the relative reactivity of the wastes. These tests may not provide quantitative leach rates expected

under disposal conditions but instead provide the relative reactivity of different waste products under similar conditions. These tests can be used to assess the safest 'waste type' for disposal. For example, arsenic bound to aluminum may be less leachable than arsenic bound to iron in a reducing environment, and arsenic co-precipitated with an iron floc may be less leachable than arsenic sorbed to a rusty metallic iron surface.

Potential management options for waste disposal must be considered and tested prior to distribution of the treatment systems. It may be understood that the waste is benign and can be readily disposed according to the end users discretion. This would need to be investigated and kinetic leach rates for arsenic must be conducted to demonstrate that the waste will pose low risk to human and environmental health. Other waste products may require special disposal conditions and this management options should be defined and tested in a manner that includes expected or measured geochemical conditions. Kinetic leach testing of sludge would provide leach rates and loading estimates (mass arsenic leached per kg of waste per unit time) and this data can be used to assess the potential for environmental and human health impacts for the selected waste management options. For underwater disposal, the tests should include expected chemical characteristics of sediment, sediment pore water and surface water within the disposal site.

### **3.2.3 Waste Reactivity Screening**

The main objective for conducting waste reactivity screening is to determine the relative stability of arsenic associated with wastes that result from different technologies. Typically, this type of screening involves TCLP (USEPA) or Reg. 347 (Ontario) testing. Indeed, many proponents have used the TCLP test to determine whether the waste generated is 'leachate toxic'. The protocol for this procedure involves subjecting a 100 g solid waste sample to;

- Aggressive acetic-acid leach at pH near 5;
- Solution volume of 2 liters; and
- Twenty hours agitation at 30 revolutions per minute (end over end)



Although this test provides a known protocol for comparing different waste types, it may not be applicable to test arsenic laden waste. For example, arsenic sorbed onto hydrous ferric oxy-hydroxides, is less leachable at pH 5 relative to near neutral pH values (i.e., pH 7) or alkaline pH values. Therefore, TCLP testing at pH 5 would show arbitrarily low leaching rates for ferric oxy-hydroxide wastes and is an inappropriate test for comparing waste types. However, modification of the leaching chemicals used for the TCLP can be made to simulate more the expected leaching conditions and provide an appropriate assessment of the potential for arsenic reactivity amongst different waste types. It is likely that wastes may be subject to permanent or temporary on-land disposal, sub-aqueous disposal or sub-aqueous and anoxic disposal conditions. These conditions can be used for screening level leaching tests.

Suggested leaching test protocols are:

- i) Modified TCLP test – using simulated rainwater to replace acetic acid (for assessment of leachable waste load on-land during the dry season).
- ii) Modified TCLP test – using simulated pond water to replace acetic acid (leaching of waste deposited in a surface water body but not buried in organic mud).
- iii) Modified TCLP test – using hydroxylamine hydrochloride (20 ml of 0.04 M  $\text{NH}_2\text{OH}\cdot\text{HCl}$  per 1 g solid in a water bath at  $96^\circ\text{C}$  for 6 hours) to replace acetic acid to simulate leaching under conditions where reductive dissolution may occur and subjects the waste to reductive dissolution (buried in surface sediments).
- iv) MARG Tests – This procedure was developed to assess solubility behavior of arsenical materials over an extended pH range (Swash and Monhemius, 1994). The pH of the solutions can be adjusted with NaOH or  $\text{H}_2\text{SO}_4$  to pH values of 5, 6, 7, 8 and 9. A liquid to solid ratio of 20:1 is used. The test samples are manually shaken once per day (pH tested and readjusted, if necessary) for a period of 7 days, after which solution samples are taken and submitted for chemical (arsenic) analysis.

Tests 1 and 2 are modified versions of typical 'wash' or SWEP tests that would show the amount of arsenic that is poorly bound to the waste and would leach during

handling, temporary storage or immediate placement in a local pond. Test 3 provides leaching characteristics that may be influenced by reductive dissolution and would simulate leaching after long-term disposal in surface water sediments. Finally, Test 4 will show the pH dependence of leaching from the various wastes. It is expected that the surface water, sediment pore water and precipitation have different pH conditions and this test will provide information to assess the effect of various pH conditions expected in Bangladesh on leaching of arsenic from wastes.

The results of these tests should be provided as mass Arsenic leached per mass of arsenic in the waste. The data can, therefore, be used to compare leaching characteristics of selected wastes under similar conditions.

### **3.3 TOXICITY CHARACTERISTIC LEACHING PROCEDURE (TCLP)**

#### **3.3.1 Scope and Application**

The TCLP is designed to determine the mobility of both organic and inorganic analytes present in liquid, solid and multiphase wastes. Following criteria is followed in determining whether the TCLP is required or not:

- a) If a total analysis of the waste demonstrates that individual analytes are not present in the waste, or that they are present but at such low concentrations that the appropriate USEPA regulatory levels could not possibly be exceeded, the TCLP need not be run.
- b) If an analysis of any of the liquid fractions of the TCLP extract indicates that a USEPA regulated compound is present at such high concentrations that, even after accounting for dilution from the other fractions of the extract, the concentration would be above the regulatory level for that compound, then the waste is hazardous and it is not necessary to analyze the remaining fractions of the extract.
- c) If an analysis of an extract obtained using a bottle extractor shows that the concentration of any USEPA regulated volatile analyte exceeds the regulatory level for that compound, then the waste is hazardous and extraction using the ZHE (Zero Headspace Extractor) is not necessary. However, extract from a bottle

extractor cannot be used to demonstrate that the concentration of volatile compounds is below the regulatory level.

### 3.3.2 Summary of the Method

- i) For liquid wastes (i.e., those containing less than 0.5% dry solid material), the wastes, after filtration through a 0.6 to 0.8  $\mu\text{m}$  glass fiber filter, is defined as the TCLP extract.
- ii) For wastes containing greater than or equal to 0.5% solids, the liquid, if any, is separated from the solid phase and stored for later analysis; the particle size of the solid phase is reduced, if necessary. The solid phase is extracted with an amount of extraction fluid equal to 20 times the weight of the solid phase of the waste. A special extractor vessel is used when testing for volatile analytes. Following extraction, the liquid extract is separated from the solid phase by filtration through a 0.6 to 0.8  $\mu\text{m}$  glass fiber filter.
- iii) If compatible (i.e., multiple phases will not form on combination), the initial liquid phase of the waste is added to the liquid extract, and these are analyzed together. If incompatible, the liquids are analyzed separately and the results are mathematically combined to yield a volume-weighted average concentration.

### 3.3.3 Reagents and Acids

Reagent grade chemicals should be used in all tests. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination. The following acids are essential in conducting TCLP:

- a) Hydrochloric acid (1 N), HCl, made from ACS reagent grade;
- b) Nitric acid (1 N),  $\text{HNO}_3$ , made from ACS reagent grade;
- c) Sodium hydroxide (1N), NaOH, made from ACS reagent grade;
- d) Glacial acetic acid,  $\text{CH}_3\text{CH}_2\text{COOH}$  ACS reagent grade.

### 3.3.4 Extraction Fluid

Extraction fluid # 1 is prepared by adding 5.7 ml glacial  $\text{CH}_3\text{CH}_2\text{COOH}$  to 500 ml of reagent water and 64.3 ml of 1 N NaOH, and diluted to a volume of 1 liter. When correctly prepared, the pH of this fluid should be  $4.93 \pm 0.05$ . Extraction fluid # 2 is prepared by diluting 5.7 ml glacial  $\text{CH}_3\text{CH}_2\text{COOH}$  with reagent water to a volume of 1 liter. When correctly prepared, the pH of this fluid should be  $2.88 \pm 0.05$ .

These extraction fluids should be monitored frequently for impurities. The pH should be checked prior to use to ensure that these fluids are made up accurately. If impurities are found or the pH is not within the above specifications, the fluid should be discarded and fresh extraction fluid be prepared. TCLP extract should be prepared for analysis and analyzed as soon as possible following extraction. Extracts or portion of extracts for metallic analyte determinations must be acidified with nitric acid to a  $\text{pH} < 2$ , unless precipitation occurs. Extracts should be preserved according to the guidance given in the individual analysis methods.

### 3.3.5 Preliminary Evaluation for TCLP

Preliminary TCLP evaluation is performed on a minimum of 100 gm aliquot of waste. This aliquot may not actually undergo TCLP extraction. These preliminary evaluations include:

- i) Determination of the percent solids;
- ii) Determination of whether the waste contains insignificant solids and is, therefore, its own extract after filtration;
- iii) Determination of whether the solid portion of the waste requires particle size reduction;
- iv) Determination of which of the two extraction fluids is to be used for the nonvolatile TCLP extraction of the waste.

### **3.3.6 Preliminary Determination of Percent Solids**

Percent solids is defined as that fraction of a waste sample (as a percentage of the total sample) from which no liquid may be forced out by an applied pressure as described below.

If the waste obviously yields no liquid when subjected to pressure filtration (i.e., is 100% solids) the extraction procedure should be followed without delay. If the sample is liquid or multiphasic, liquid / solid separation to make a preliminary determination of percent solids is required.

If the percent dry solids is less than 0.5%, the multiphasic analysis method should be followed for nonvolatile TCLP. Otherwise, if the percent dry solids is greater than or equal to 0.5%, and if the nonvolatile TCLP is to be performed, particle size reduction analysis should be performed with a fresh portion of waste. Then the appropriate extraction liquid should be determined.

### **3.3.7 Determination of Appropriate Extraction Fluid**

If the solid content of the waste is greater than or equal to 0.5% and if the sample will be extracted for nonvolatile constituents, the appropriate fluid for the nonvolatile extraction should be determined as below:

Weigh out a sub-sample of the solid phase of the waste, reduce the solid (if necessary) to a particle size of approximately 1 mm in diameter or less, and transfer 5.0 grams of the solid phase of the waste to a 500 ml beaker. Add 96.5 ml of reagent water to the beaker, cover with a watch glass, and stir vigorously for 5 minutes using a magnetic stirrer. Measure and record the pH. If the pH is <5.0, extraction fluid # 1 should be used. If the pH is >5.0, add 3.5 ml of 1 N HCl, slurry briefly, cover with a watch glass, heat to 50<sup>0</sup> C, and hold at 50<sup>0</sup> C for 10 minutes. Let the solution cool to room temperature and record the pH. If the pH is <5.0, use extraction fluid # 1. If the pH is >5.0, use extraction fluid # 2.

### 3.3.8 TCLP for Non-volatiles

A minimum sample size of 100 grams (solid and liquid phases) is recommended. In some cases, a larger sample size may be appropriate, depending on the solids content of the waste sample, whether the initial liquid phase of the waste will be miscible with the aqueous extract of the solid, and whether inorganics, semivolatile organics, pesticides, and herbicides are all analytes of concern. Enough solids should be generated for extraction such that the volume of TCLP extract will be sufficient to support all of the analyses required. If the amount of extract generated by a single TCLP extraction will not be sufficient to perform all of the analyses, more than one extraction may be performed and the extracts from each combined and aliquoted for analysis.

If the waste will obviously yield no liquid when subjected to pressure filtration (i.e., is 100% solids), Weigh out a sub-sample of the waste (100 grams minimum) and extraction should be done directly as described later. Otherwise, if the sample is liquid or multiphase, liquid / solid separation is required. This involves the filtration as described earlier in the pre-evaluation steps.

Following filtration, if required, the material in the filter holder is defined as the solid phase of the waste, and the filtrate is defined as the liquid phase. The filtrate should be weighed. The liquid phase may now be either analyzed (as described later) or stored at 4° C until time of analysis.

If the waste contains <0.5% dry solids then it should be considered the TCLP extract and be preserved for analysis by following the instruction described later. However, if the percent of solids is >0.5% then it should be determined whether particle size reduction is necessary. If not, then TCLP extraction procedure should be followed. Amount of extraction fluid needs to be added in the extraction vessels is determined by

Wt. of extraction fluid =  $[20 * \% \text{ solids} * \text{wt. of waste filtered}] / 100$

This amount of appropriate extraction fluid is slowly added to the extractor vessel. It is then closed tightly, secured in rotary agitation device, and is rotated at  $30 \pm 2$  rpm for  $18 \pm 2$  hours. Ambient temperature (i.e., temperature of room in which extraction takes place) shall be maintained at  $23 \pm 2$  during the extraction period. It is important to note that as agitation continues, pressure may build up within the extractor bottle for some types of wastes (limed or calcium carbonate containing waste may evolve gases such as carbon dioxide). To relieve excess pressure, the extractor bottle may be periodically opened (e.g., after 15 minutes, 30 minutes, and 1 hour) and vented into a hood.

Following the  $18 \pm 2$  hours extraction, the material in the extractor vessel should be separated into its component liquid and solid phases by filtering through a new glass fiber filter. If compatible (i.e., multiphasic phases will not result on combination), the filtered liquid resulting from the above step should be combined with the initial liquid phases of the waste obtained. This combined liquid is defined as the TCLP extract.

### **3.3.9 Analysis of TCLP Extract**

Following collection of the TCLP extract, the pH of the extract should be recorded. Immediately aliquot and preserve the extract for analysis. Metals aliquots must be acidified with nitric acid to  $\text{pH} < 2$ . If precipitation is observed upon addition of nitric acid to a small aliquot of the extract, then the remaining portion of the extract for metal analyses shall not be acidified and the extract shall be analyzed as soon as possible. All other aliquots must be stored under refrigeration ( $4^{\circ}\text{C}$ ) until analyzed. The TCLP extract should be prepared and analyzed according to appropriate analytical methods. TCLP extracts to be analyzed for metals should be acid digested except in those instances where digestion causes loss of metallic analytes. If an analysis of the undigested extract shows that the concentration of any regulated metallic analyte exceeds the regulatory level, then the waste is hazardous and digestion of the extract is not necessary. However, data on undigested extracts cannot be used to demonstrate that the waste is not hazardous. If the individual phases are to be analyzed separately, determine the volume of the individual phases (to  $\pm 0.5\%$ ),

conduct the appropriate analyses, and combine the results mathematically by using a simple volume-weighted average:

$$\text{Final analyte concentration} = [V_1C_1 + V_2C_2] / [V_1 + V_2]$$

Where

$V_1$  = The volume of the first phase (L)

$C_1$  = The concentration of the analyte of concern in the first phase (mg/L)

$V_2$  = The volume of the second phase (L)

$C_2$  = The concentration of the analyte of concern in the second phase (mg/L).

### **3.4 MATERIALS AND METHODS**

#### **3.4.1 Collection of Treatment Waste Samples**

At the beginning of the study, wastes generated from different types of arsenic removal systems have been collected for conducting TCLP as well as column experiment (discussed in the following chapter) in order to evaluate leaching characteristics of treatment wastes. Broadly, the arsenic rich waste materials, collected from different types of arsenic removal units, can be classified into two categories:

- wastes generated from coagulation-based arsenic removal systems, and
- wastes generated from arsenic removal systems based on adsorptive filtration and other techniques (e.g., ion exchange).

The waste belonging to the first category is primarily liquid or semi-solid containing coagulated flocs of alum or iron salt, rich in arsenic. Currently, disposal of such wastes in cow-dung bed is widely practiced. It has been suggested that biochemical processes in cow-dung bed transform inorganic arsenic and release it into the air. However, data supporting such processes are scant. The waste belonging to the second category is primarily spent adsorption / ion exchange media, rich in arsenic. With increasing use of arsenic removal units, concerns have been raised regarding



safe disposal of these wastes and possible contamination environment from arsenic present in the wastes. However, there is only limited data on the quantities and characteristics of these wastes (e.g., Hamel and Zinia, 2001) and possible mobilization of arsenic from these wastes.

In this study, both of the above mentioned wastes have been collected. Arsenic rich wastes, generated from coagulation-based arsenic removal systems, have been collected from two different types of ARUs. These are:

- STAR bucket treatment unit (based on iron coagulation), and
- BUET-UNU bucket treatment unit (based on ferric chloride coagulation)

Wastes from the first type of ARU have been collected from Laksmipur district, where a number of such ARUs are currently in operation. Two types of samples have been collected from the BUET-UNU bucket treatment units, slurry from the upper bucket and sand filter media from the lower bucket. These wastes have been collected from the BUET-UNU field site at Adda village in Barura thana of Comilla district.

Arsenic rich wastes have also been collected from three different types of filtration-based arsenic removal systems. These are:

- “Shapla” filter (based on filtration through iron-coated brick chips),
- BUET-UNU iron-coated sand filtration units and
- SIDKO granular ferric hydroxide units.

Spent media from “Shapla” filter have been collected from Ashwadia union in Noakhali Sadar Upazila of Noakhali District. A number of such ARUs were installed in this region and are currently in operation. Spent iron-coated sand media have been collected from Adda village in Barura Thana of Comilla district. SIDKO filter media have been collected from Manikganj district, where a large arsenic treatment plant is currently in operation.

### **3.4.2 Estimation of Treatment Waste Generation**

Quantity of wastes generated from arsenic removal processes was evaluated for above mentioned arsenic removal systems. In the BUET-UNU bucket treatment unit, a chemical packet (containing ferric chloride, potassium permanganate and bleaching powder) is added to 25 litres of water in the upper bucket of the unit. After stirring for a few minutes, the water is kept undisturbed for about one hour and then the water is allowed to flow to the lower bucket through a tap located at the bottom of the bucket. Information gathered from the field suggest that after each run, about 24.5 litres of treated water is produced and about 500 ml of slurry (arsenic rich) containing mainly ferric hydroxide flocs accumulate at the bottom of the upper bucket, which is later disposed of. Thus, waster generation rate for this unit is about 500 ml slurry per 24.5 litres of treated water. The STAR filter runs in a similar principle. However, information gathered from the field suggests that most users dispose of the slurry (accumulated at the bottom of the bucket) after treating two or three buckets of water. It was estimated that on an average, about 250 ml of slurry waste is generated per 40 litres of treated water.

In each unit of 'Shapla' filter, about 20 kg of filter media (iron-coated brick chips) is used for treatment of water. This media can treat about 3000 to 6000 litres of water (depending on arsenic and other water quality parameters). The media is discarded after exhaustion. Thus, on an average, 20 kg of arsenic rich spent filter media is produced for about 4500 litres of treated water. Good estimates of some other types of arsenic removal units (e.g., SIDKO granular ferric hydroxide units, BUET-UNU iron-coated sand units) could not be obtained due to lack of reliable field data.

### **3.4.3 Determination of Raw Arsenic Concentration in the Sample**

Arsenic rich treatment wastes (liquid or semi-solid and solid) collected from the aforementioned treatment units were stored in the laboratory and a portion of each of the sample was used for the determination of total arsenic content. For solid samples, the sample was dried in an oven at a temperature of 110<sup>o</sup> C for 24 hours to ensure that there was no moisture left in the wastes. The sample was then digested using aqua

regia as described in the Standard Methods (Clesceri, et al., 1998) for total extraction of heavy metals. Briefly, the sample digestion procedure consisted of the following steps: the sample was ground and 5 gram of it was taken in a volumetric flask. Then 5 ml of concentrated nitric acid and 15 ml of concentrated hydrochloric acid was added to the sample and it was kept overnight. After that, the sample was heated for 2 to 3 hours to boiling. After heating, it was allowed to cool and volume was adjusted to 500 ml by adding deionized water. Finally, the sample was filtered and stored. Following extraction, the amount of arsenic present in each extracted liquid was determined using an Atomic Absorption Spectrophotometer equipped with a graphite furnace (Shimadzu Model AA-6800). The digestion procedure for the liquid sample was same as that for solid sample with the exception that in this case 50 ml of sample was taken instead of 5 gm, which was used for solid samples.

#### **3.4.4 Carrying out TCLP**

Leaching characteristics of wastes collected from different arsenic removal units have been evaluated through Toxicity Characteristic Leaching Procedure (TCLP) developed by USEPA. The procedure was described earlier in this chapter. TCLP was performed for sixteen semi-solid (slurry) waste samples, of which fourteen samples were collected from STAR bucket treatment units while the rest two samples from BUET-UNU bucket treatment units. TCLP was also carried out for nineteen solid waste samples, of which fifteen samples were from Shapla filter, two from BUET-UNU iron coated sand units and two from SIDKO units. All TCLP tests for solid samples were performed in duplicates and averages of these results have been reported here. Detail results of TCLP for both semi-solid and solid samples have been presented in Appendix B. In all cases, arsenic concentrations in the TCLP extracts were measured using an Atomic Absorption Spectrophotometer equipped with a graphite furnace (Shimadzu Model AA-6800).

### 3.5 RESULTS AND DISCUSSION

#### 3.5.1 Semi-solid Samples

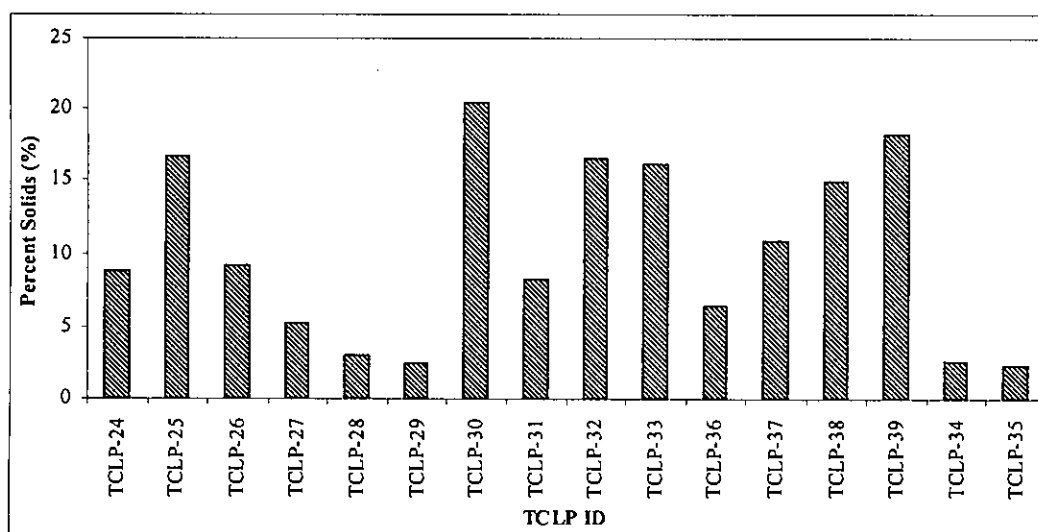
TCLP results of semi-solid (slurry) waste samples collected from STAR and BUET-UNU bucket treatment units are presented in Table 3.1. In the fourteen slurry samples collected from STAR bucket treatment units, percent solids varied from 2.47 percent to 20.44 (Figure 3.1) and arsenic concentration in the raw samples varied from 1.2 mg/L to 38.46 mg/L. For these samples, the arsenic content in the TCLP extract varied from 0.011 mg/L to 1.255 mg/L (Figure 3.2). For both the samples collected from BUET-UNU bucket treatment units, solid content was about two and a half percent and initial arsenic content was about 0.9 mg/L. Arsenic content in the TCLP extract of these two samples was 0.190 mg/L and 0.411 mg/L. The arsenic content of these wastes primarily depends on the arsenic concentration of the groundwater treated and other water quality parameters.

**Table 3.1: Results of TCLP performed on slurry waste samples from 'STAR' and 'BUET-UNU' bucket treatment units.**

Serial No.	Sample ID	Name of Treatment Unit	Location	Percent Solids	As Conc. in Raw Sample (mg/l)	As Conc. in TCLP Extract (mg/l)	Percent Leaching
1	TCLP-24	STAR BTU	Laksmipur	8.82	13.0	0.04	0.3
2	TCLP-25	STAR BTU	Laksmipur	16.62	1.35	0.01	0.8
3	TCLP-26	STAR BTU	Laksmipur	9.17	38.5	1.26	3.3
4	TCLP-27	STAR BTU	Laksmipur	5.23	10.9	0.09	0.9
5	TCLP-28	STAR BTU	Laksmipur	3.05	1.69	0.40	23.5
6	TCLP-29	STAR BTU	Laksmipur	2.47	6.51	0.20	3.1
7	TCLP-30	STAR BTU	Laksmipur	20.44	17.1	0.10	0.6
8	TCLP-31	STAR BTU	Laksmipur	8.25	10.8	0.07	0.7
9	TCLP-32	STAR BTU	Laksmipur	16.56	30.3	1.12	3.7
10	TCLP-33	STAR BTU	Laksmipur	16.07	18.6	0.31	1.7
11	TCLP-36	STAR BTU	Laksmipur	6.41	1.20	0.45	37.6
12	TCLP-37	STAR BTU	Laksmipur	10.80	24.5	0.14	0.6
13	TCLP-38	STAR BTU	Laksmipur	14.98	3.29	0.15	4.6
14	TCLP-39	STAR BTU	Laksmipur	18.22	26.2	0.36	1.4
15	TCLP-34	BUET-UNU	Comilla	2.56	0.91	0.19	21.0
16	TCLP-35	BUET-UNU	Comilla	2.41	0.93	0.41	44.2

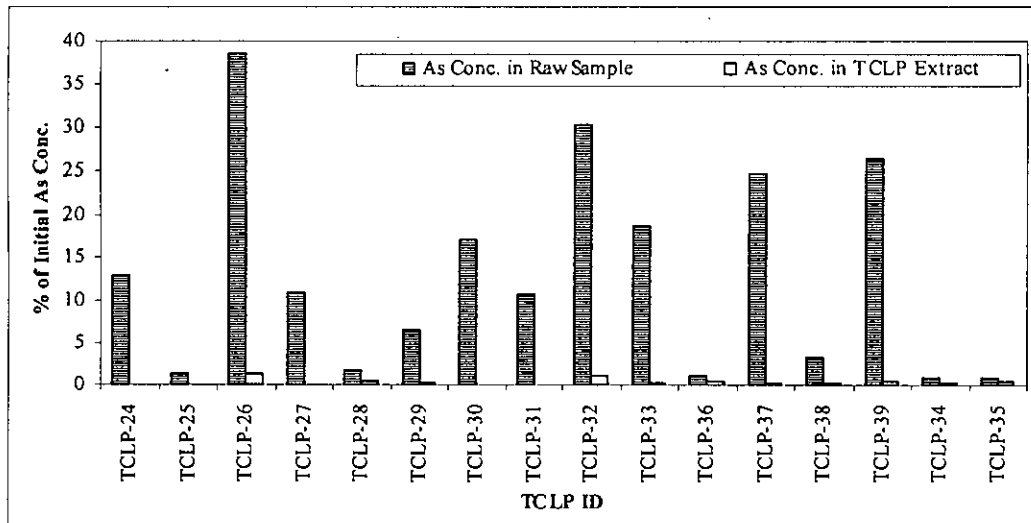
Figure 3.3 represents the percent leaching of sixteen slurry samples collected from STAR and BUET-UNU arsenic removal units. The figure (also Table 3.1) shows that for majority of the samples from STAR units, leaching of arsenic expressed as percent of initial arsenic present is very low.

For six samples leaching was less than one percent, for six samples it was more than one percent but less than five percent. Higher leaching (23.5 and 37.6 percent) was found for only two samples (TCLP-28 and TCLP-36). It is mentionable here that initial arsenic concentration of these two samples is very low (1.69 mg/L and 1.20 mg/L). Relatively high leaching was observed for the samples from BUET-UNU units (21.0 and 44.2 percent). Initial arsenic concentrations of these samples were also very low (0.91 mg/L and 0.93 mg/L).

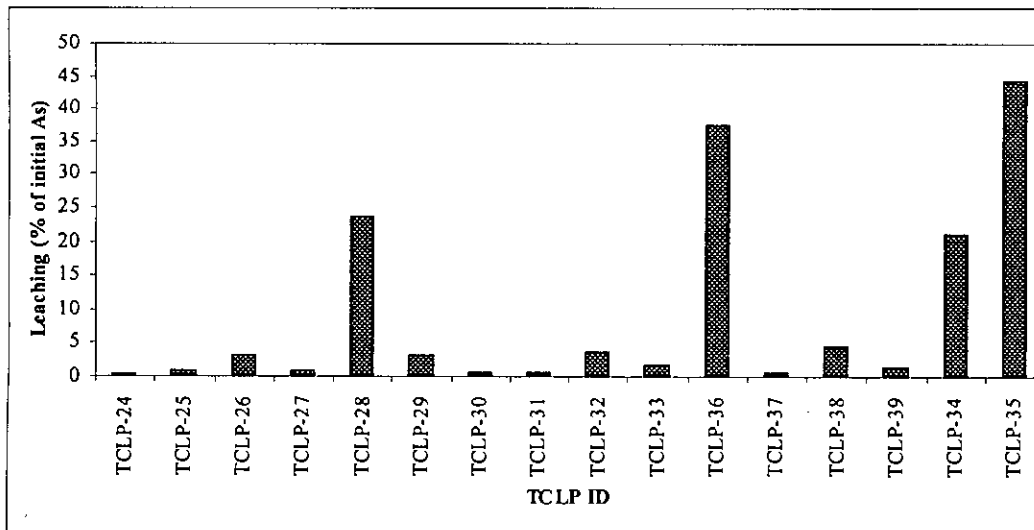


**Figure 3.1: Percent solids of slurry waste samples from ‘STAR’ and ‘BUET-UNU’ bucket treatment units.**

The TCLP results shown in Table 3.1 (also presented in Figure 3.2) confirm that the semi-solid (slurry) waste samples from different arsenic removal units do not fall into hazardous category as defined by the USEPA.



**Figure 3.2: Arsenic concentration in raw waste sample and in TCLP extract expressed as % of initial As concentration in the waste.**



**Figure 3.3: Leaching of arsenic from slurry waste samples from 'STAR' and 'BUET-UNU' bucket treatment units expressed as % of initial As concentration in the waste.**

### 3.5.2 Solid Samples

TCLP results of solid waste samples are presented in Table 3.2. In the fifteen solid samples collected from Shapla filter, arsenic concentration in the raw samples varied from 8.0 mg/Kg to 38.8 mg/Kg. For these samples, the arsenic content in the TCLP extract varied from 0.17 mg/Kg to 0.65 mg/Kg. For the samples collected from SIDKO arsenic removal units, initial arsenic content was very high (797.7 mg/Kg and

707.7 mg/Kg). Initial arsenic content of the two samples collected from FeCl<sub>3</sub> based arsenic removal units was 37.0 mg/Kg and 19.2 mg/Kg.

Figure 3.4 shows the arsenic concentration in raw sample and in TCLP extract of seventeen samples. In this figure, results of two samples collected from SIDKO units have been excluded because of extremely high initial arsenic content compared to that of other seventeen samples.

**Table 3.2: Results of TCLP performed on solid waste samples from different arsenic removal units.**

Serial No.	Sample ID	Type of Sample	Name of Treatment Unit	Location	As Conc. in Raw Sample (mg/kg)	As Conc. in TCLP Extract (mg/kg)	Percent Leaching
1	TCLP-02	Brick Chips	Shapla Filter	Noakhali	38.8	0.46	1.2
2	TCLP-06	Brick Chips	Shapla Filter	Noakhali	18.1	0.33	1.8
3	TCLP-07	Brick Chips	Shapla Filter	Noakhali	8.0	0.20	2.5
4	TCLP-08	Brick Chips	Shapla Filter	Noakhali	37.9	0.26	0.7
5	TCLP-11	Brick Chips	Shapla Filter	Noakhali	14.7	0.22	1.5
6	TCLP-12	Brick Chips	Shapla Filter	Noakhali	25.1	0.65	2.6
7	TCLP-13	Brick Chips	Shapla Filter	Noakhali	23.2	0.27	1.2
8	TCLP-14	Brick Chips	Shapla Filter	Noakhali	30.2	0.26	0.9
9	TCLP-15	Brick Chips	Shapla Filter	Noakhali	14.2	0.17	1.2
10	TCLP-16	Brick Chips	Shapla Filter	Noakhali	9.7	0.32	3.3
11	TCLP-17	Brick Chips	Shapla Filter	Noakhali	22.5	0.22	1.0
12	TCLP-18	Brick Chips	Shapla Filter	Noakhali	24.5	0.42	1.7
13	TCLP-19	Brick Chips	Shapla Filter	Noakhali	19.7	0.20	1.0
14	TCLP-20	Brick Chips	Shapla Filter	Noakhali	12.7	0.21	1.6
15	TCLP-21	Brick Chips	Shapla Filter	Noakhali	24.8	0.62	2.5
16	TCLP-09	Granular Soil	SIDKO ARU	Manikganj	797.7	0.70	0.1
17	TCLP-10	Granular Soil	SIDKO ARU	Manikganj	707.8	0.99	0.1
18	TCLP-22	Sand	FeCl <sub>3</sub> Based ARU	Comilla	37.0	0.28	0.8
19	TCLP-23	Sand	FeCl <sub>3</sub> Based ARU	Comilla	19.2	0.09	0.5

Figure 3.5 shows percent leaching of nineteen solid samples. For these solid samples, leaching of arsenic expressed as percent of initial arsenic present was very low. For the samples from spent “Shapla” filter media, it ranged from 0.7 to 3.3 percent. This variation in percent leaching may be related to the arsenic concentration in the raw waste sample. It seems that higher the arsenic concentration in the raw waste sample, lower the percent leaching and vice versa.

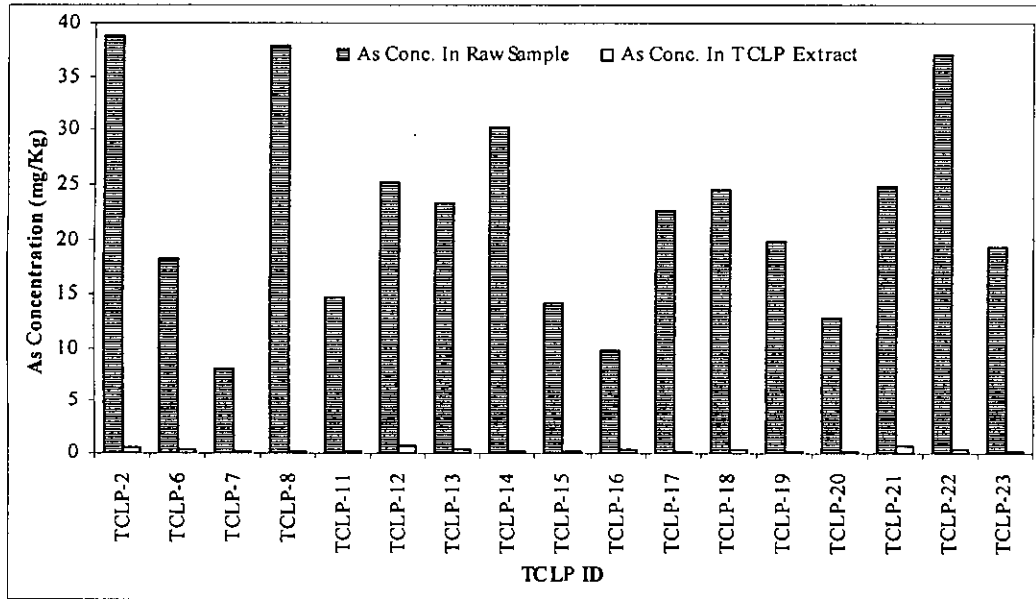


Figure 3.4: As concentration in raw waste samples and in TCLP extracts (solid sample).

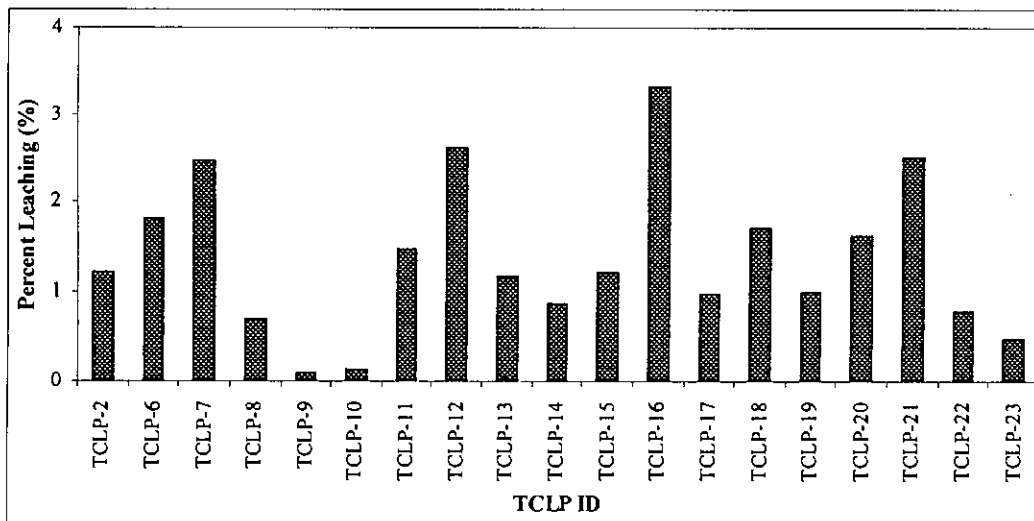


Figure 3.5: Leaching of arsenic from solid waste samples expressed as % of initial As concentration in the waste.



Leaching from the spent SIDKO media and sand from FeCl<sub>3</sub> based arsenic removal units is negligible. It is noticeable here that although initial arsenic concentration in two samples from SIDKO units were extremely high, percent leaching is quite low. This is because waste sample from these arsenic removal units has strong adsorbing capacity resulting in little desorption of arsenic from the surface of the waste sample with the flowing fluid during the column experiment. None of the solid samples collected from different arsenic removal units fall into the category to be specified as hazardous material, as defined by the USEPA.

### **3.6 AN OVERVIEW: SUMMARY OF SHORT-TERM LEACHING**

Short-term leaching of arsenic from solid and slurry waste samples was found to be very low. For majority of the slurry samples, leaching of arsenic expressed as percent of initial arsenic present was negligible. Leaching was found to be less than one percent for six samples, more than one percent but less than five percent for another six samples and relatively higher leaching (23.5 % and 37.6 %) was found in only two samples. However, initial arsenic concentration of these two samples was very low (1.69 mg/L and 1.20 mg/L). In the case of nineteen solid waste samples, leaching of arsenic expressed as percent of initial arsenic present was also found to be very low. For fifteen samples, leaching of arsenic ranged from 0.7 to 3.3 percent whereas leaching of other samples was negligible. Although initial arsenic concentration of some of the solid waste samples was extremely high, percent leaching was quite low. In the context of short-term leaching, the waste samples, both slurry and solid, do not belong to the "hazardous" category as defined by the USEPA.

## **CHAPTER - 4**

### **LONG -TERM LEACHING OF ARSENIC**

#### **4.1 INTRODUCTION**

Since arsenic in groundwater was recognized as a potential threat to human life, much effort has been directed towards ensuring safe drinking water either through mitigation techniques or through finding alternative water sources. The serious arsenic problem has become a matter of great concern in Bangladesh and has led to massive concerted efforts of Government, NGOs and donor agencies in mitigating the crisis. It is unfortunate that most of the focus has been on awareness building and development of water treatment system removing arsenic from drinking water. Almost all the arsenic removal systems developed so far in this country generate some form of arsenic rich sludge or waste. The disposal of this arsenic rich sludge or waste is one of the issues that have received little attention from the sponsors of the technologies and the users. In Chapter 3, results of TCLP performed on arsenic rich wastes were presented. From the TCLP results, it can easily be realized that arsenic rich wastes do not produce leachate concentration significant enough to term the wastes toxic as per the USEPA regulatory level. However, TCLP may not be suitable for assessment of long-term leaching of arsenic from arsenic rich wastes, because such leaching may be kinetically restricted.

#### **4.2 LONG-TERM LEACHING OF ARSENIC**

It was described in Chapter 3 that short-term leaching involves an aggressive acetic acid leaching at a lower pH following  $18 \pm 2$  hours agitation at a speed of  $30 \pm 2$  rpm. In the case of long-term leaching arsenic rich wastes are not stimulated and leaching occurs naturally over a relatively longer period of time compared to short-term leaching. This process provides quantitative leach rates expected when waste is disposed in open environment as well as relative reactivity of different wastes under similar conditions.

### 4.3 MATERIALS AND METHODS

In order to evaluate long-term leaching characteristics of treatment wastes, column experiments have been carried out with spent filter media collected from 'Shapla' filter which is described later in this chapter. A total of five columns were set up and leaching of arsenic from 'Shapla' filter media was evaluated under continuous flow with five different fluids (one for each column). The fluids were: (i) distilled water (ii) arsenic free natural groundwater (iii) rainwater (iv) pond water and (v) extraction fluid # 1 which was used in the TCLP.

#### 4.3.1 Collection of Treatment Waste Samples

In order to perform the column experiment, first, the arsenic rich treatment wastes were collected from "Shapla Filter", which is a filtration based arsenic removal unit. A number of such ARUs were installed at Ashwadia union in Noakhali Sadar Upazila of Noakhali District. In these units, 20 kg of iron-coated brick chips were used. There were two types of units depending on the size of the unit, small and big. In both of the units, equal amount of brick chips were placed for treating the arsenic contaminated water. Only difference was that, the filtering capacity of big and small units was twelve liters and six liters, respectively. In these filters, the aforementioned amount of filter media (iron-coated brick chips), contained in an earthen bucket, was used as filter, through which arsenic contaminated water was allowed to pass. While passing through the filter, arsenic present in water was adsorbed onto the surface of the filter media and arsenic free water or water with low arsenic concentration was collected from the bottom of the unit. After certain period of time (after treating a considerable amount of water) the efficiency of the filter media decreased and ultimately it was disposed of. The discarded filter media was collected in adequate quantity during the beginning of the study for conducting the column experiment as well as TCLP.

### **4.3.2 Characteristics of Collected Sample**

The waste samples collected from “Shapla Filter” are basically filter media consisting of crushed brick chips coated with iron. The arsenic contaminated water is allowed to pass through this filter media in a down flow mode and arsenic present in water is adsorbed onto the surface of the filter material. After treating a considerable amount of water the efficiency of the media decreases because of the accumulation of a high amount of arsenic on the surface of the material resulting in decrease of adsorbing capacity of the filter media. Sample from a number of ARUs (Shapla Filter) was collected and analyzed in the laboratory for arsenic. Results show a high accumulation of arsenic in almost all the samples.

### **4.3.3 Determination of Arsenic Concentration in the Raw Sample**

Arsenic rich treatment wastes (filter media) collected from the aforementioned treatment units were first mixed thoroughly and dried in an oven at a temperature of 110<sup>o</sup> C for 24 hours to ensure that there was no moisture left in the wastes. A portion of the dried sample was used for the determination of total arsenic content per unit weight of the dry sample. For this, the sample was digested using aqua regia as described in the Standard Methods (Clesceri, et al., 1998) for total extraction of heavy metals. Briefly, the sample digestion procedure consisted of the following steps: the sample was ground and 5 gram of it was taken in a volumetric flask. Then 2.5 ml of concentrated nitric acid and 7.5 ml of concentrated hydrochloric acid was added to the sample and it was kept overnight. After that, the sample was heated for 2 to 3 hours to boiling. After heating, it was allowed to cool and volume was adjusted to 500 ml by adding deionized water. Finally, the sample was filtered and stored. Following extraction, the amount of arsenic present in each extracted liquid was determined using an Atomic Absorption Spectrophotometer equipped with a graphite furnace (Shimadzu Model AA-6800).

#### 4.3.4 Sieve Analysis

Table 4.1: Sieve analysis results of the collected waste sample used for column experiment.

Sieve No.	Opening Size (mm)	Retained (gm)	Cumulative Retained (gm)	Percent Passing
4	4.760	0.0	0.0	100.0
8	2.380	4.9	4.9	95.1
16	1.190	24.1	29.0	71.0
30	0.590	29.6	58.6	41.4
40	0.420	23.8	82.4	17.6
50	0.297	9.0	91.4	8.6
100	0.149	5.0	96.4	3.6
Pan	0.074	3.5	99.9	0.1
Total		99.9		

A portion of the dried sample was used for performing the sieve analysis for particle size distribution of the waste. Sieve analysis results are presented in Table 4.1. From the sieve analysis,  $D_{10}$  of the sample was found to be 0.32 mm and  $D_{60}$  of the sample was found to be 0.90 mm with a uniformity coefficient,  $\mu$  of 2.81.

#### 4.3.5 Column Experiment

Finally, a large portion of the sample was used for column experiment. Column experiments were carried out with the waste sample in order to evaluate the long-term leaching characteristics of the waste. In this study, a total of five columns were set up for investigating the leaching characteristics of the waste by flowing five different types of water through the column. In each column, a small amount of (10-15 gm) stone chips were placed at the bottom of the column so that they could act as screen for protecting the small particles of the sample from draining out of the column with the flowing water. Then 80 grams of sample, with an arsenic concentration of 38.8 mg/kg, was taken into the column slowly and very carefully. After that a small amount of water was passed through the material to wet the sample and to compact

the sample. Each of the columns was kept vertical with a tripod stand. Every column was connected to a plastic container by a narrow plastic tube to supply water to the column. Water was stored in the container and this water reached the material in the column through the narrow tube by the principle of cyphonic action. A small bucket placed directly below the column collected the leachate coming out of the column after passing through the material in the column. In each of the five columns the equal amount (80 gram) of waste sample was taken and five different types of water used in the columns were distilled water, natural ground water, rainwater, pond water and TCLP extraction fluid #1 which was used in the TCLP. Five different types of water mentioned above were passed through the five columns in a down-flow mode at a controlled flow rate. The flow rate was kept constant at 40 ( $\pm 1.5$ ) ml/hour although it varied slightly with the passage of time. The reason for maintaining this flow rate was that if the flow rate would be higher, the bucket collecting the leachate would be overflowed after collecting the leachate for three or sometimes more days at the week end. Another reason was that sometimes the narrow opening of the columns got clogged resulting in decrease in the flow rate which would impose a large daily variation in the flow rate.

The leachate coming out from the column after passing through the material in the column was collected in the bucket, acidified with a few ml of hydrochloric acid, filtered with a normal filter paper and finally stored in plastic bottles for determining arsenic concentration using an Atomic Absorption Spectrophotometer equipped with a graphite furnace (Shimadzu Model AA-6800). From the column experiment it was observed that as the time passed and volume of passing water increased, the concentration of arsenic in the leachate decreased. During the beginning of the experiment the decrease was sharp and later the concentration decreased gradually. After a long period of time (about 4 to 5 months) the arsenic concentration in the leachate reached below the method detection limit (MDL) indicating that no further arsenic would be leached out from the media with the flowing water. Column experiments were continued for this period of time (4 to 5 months), which is much greater relative to the time required for arsenic to leach through the TCLP. When the arsenic concentration in the leachate reached below the method detection limit

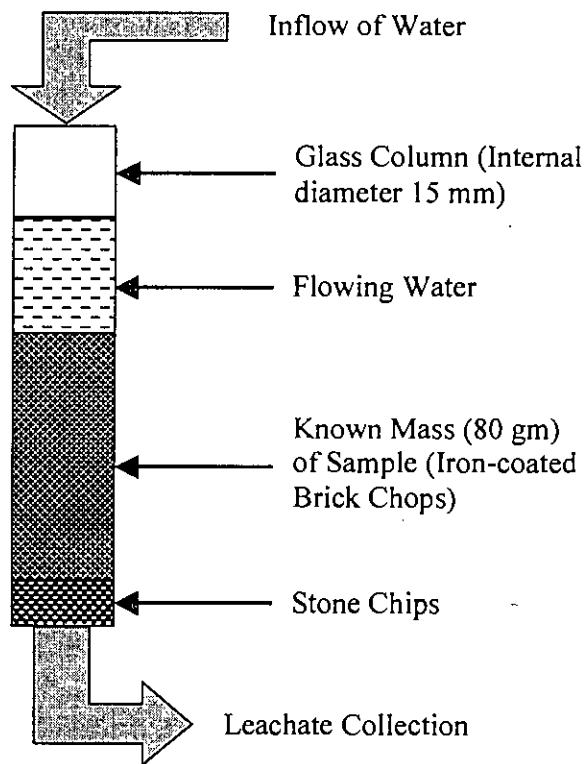
(MDL), it seemed that no further water would be needed to pass through the media and column experiments were stopped.

#### **4.3.6 Experimental Design**

The objectives of the experimental investigation performed in this study were to evaluate long-term leaching characteristics of treatment wastes produced from filtration based arsenic removal units using five different types of water flowing in a down flow mode. This experiment was performed over relatively long time periods (about four months) and was stopped when the concentration of arsenic in the leachate coming out from the column reached below the method detection limit (MDL).

#### **4.3.7 Experimental Set-up**

A schematic diagram of the experimental set-up is shown in Figure 4.1. A 100 ml capacity Pyrex glass burette with an inner diameter of 15 mm was used as column for the experiment. The height of the column was about 660 mm, of which lower 25 mm was filled with small stone chips and the next 380 mm was filled with the sample. Stone chips were placed at the lower end of the column in order to protect fine particles of the sample from draining out of the column with the flowing water. It also helped to avoid clogging of sample particles at the narrow opening of the column through which leachate was collected.



**Figure 4.1: Column Experimental Set up**

#### 4.3.8 Water Used for Column Experiment

In this study five different types of water were used for five columns. They were

- i) Distilled water
- ii) Ground water
- iii) Rain water
- iv) Pond water
- v) Extraction fluid #1 used for the TCLP

Distilled water used for the column experiment was collected from the Environmental Engineering Laboratory of BUET. The pH value of the water was 7.10 and arsenic concentration was below 1 ppb, the method detection limit (MDL) of the instrument. Ground water was collected from the laboratory basins, which collect water from the deep tube wells installed in the BUET campus. This water had a pH value of 6.80 and arsenic concentration below the method detection limit (MDL).



Rainwater was collected during the time of rain. For collecting rainwater, buckets were placed at open space (on the roof of Civil Engineering Building) during the time of rain and when the buckets were filled with rainwater, they were taken to the laboratory and stored for use in the column experiment. Every time the rainwater was collected, the pH value of this water was measured. There was a little fluctuation of pH value of rainwater collected at different times. Most of the time pH was found to be 7.50. The arsenic concentration of rainwater was also found to be below the method detection limit (MDL).

**Table 4.2: Detailed characterization of different types of water used in the column experiments.**

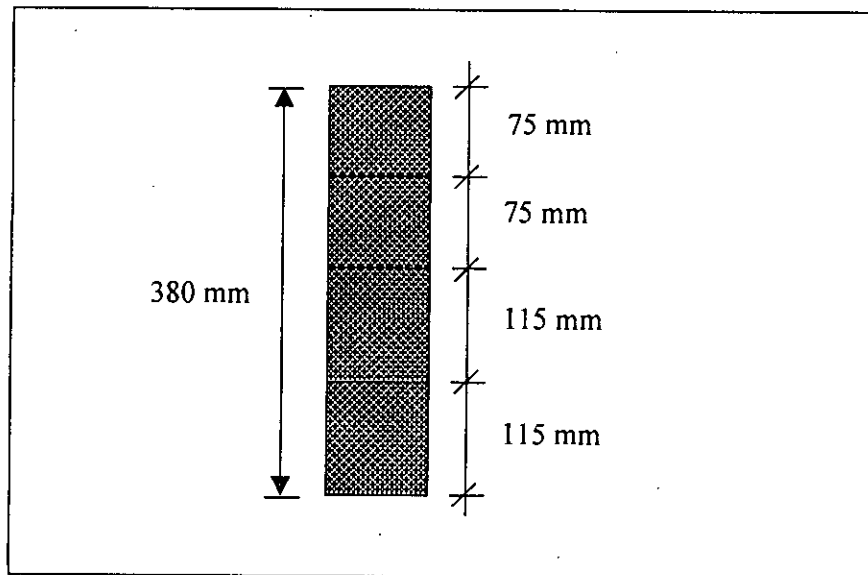
Parameter	Unit	Concentration			
		Distilled Water	Ground Water	Rainwater	Pond Water
pH	--	7.10	6.80	7.50	7.30
Alkalinity as CaCO <sub>3</sub>	mg/L	14	193	40	97
Hardness as CaCO <sub>3</sub>	mg/L	4	292	42	124
Conductivity	μS/cm	9	825	105	335
Chloride	mg/L	6	175	11	43
Sulfate	mg/L	1.1	42	3.2	25.7
Nitrate	mg/L	Nil	1.2	0.6	0.2
Phosphate	mg/L	0.057	0.189	0.092	0.09
Fluoride	mg/L	Nil	0.1	0.04	0.18
Iron	mg/L	<0.02	<0.02	<0.02	0.02
Manganese	mg/L	<0.02	<0.02	<0.02	<0.02
Aluminum	mg/L	<0.20	<0.20	<0.20	<0.20
Arsenic	μg/L	<1.0	<1.0	<1.0	<1.0
Silica	mg/L	0.6	11.3	3.4	1.8

Pond water was collected from a pond situated in the premises of Shahidullah Hall of Dhaka University. The pH and arsenic concentration of pond water were found to be 7.30 and below method detection limit (MDL), respectively. Extraction fluid #1 was prepared in the laboratory in order to get a solution with a pH of 4.93±0.05 using 1N NaOH and 0.4 % acetic acid. This solution was used in the column experiment for it

was the standard solution used in the TCLP developed and followed by the USEPA. This solution had an arsenic concentration below the method detection limit (MDL). Since distilled water was used in preparing this solution, the concentration of other parameters was expected to be the same as was found for the distilled water. A number of parameters were measured for the above-mentioned four types of water. Table 4.2 provides a detailed characterization of distilled water, ground water, rainwater and pond water, which were used in the column experiments.

#### 4.3.9 Mass Balance

When the column experiment was completed, the sample in the column was divided into four segments: the first segment consisting of the top 75 mm of sample, the second segment consisting of the next 75 mm and the third and fourth segment consisting of the next 115 mm each. Then the sample in each segment was dried in the same way it was dried before.



**Figure 4.2: Segmentation of the sample in the column**

A portion of the sample from each segment was digested and analyzed as before for determining the arsenic content. This was done to assess the amount of arsenic remained in different segments and consequently the amount of arsenic leached from

various depths of the column. Prior to this, the weight of the sample in each segment was taken to see whether there was any loss or increase of material. In fact, segmentation of the column was done in order to observe whether there was any variation in leaching of arsenic from various depths of the column. Finally, a mass balance analysis was performed.

#### **4.4 RESULTS AND DISCUSSIONS**

In order to evaluate the long-term leaching characteristics of arsenic rich filter media, a total of five column experiments were carried out using five different waters. The same filter media was taken equally (80 gm) in each of the columns and five different types of water (distilled water, ground water, rainwater, pond water and extraction fluid #1) were passed through the columns. The leachate coming out of the columns was collected daily in a plastic bucket. Then the leachate was acidified with a few drops of concentrated hydrochloric acid to lower the pH of the leachate because sometimes it would not be possible to analyze the leachate immediately after collection for the determination of arsenic.

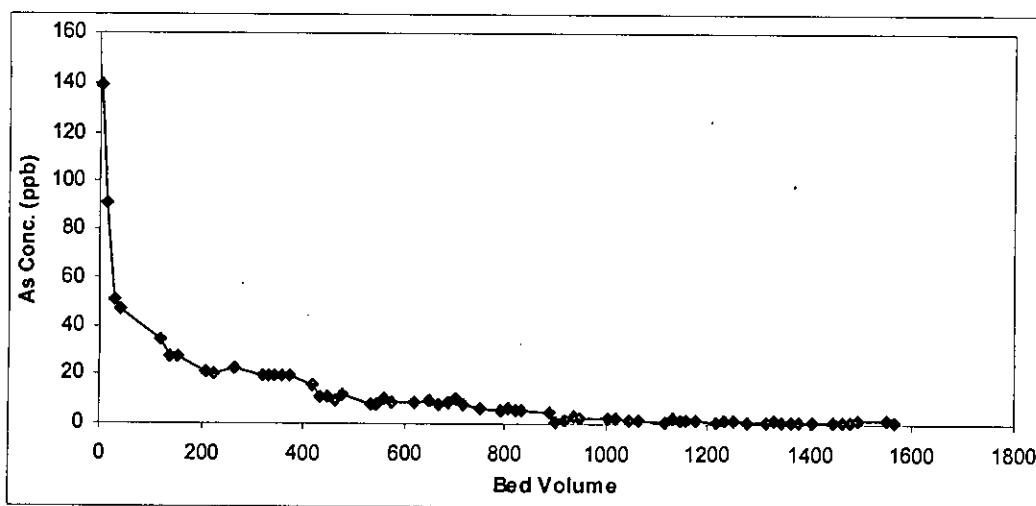
During the column experiment, it was tried to keep the flow rate constant, but daily flow rate varied considerably due to various reasons, sometimes for clogging of the narrow opening of the burette, sometimes for inaccurate adjustment of the stopcock of burette.

##### **4.4.1 Column 1 (Fluid: Distilled Water)**

Figure 4.3 shows arsenic concentration in column effluents as a function of bed volume of fluid passed through the column. It is evident from the figure that arsenic concentration in the column effluent was initially very high, but then dropped sharply. Arsenic concentration in the initial leachate was 139 ppb and the concentration reached to 21 ppb just after passing only 208 bed volume of water. The reason for such a sharp decrease in arsenic concentration in the leachate is that some of the arsenic present in the filter media was loosely bound on the surface of the media

particle. This portion was immediately leached out with the flowing water through desorption resulting in high arsenic concentration in the leachate collected at the earlier period of the column experiment. Once the loosely bound arsenic was leached out, the remaining arsenic, which was adsorbed strongly on the surface of the filter particles, leached gradually.

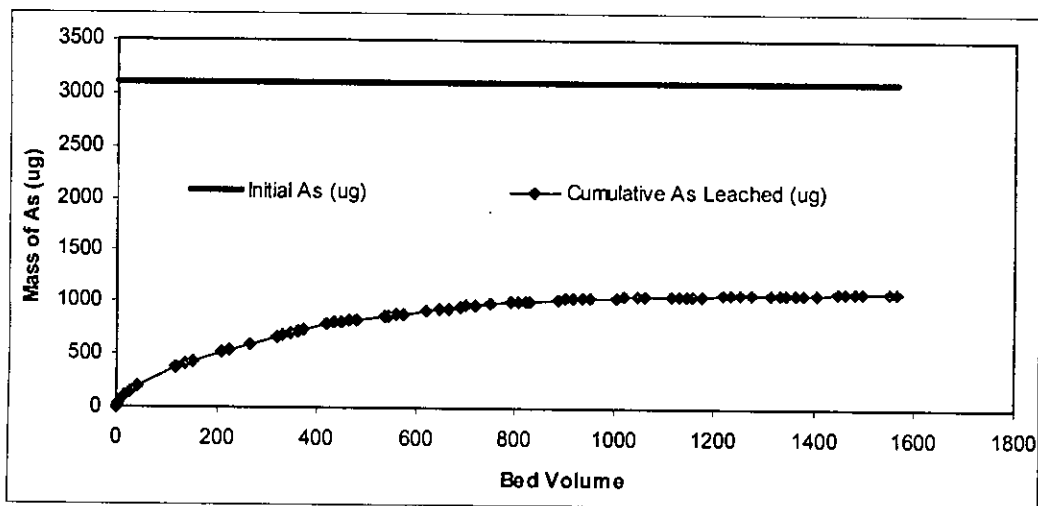
After passing about 1564 bed volumes of distilled water through the filter media, the arsenic concentration in the leachate was found to be less than 1 ppb, which is the method detection limit (MDL) of the AAS. Instead of stopping the column experiment at this stage, it was further continued to collect 5 more leachate samples the arsenic concentrations of which were found to be less than the method detection limit (MDL), indicating that no more arsenic was actually being leached out from the samaple. Then the experiment was stopped and this approach was followed for all of the five columns.



**Figure 4.3: Arsenic in column effluent as a function of bed volume of fluid passed through the column (Column 1, Fluid: Distilled Water)**

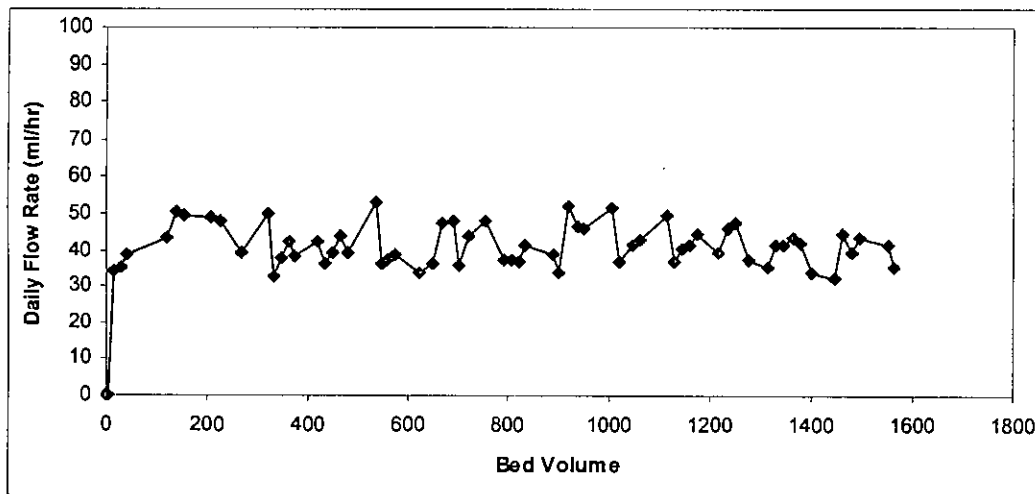
The initial arsenic concentration of the filter media was 38.8 mg/kg (equivalent to 38.8  $\mu\text{g/g}$ ). So, a total of 3104  $\mu\text{g}$  (80 gm of sample) of arsenic was taken in the column. After the end of the experiment, about 106 days after the commencement of the experiment, it is observed that 1097  $\mu\text{g}$  (35.3 %) of arsenic has leached out. Figure

4.4 shows the initial arsenic concentration in the sample and cumulative arsenic leached as a function of bed volume of fluid passed through the column. It shows that during earlier period the cumulative arsenic leaching was increasing and with the passage of time as the bed volume of passing water increased, the curve takes the form of a horizontal straight line, which indicates that no more arsenic would leach out resulting the stabilization of the filter material in the column. During this time period, a total of 64 leachate was collected and the volume of water that passed through the filter media in the column was 105.28 litres, which is equivalent to 1563.64 bed volume (bed volume = 67.33 cc). It is noticeable from Figure 4.4 that out of 1097  $\mu\text{g}$  of arsenic leached from the column material, 1032  $\mu\text{g}$  (33.3 %) leached out with only 900 bed volume of flowing water and the rest 65  $\mu\text{g}$  (2.1 %) of arsenic leached out with 663 bed volume of water.



**Figure 4.4: Initial arsenic and cumulative arsenic leached as a function of bed volume of fluid passed through the column (Column 1, Fluid: Distilled Water).**

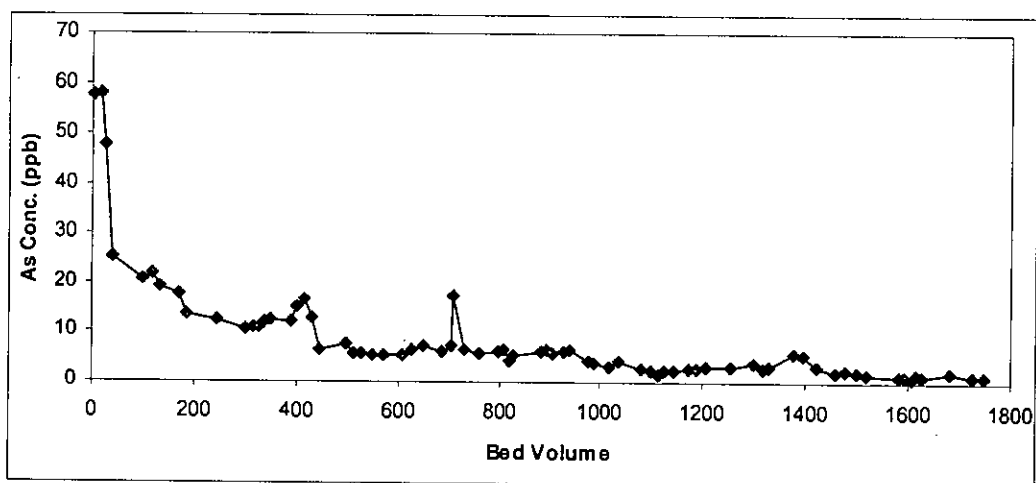
During the column experiment, there was a slight fluctuation in the daily flow rate. Figure 4.5 shows the daily variation of flow rate as a function of bed volume. Other figures such as cumulative flow rate, arsenic remaining etc. are presented in Appendix C.



**Figure 4.5: Daily flow rate as a function of bed volume of fluid passed through the column (Column 1, Fluid: Distilled Water)**

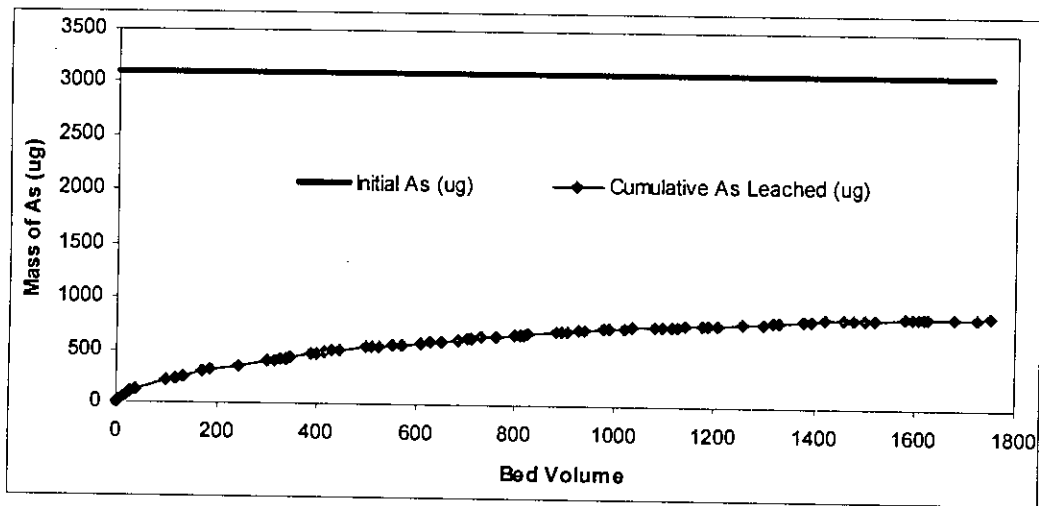
#### **4.4.2 Column 2 (Fluid: Ground Water)**

In column 2, arsenic free natural groundwater was flowed in order to evaluate the leaching characteristics. As in the case of column 1, 38.8 gm of filter material with a total of 3104  $\mu\text{g}$  arsenic was taken in the column. Figure 4.6 shows arsenic concentration in column effluents as a function of bed volume of fluid passed through the column. In this case also arsenic concentration in the column effluent was initially very high, but then dropped sharply. The arsenic concentration in the leachate collected initially was found to be 58 ppb. The arsenic concentration in the leachate decreased rapidly at the earlier period while it decreased gradually in the the latter and ultimately the concentration reached below the method detection limit (MDL) after running for about 120 days. During this time period, 72 nos leachate was collected and 1750 bed volume (equivalent to 117.8 litre) of groundwater was passed through the filter media in the column.



**Figure 4.6: Arsenic in column effluent as a function of bed volume of fluid passed through the column (Column 2, Fluid: Ground Water)**

After the end of the experiment, about 120 days after the commencement of the experiment, it is observed that 871  $\mu\text{g}$  of arsenic has been leached out which is equivalent to 28.06% of the total arsenic contained in the sample in the column. Figure 4.7 shows the initial arsenic content and cumulative arsenic leached as a function of bed volume of fluid passed through the column. It is seen from the figure that this curve also takes the same form of column 1. It is noticeable from Figure 4.7 that larger amount of arsenic was leached in the earlier period and smaller amount of arsenic was leached in the later. In this case, out of 871  $\mu\text{g}$  of arsenic leached from the column material, 706  $\mu\text{g}$  (22.7 %) leached out with 893 bed volume of flowing water and the rest 165 (5.3 %)  $\mu\text{g}$  of arsenic leached out with 856 bed volume of water. The filter media in column 2 has been stabilized after passing 1750 bed volume of arsenic free natural groundwater. As in the case of column 1, there was a little variation in the daily flow rate as a function of bed volume passed through the column. The figures showing variation in daily flow rate, cumulative flow rate, arsenic remaining etc. as function of bed volume, are presented in Appendix C.

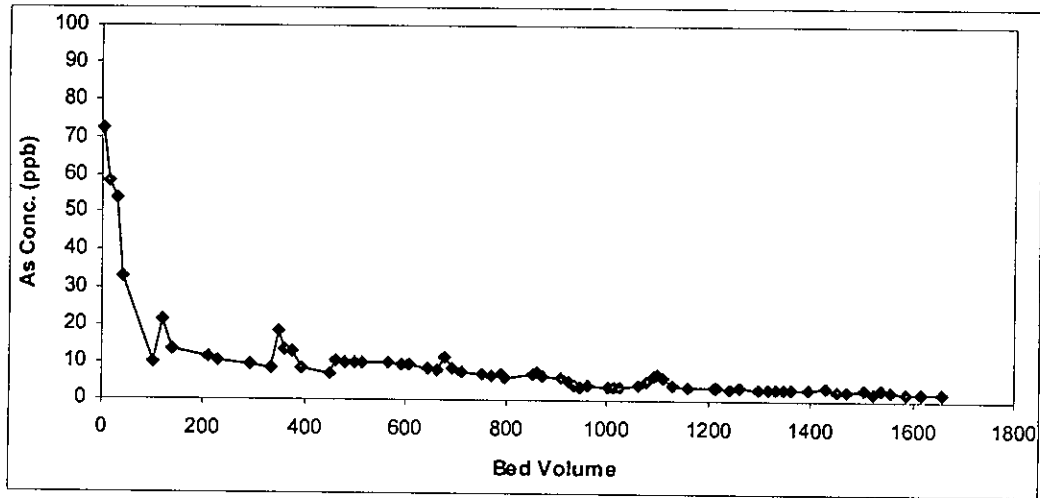


**Figure 4.7: Initial arsenic and cumulative arsenic leached as a function of bed volume of fluid passed through the column (Column 2, Fluid: Ground Water)**

#### 4.4.3 Column 3 (Fluid: Rainwater)

In column 3, rainwater was flowed through the filter media in the column in order to evaluate the leaching characteristics. Figure 4.8 shows arsenic concentration in column effluents as a function of bed volume of fluid passed through the column. The arsenic concentration in the initial leachate was 72 ppb. The arsenic concentration in the leachate decreased rapidly at the earlier period while it decreased gradually in the the later and ultimately the concentration reached below the method detection limit (MDL) after running for about 113 days. During this time period, 69 leachate samples were collected and 1658 bed volume (equivalent to 111.6 litre) of rainwater was passed through the filter media in the column.

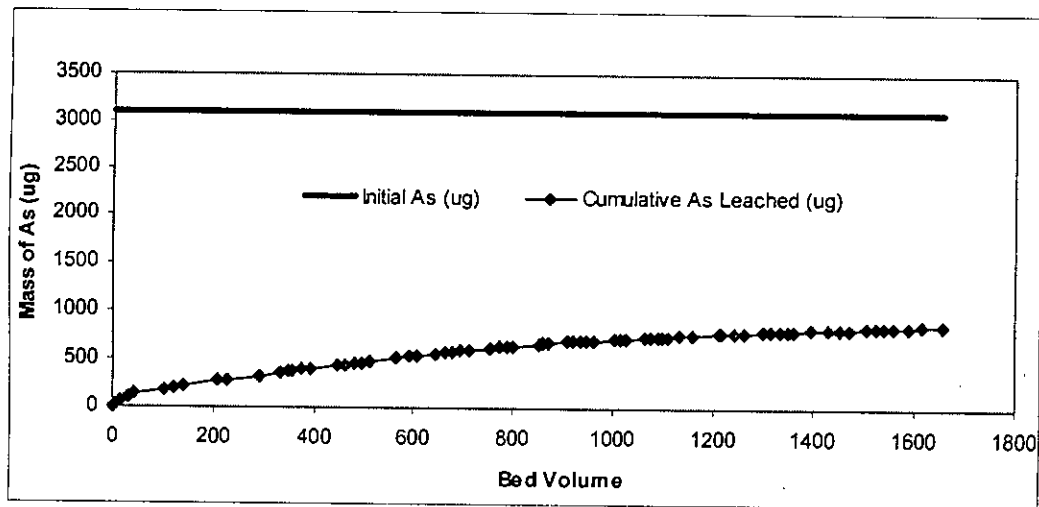




**Figure 4.8: Arsenic in column effluent as a function of bed volume of fluid passed through the column (Column 3, Fluid: Rainwater)**

After the end of the experiment, about 113 days after the commencement of the experiment, it has been observed that 851.00  $\mu\text{g}$  of arsenic has leached out, which is equivalent to 27.42% of the total arsenic contained in the sample in the column.

Figure 4.9 shows the cumulative arsenic leached as a function of bed volume.

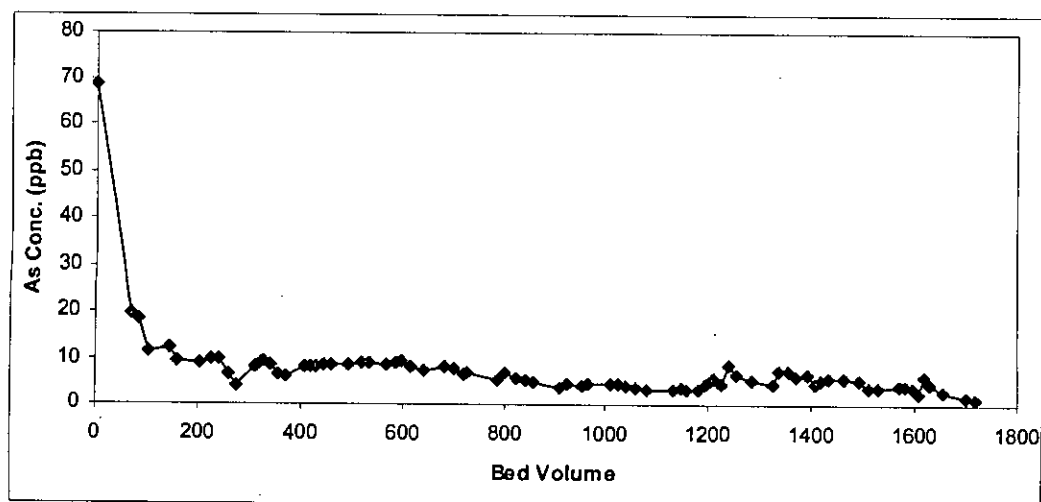


**Figure 4.9: Initial arsenic and cumulative arsenic leached as a function of bed volume of fluid passed through the column (Column 3, Fluid: Rain Water)**

It is noticeable from Figure 4.9 that out of 851  $\mu\text{g}$  of arsenic leached from the column material, 638  $\mu\text{g}$  (22.7 %) leached out with 798 bed volume of flowing water and the rest 213 (5.3 %)  $\mu\text{g}$  of arsenic leached out with 860 bed volume of water.

#### 4.4.4 Column 4 (Fluid: Pond Water)

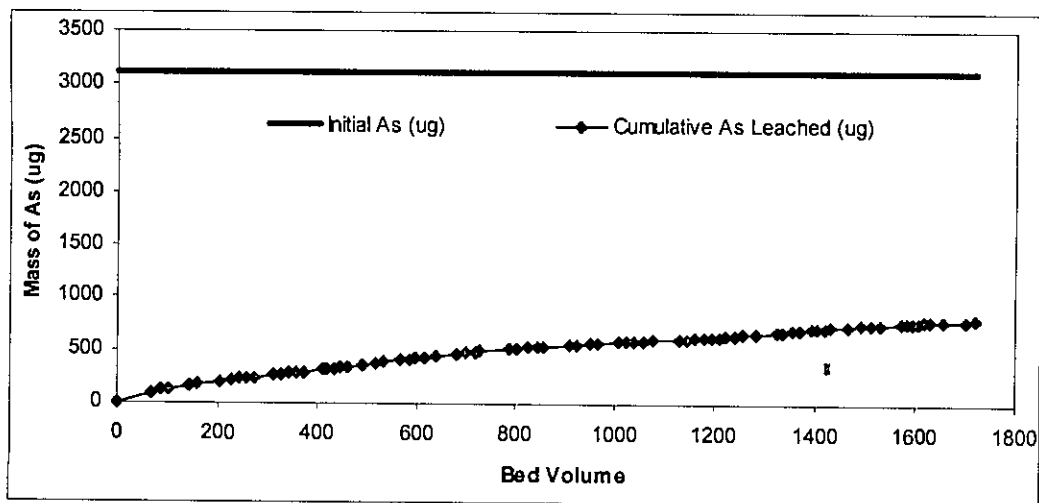
In column 4, pond water was flowed through the filter media in the column in order to evaluate the leaching characteristics. Figure 4.10 shows arsenic concentration in column effluents as a function of bed volume of fluid passed through the column. The arsenic concentration in the initial leachate was 68 ppb. The arsenic concentration in the leachate decreased rapidly at the earlier period while it decreased gradually in the the latter and ultimately the concentration reached below the method detection limit (MDL) after running for about 122 days. During this time period, 77 leachate samples were collected and 1720 bed volume (equivalent to 1116 litre) of pond water was passed through the filter media in the column.



**Figure 4.10: Arsenic in column effluent as a function of bed volume of fluid passed through the column (Column 4, Fluid: Pond Water)**

After the end of the experiment, about 122 days after the commencement of the experiment, it is observed that 787  $\mu\text{g}$  of arsenic has been leached out which is

equivalent to 25.4 % of the total arsenic contained in the sample in the column. Figure 4.11 shows the cumulative arsenic leached as a function of bed volume.

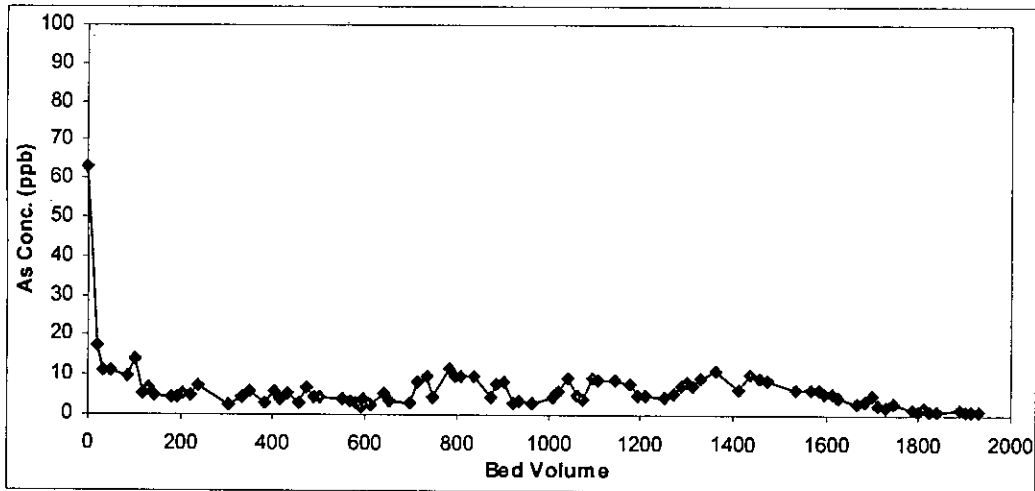


**Figure 4.11: Initial arsenic and cumulative arsenic leached as a function of bed volume of fluid passed through the column (Column 4, Fluid: Pond Water)**

It is noticeable from Figure 4.11 that out of 787  $\mu\text{g}$  of arsenic leached from the column material, 534  $\mu\text{g}$  (17.2 %) leached out with 857 bed volume of flowing water and the rest 253 (8.1 %)  $\mu\text{g}$  of arsenic leached out with 863 bed volume of water.

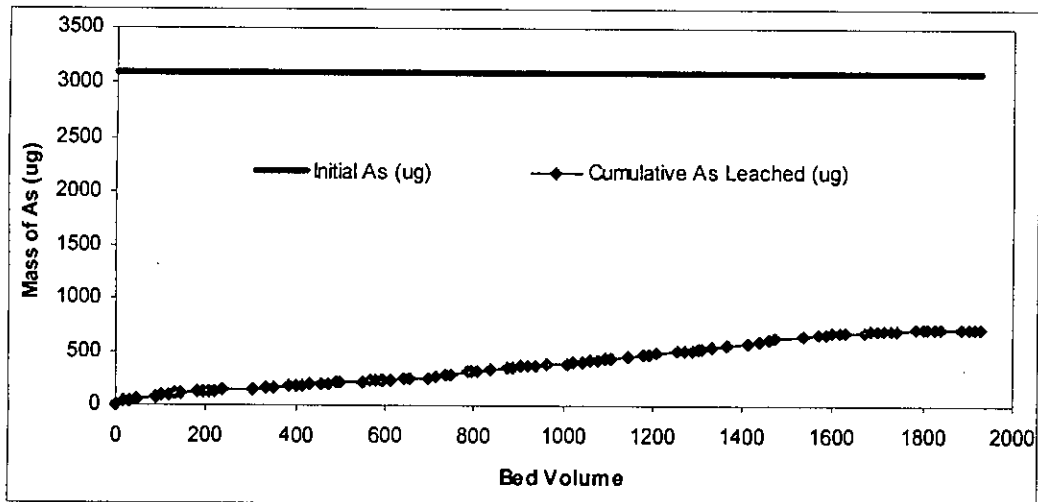
#### 4.4.5 Column 5 (Fluid: Extraction Fluid # 1)

In column 5, extraction fluid # 1 was flowed through the filter media in the column in order to evaluate the leaching characteristics. This fluid was used in the column because it was also used for performing the TCLP of the samples. Figure 4.12 shows arsenic concentration in column effluents as a function of bed volume of fluid passed through the column. The arsenic concentration in the initial leachate was 63 ppb. The arsenic concentration in the leachate decreased rapidly at the earlier period while it decreased gradually in the the latter and ultimately the concentration reached below the method detection limit (MDL) after running for about 134 days. During this time period, 89 nos leachate was collected and 1929 bed volume (equivalent to 130 litre) of extraction fluid # 1 was passed through the filter media in the column.



**Figure 4.12: Arsenic in column effluent as a function of bed volume of fluid passed through the column (Column 5, Fluid: Extraction Fluid # 1)**

After the end of the experiment, about 133 days after the commencement of the experiment, it is observed that 726  $\mu\text{g}$  of arsenic has leached out which is equivalent to 23.4 % of the total arsenic contained in the sample in the column. Figure 4.13 shows the cumulative arsenic leached as a function of bed volume.

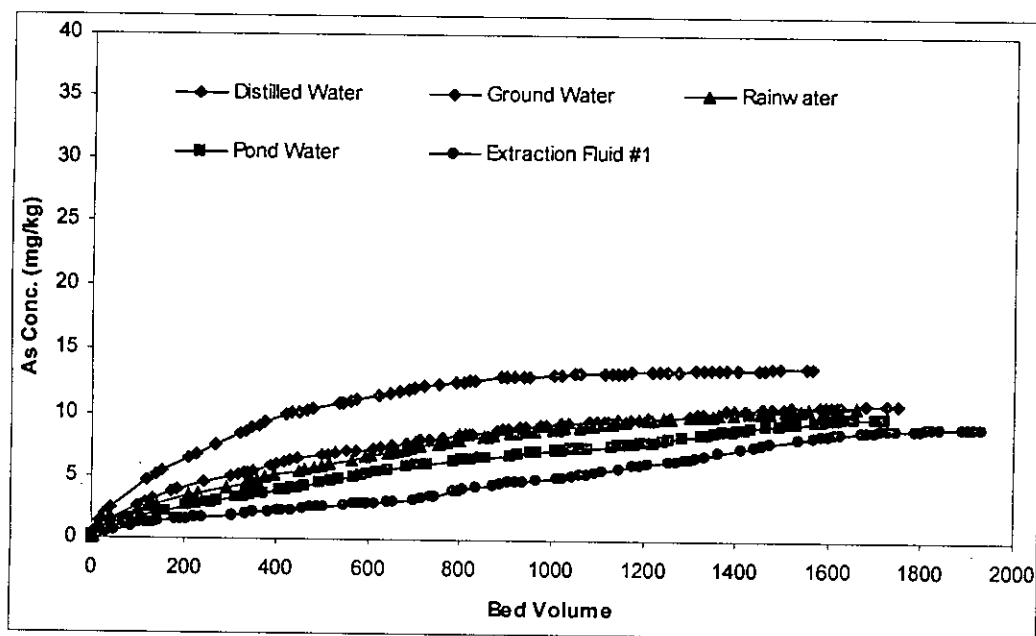


**Figure 4.13: Initial arsenic and cumulative arsenic leached as a function of bed volume of fluid passed through the column (Column 5, Fluid: Extraction Fluid # 1)**

It is noticeable from Figure 4.13 that out of 726  $\mu\text{g}$  of arsenic leached out from the column material, 381  $\mu\text{g}$  (12.3 %) leached out with 966 bed volume of flowing fluid and the rest 345 (11.1%)  $\mu\text{g}$  of arsenic leached out with 963 bed volume of water.

#### 4.5 GENERAL DISCUSSION

Figure 4.14 shows leaching of arsenic from waste as a function of bed volume of fluid passed through the columns (all columns). It shows that the highest amount of arsenic leached from the filter media contained in column 1 through which distilled water was allowed to pass. From this column the amount of leached arsenic was 1097  $\mu\text{g}$  (35.3%) and this is followed by column 2, column 3, column 4 and column 5 from which amount of leached arsenic was 871  $\mu\text{g}$  (28.1 %), 851  $\mu\text{g}$  (27.4 %), 787  $\mu\text{g}$  (25.4%) and 726  $\mu\text{g}$  (23.4 %), respectively. It can also be mentioned here that the highest amount of arsenic leached with distilled water from column 1 but it required lowest time (106 days) to become completely stabilized (also shown in Tables 1 and 2 in Appendix D).



**Figure 4.14: Cumulative arsenic leached as a function of bed volume of fluid passed through the columns (all columns)**

On the other hand, the lowest amount of arsenic was leached from column 5 but it required highest time (134 days). This is also true for volume of water (fluid) passed through the filter media in different columns. Lowest volume (1564 bed volume) of water was passed through column 1 while the highest volume (1929 bed volume) of extraction fluid # 1 was passed through column 5. It is clear from the above results and discussion that distilled water has the highest leaching capacity and is most aggressive in nature.

#### 4.6 MASS BALANCE

After the completion of the column experiment i.e. when the arsenic concentration in the leachate coming out of the column after passing through the sample in the column was found to be below the method detection limit (MDL) indicating complete stabilization of the sample, a mass balance analysis was performed. Mass balance analysis was done mainly for two purposes, first, to see whether there was any variation of weight of sample after the completion of experiment, and second, to see whether there was any variation of leaching of arsenic from various depth of the column. For these purposes, the columns were divided into four segments along the depth of the column. The total depth of each column was 380 mm of which upper 75 mm was taken as the first segment and second, third and fourth segment consist of 75 mm, 115 mm and 115 mm, respectively along the column depth. The columns were broken segment-wise in order to collect the samples (filter media) from different segments. Care was taken during the collection of samples from the segments so that there was no loss of sample. The sample from each of the segments was weighed and was compared to the initial weight of the sample in the column. Table 4.3 shows depths, weights, arsenic content, arsenic leaching, etc. of the sample in different segments of column 1. A total of 80 gm of sample was taken in each of the columns, but from Table 4.3, it is seen that the sum of the weights of samples in four segments of column 1 is 79.523 gm. Segment-wise depth, weight, arsenic concentrations, arsenic leaching, etc. of other columns are presented in Tables 5 to 8 in Appendix D, which show that the sum of the weights of samples in four segments of column 2, column 3, column 4 and column 5 stands to 79.264 gm, 78.915 gm, 78.994 gm and 79.134 gm, respectively. So, there was a little variation in the weight of sample. This

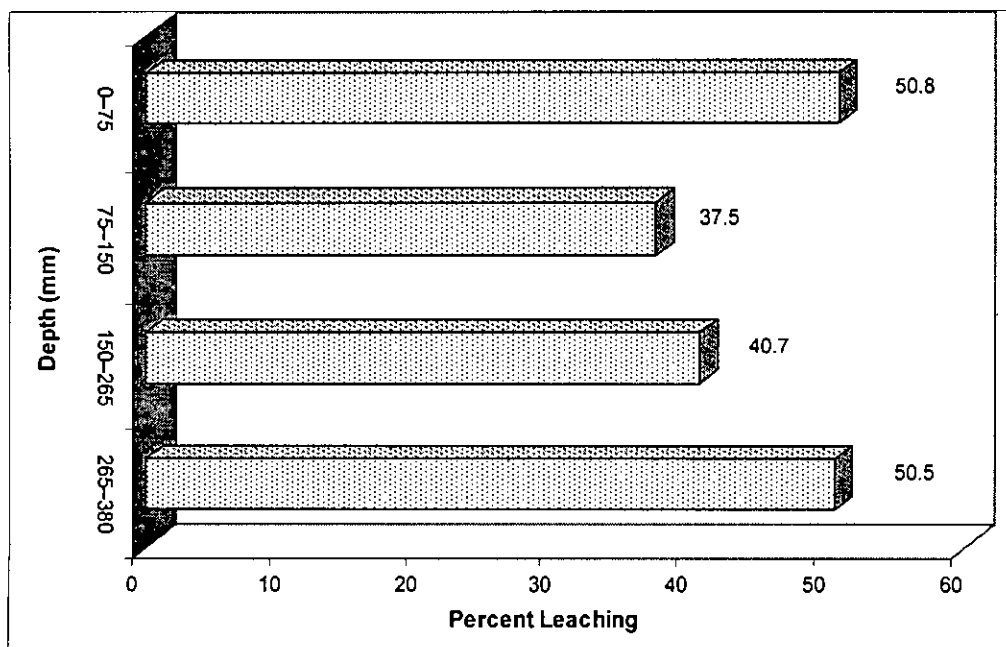
variation may be due to inaccuracy of the balance which was used for taking weight of the sample or due to loosing a small amount of sample somehow during the entire period of experiment.

The total arsenic content of the sample in different segments was determined in a procedure described in article 4.2.3. The data were compared to the initial arsenic concentration. For example, in the case of column 1, the initial arsenic concentration of sample in all the segments was 38.80 mg/kg, but after the completion of the experiment the arsenic concentration was found to be 19.08, 24.25, 23.00, 19.20 mg/Kg in segment 1, segment 2, segment 3 and segment 4, respectively.

**Table 4.3: Segment wise depth, weight, arsenic concentration, arsenic leaching etc. of Column 1 (Fluid: Distilled Water)**

Segment No.	Depth (mm)	Weight (gm)	As Conc. (mg/kg)	Total As at the end of column experiment ( $\mu\text{g}$ )	Initial As ( $\mu\text{g}$ )	Calculated As Leached ( $\mu\text{g}$ )	% As Leached
1	2	3	4	5	6	7=6-5	8
1	0-75	15.618	19.08	298	606	308	50.8
2	75-150	16.028	24.25	389	622	233	37.5
3	150-265	24.130	23.00	555	936	381	40.7
4	265-380	23.747	19.20	456	921	465	50.5
Total	-	79.523	-	1698	3085	1387	45.0

Arsenic concentration of four segments of other columns (column 2, column 3, column 4 and column 5) is shown in Tables 5 to 8 in Appendix D. It can be seen from Table 4.3 that 1698  $\mu\text{g}$  of arsenic remained in the waste sample after the end of column experiment. So, the rest (1387  $\mu\text{g}$ ) of the arsenic is supposed to leach out with the flowing fluid (distilled water in this case) during the time of column experiment.

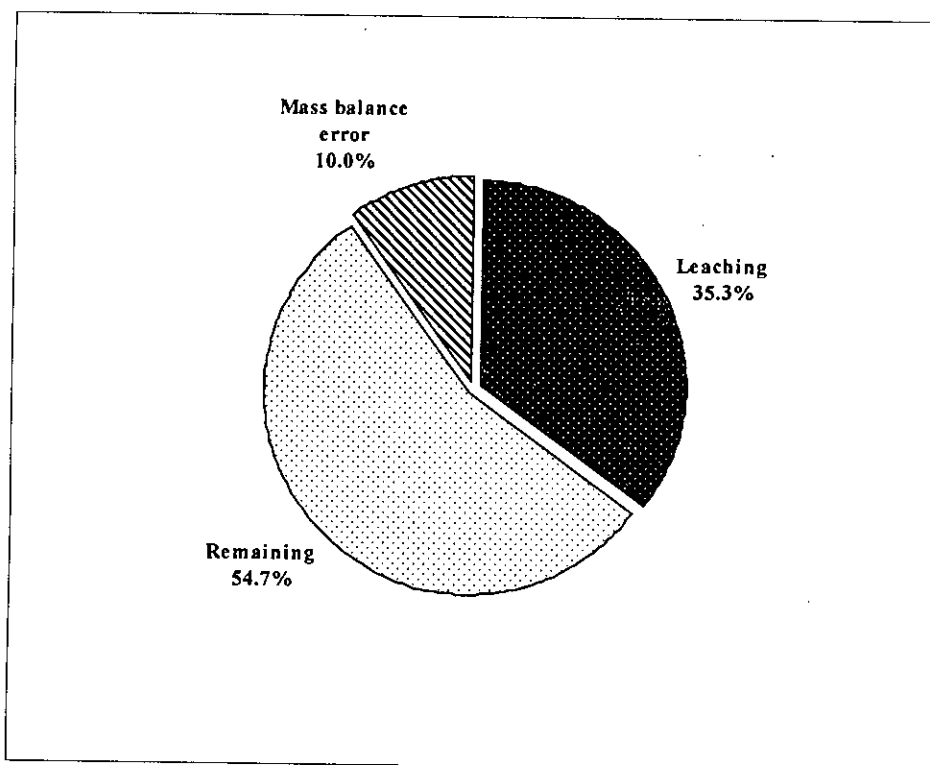


**Figure 4.15: Percent leaching of arsenic from various segments of column 1  
(Fluid: Distilled Water)**

Calculated percent leaching of arsenic from various segments of column 1 is presented in Figure 4.15. It can be seen from Figure 4.15 (also from Table 4.3) that there was a little variation in leaching of arsenic from various depths of the column. Leaching of arsenic from the first segment was 50.8 % and that from second, third and fourth segments were found to be 37.5 %, 40.7 % and 50.5 %, respectively. However, the reason for leaching of arsenic from various segments in such a pattern is not clear. Calculated percent leaching of arsenic from various segments of other columns is shown in Figures 45 to 50 in Appendix C.

The arsenic content in the sample was also determined in order to perform a mass balance. A total of 3104  $\mu\text{g}$  arsenic (80 gm of sample with concentration 38.8  $\mu\text{g}/\text{gm}$ ) was taken in the column. After the end of the column experiment i.e. when the arsenic concentration in leachate reached below the MDL, a total of 1097  $\mu\text{g}$  (35.3 % of initial arsenic present) of arsenic, which was measured by determining the arsenic concentration of the leachate collected during the period of column experiment, leached out from column 1.





**Figure 4.16: Total amount of arsenic leached, arsenic remaining and mass balance error of arsenic in column 1 (Fluid: Distilled Water).**

From Figure 4.16, mass balance error for column 1, in which distilled water was allowed to pass, was about 10 %. The Tables in Appendix D show that the cumulative leaching of arsenic from column 2, column 3, column 4 and column 5 are 871  $\mu\text{g}$  (28.1 %), 851  $\mu\text{g}$  (27.4 %), 787  $\mu\text{g}$  (25.4 %) and 726  $\mu\text{g}$  (22.7 %), respectively. The mass balance error for these columns are found to be 12.8 %, 16.6 %, 18.8 % and 18.9%, respectively (These are shown in Table 3 in Appendix D and also in Figures 51 to 55 in Appendix C).

#### **4.7 AN OVERVIEW: SHORT-TERM AND LONG-TERM LEACHING - A BRIEF COMPARISON**

One of the objectives of this study is to compare short-term (through TCLP) and long-term (through Column experiment) leaching of arsenic from wastes generated from filtration based arsenic removal units. The TCLP is performed in order to evaluate short-term leaching of arsenic from a waste sample using appropriate extraction fluid

which is determined following a procedure described in article 3.3.7. TCLP results of 16 slurry samples and 19 solid samples are presented in chapter 3. These test results show that for majority of the samples, leaching of arsenic expressed as a percent of initial arsenic present is very low.

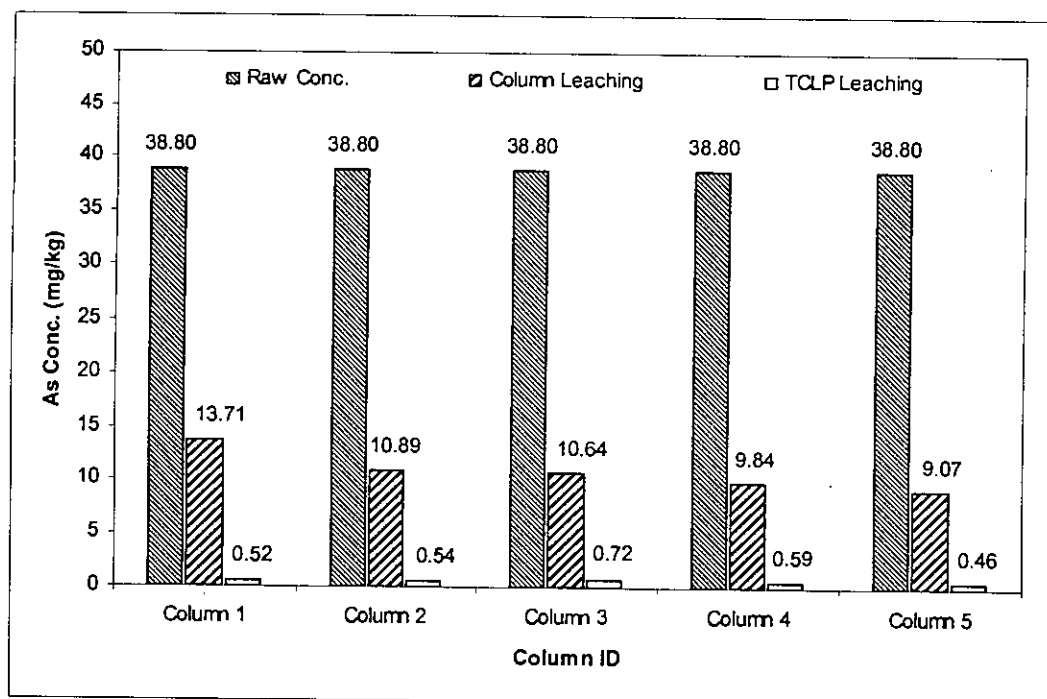
The TCLP results in chapter 3 confirm that the waste samples, both slurry and solid, are not "hazardous" as defined by the USEPA. However, TCLP may not be the appropriate test to determine the hazardous status arsenic rich wastes. Column experiment was performed in order to evaluate long-term leaching characteristics of the solid waste samples collected from filtration based arsenic removal units. Extraction fluid # 1 was used in TCLP for waste sample from 'Shapla' filter. So, this extraction fluid was also used in the column experiments to compare the leaching of arsenic from the same filter media. On the other hand, four types of different water e.g. distilled water, ground water, rainwater and pond water was used in column experiment and similar tests (like TCLP) were performed using these four types of water in stead of extraction fluid # 1 with a view to comparing short-term leaching and long-term leaching with the same fluid in the same waste sample.

**Table 4.4: Initial arsenic content, short-term leaching and long-term leaching of waste sample collected from 'Shapla' filter.**

Sl No.	Column	Fluid used	Raw As Conc. (mg/kg)	Long-term Leaching (mg/kg)	Short-term Leaching (mg/kg)	% Long-term Leaching	% Short-term Leaching
1	Column 1	Distilled Water	38.80	13.71	0.52	35.3	1.33
2	Column 2	Ground water	38.80	10.89	0.54	28.1	1.39
3	Column 3	Rainwater	38.80	10.64	0.72	27.4	1.85
4	Column 4	Pond water	38.80	9.84	0.59	25.4	1.53
5	Column 5	Extraction Fluid # 1	38.80	9.07	0.46	22.7	1.20

Table 4.4 shows short-term leaching and long-term leaching of waste sample with the above mentioned five different types of fluid. From this table we see that short-term leaching of arsenic is 0.52 mg/kg (1.33%), 0.54 mg/Kg (1.39%), 0.72 mg/Kg (1.85%), 0.59 mg/Kg (1.53%) and 0.46 mg/Kg (1.20%) when distilled water, ground water,

rainwater, pond water and extraction fluid # 1, respectively, were used as extraction fluid while long-term leaching through column experiment is found to be 13.71 mg/Kg (35.3 %), 10.89 mg/Kg (28.1 %), 10.64 mg/Kg (27.4 %), 9.84 mg/Kg (25.4 %) and 9.07 mg/Kg (22.7 %), respectively, by using the same fluid. Although the initial arsenic content was same (38.80 mg/Kg) for all the cases, there is a large variation in short-term leaching and long-term leaching. These are also presented in Figure 4.17.



**Figure 4.17: Initial arsenic content, long-term leaching and short-term leaching of waste sample collected from 'Shapla' filter.**

From the above discussion, it can easily be realized that long-term leaching causes greater release of arsenic than short-term leaching. Short-term leaching is found to be less than 2 % for five types of fluid whereas long-term leaching (column leaching) is found to be between 22.7 % and 35.3 %. In the context to short-term leaching, the waste sample does not belong to the "hazardous" category as defined by the USEPA. But if we consider long-term leaching, the waste sample is said to be "hazardous". It can be concluded from the above results and discussion that TCLP tests are not appropriate for assessing long-term leaching of arsenic from as well as stabilization of treatment wastes.

## CHAPTER - 5

### CONCLUSIONS AND RECOMMENDATIONS

#### 5.1 INTRODUCTION

The problem of arsenic contamination in groundwater of Bangladesh has not occurred overnight. It is difficult to prove beyond all doubt how the arsenic crisis has evolved since there is no historical record of its development. There may be a number of causes for arsenic contamination in groundwater. The development of strongly reducing environment is believed to be one reason that has been responsible for the release of naturally occurring arsenic from the sediment into the groundwater. Occurrence of arsenic in Bangladesh is highly scattered adding to the complexities of the problem.

It is fortunate that a large number of different types of arsenic removal technologies have been developed by Government, Non-Govt. Organizations (NGOs), donor agencies and private entrepreneurs and are now being used in Bangladesh in order to mitigate the disaster. Most of the technologies are more or less effective in removing arsenic from the groundwater below the acceptable limit set by the ECR 1997.

Almost all the technologies for removal of arsenic from groundwater in Bangladesh generate arsenic rich wastes in the form of solid, multiphasic sludge or solution. Various arsenic removal units use different chemicals for coagulation and subsequent co-precipitation, which produce multiphasic sludge. Besides, materials are used in the filtration based arsenic removal units for filtration of water. These filter media also produce high arsenic contaminated solid waste.

The arsenic rich solid wastes and multiphasic sludge generated from different types of arsenic removal units will require disposal in a manner that does not adversely affect the environment and human health.

## 5.2 CONCLUSIONS

Different arsenic removal systems practiced in Bangladesh may generate significant quantities of arsenic-rich treatment wastes and indiscriminate disposal of these wastes may lead to environmental pollution. Short-term leaching is determined following TCLP. Usually, this test is used to evaluate the leaching potential of the solid waste disposed in landfill sites. This procedure involves an aggressive acetic acid leaching at a lower pH following  $18 \pm 2$  hours agitation at a speed of  $30 \pm 2$  rpm. In this process arsenic rich wastes are stimulated and leaching occurs within a very short period of time. On the other hand, leaching occurs naturally over a relatively longer period of time in long-term leaching. This process provides quantitative leach rates expected when waste is disposed in open environment.

Short-term leaching of arsenic which was measured through TCLP was found to be very low. For majority of the slurry samples, leaching of arsenic expressed as percent of initial arsenic present was negligible. In the case of solid waste samples for which TCLP were performed, leaching of arsenic expressed as percent of initial arsenic present was also found to be very low. Although initial arsenic concentration of some of the solid waste sample was extremely high, percent leached out following aggressive leaching was quite low. In context to short-term leaching, the waste samples, both slurry and solid, do not fall into the "hazardous" category as defined by the USEPA.

Long-term leaching of arsenic measured through column experiment, was found to be quite significant compared to short-term leaching. Solid samples collected from 'Shapla Filter' was used for conducting column experiment. Five types of fluids namely distilled water, natural ground water, rainwater, pond water and extraction fluid #1 were used in the column experiment. These five types of fluids were also used for assessing short-term leaching of arsenic from the same waste samples. Long-term leaching of arsenic from the waste sample expressed as percent of initial arsenic present ranged from 22.7 % to 35.3 % whereas short-term leaching of arsenic from the same waste sample using the same fluids ranged from 1.20 % to 1.85 %. So, it can easily be realized that long-term leaching poses more threat to the environment than the short-term leaching. Although, in context to the short-term leaching, the waste

samples do not belong to the “hazardous” category according to the USEPA, it may be “hazardous” if subjected to long-term leaching. Therefore, pollution potential is higher if the waste is subjected to long-term leaching in an environment such as pond, open surface etc. It can be concluded that TCLP are not appropriate for assessing long-term leaching of arsenic.

As a result, it is not safe to dispose of the arsenic rich wastes generated from different arsenic removal units in the open environment. Indiscriminate disposal of arsenic rich waste may cause environmental hazard through leaching out of significant amount of arsenic after a considerable period of time.

### **5.3 RECOMMENDATIONS**

Almost all the technologies used in Bangladesh for removal of arsenic generate solid waste and multiphasic sludge, which are to be disposed of after the treatment. These highly contaminated wastes and sludge may create an environmental hazard through leaching of arsenic to the nature.

The mobility of arsenic has been evaluated through TCLP for short-term leaching and through column experiment for long-term leaching in the laboratory. But it has not been investigated in the field condition. So, extensive research work should be undertaken in order to investigate the mobility of arsenic. Effects of natural (e.g. reducing environment, microbial process) and anthropogenic (e.g. extraction of ground water) processes on mobilization of arsenic should be investigated.

Another task is to create awareness among the users of different arsenic removal units about the disposal of waste materials and sludge generated from the units. The users of the arsenic removal units should be careful about the disposal of generated sludge. Because, the arsenic rich wastes, either slurry or solid, generated from different arsenic removal units are often disposed of indiscriminately according to the end users discretion.

Potential management options for waste disposal must be considered and tested prior to distribution of the treatment systems. This needs to be investigated and kinetic leach tests for arsenic must be conducted to demonstrate that the waste will pose low risk to human and environmental health. Other waste products may require special disposal conditions and these management options should be defined and tested in a manner that includes expected or measured geochemical conditions. Kinetic leach testing of sludge would provide leach rates and loading estimates (mass arsenic leached per kg of waste per unit time) and this data can be used to assess the potential for environmental and human health impacts for the selected waste management options. For underwater disposal, the tests should include expected chemical characteristics of sediment, sediment pore water and surface water within the disposal site. The protocol for management of sludge generation from the arsenic removal units is currently being developed. It is expected that this study will help the process of protocol development.

After disposal, the sludge is likely to be mixed with the materials at the disposal site and will gradually penetrate below the surface. After certain time, the sludge will reach below the surface and may undergo anaerobic digestion. Therefore, research work should be extended for conducting anaerobic digestion of the sludge in order to investigate the leaching characteristics of sludge under anaerobic condition.

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**APPENDIX A: DETAIL RESULTS OF COLUMN  
EXPERIMENTS**

Column ID: C - 1; Water used: Distilled Water; pH = 7.10; Initial Volume = 250 ml; Start: 25/08/2002.

Leachate No.	Start		End		Volume (ml)	Time (Min)	Flow Rate (ml/hr)	Cumulative volume (ml)	Cumulative Time (min)	Cumulative Flow Rate (ml/hr)	As Conc. (ppb)	Mass of As (ug)	Cumulative Mass of As (ug)
	Time	Date	Time	Date									
Initial					250			250			138.99	34.748	34.748
L - 1	11:30	25.08.02	11:30	26.08.02	825	1440	34.38	1075	1440	44.79	90.83	74.935	109.682
L - 2	11:30	26.08.02	11:13	27.08.02	840	1423	35.42	1915	2863	40.13	50.71	42.596	152.279
L - 3	11:13	27.08.02	11:50	28.08.02	960	1477	39.00	2875	4340	39.75	46.60	44.736	197.015
L - 4	11:50	28.08.02	10:33	02.09.02	5120	7123	43.13	7995	11463	41.85	34.11	174.643	371.658
L - 5	10:33	02.09.02	12:11	03.09.02	1290	1538	50.33	9285	13001	42.85	27.42	35.372	407.030
L - 6	12:11	03.09.02	10:13	04.09.02	1085	1322	49.24	10370	14323	43.44	27.31	29.631	436.661
L - 7	10:13	04.09.02	12:28	07.09.02	3650	4455	49.16	14020	18778	44.80	21.32	77.818	514.479
L - 8	12:28	07.09.02	12:22	08.09.02	1150	1434	48.12	15170	20212	45.03	20.34	23.391	537.870
L - 9	12:22	08.09.02	9:45	11.09.02	2740	4163	39.49	17910	24375	44.09	22.60	61.924	599.794
L - 10	9:45	11.09.02	10:00	14.09.02	3600	4335	49.83	21510	28710	44.95	19.75	71.100	670.894
L - 11	10:00	14.09.02	12:29	15.09.02	850	1569	32.50	22360	30279	44.31	19.20	16.320	687.214
L - 12	12:29	15.09.02	12:08	16.09.02	895	1419	37.84	23255	31698	44.02	19.66	17.596	704.810
L - 13	12:08	16.09.02	11:52	17.09.02	1000	1424	42.13	24255	33122	43.94	19.12	19.120	723.930
L - 14	11:52	17.09.02	12:35	18.09.02	950	1483	38.44	25205	34605	43.70	19.42	18.449	742.379
L - 15	12:35	18.09.02	10:20	21.09.02	2960	4185	42.44	28165	38790	43.57	15.69	46.442	788.821
L - 16	10:20	21.09.02	3:14	22.09.02	1050	1734	36.33	29215	40524	43.26	10.90	11.445	800.266
L - 17	3:14	22.09.02	3:43	23.09.02	960	1469	39.21	30175	41993	43.11	10.82	10.387	810.653
L - 18	3:43	23.09.02	4:08	24.09.02	1075	1465	44.03	31250	43458	43.15	9.52	10.234	820.887

Leachate No.	Start		End		Volume (ml)	Time (Min)	Flow Rate (ml/hr)	Cumulative volume (ml)	Cumulative Time (min)	Cumulative Flow Rate (ml/hr)	As Conc. (ppb)	Mass of As (ug)	Cumulative Mass of As (ug)
	Time	Date	Time	Date									
L - 19	4:08	24.09.02	4:12	25.09.02	950	1444	39.47	32200	44902	43.03	11.59	11.011	831.898
L - 20	4:12	25.09.02	4:42	28.09.09	3850	4350	53.10	36050	49252	43.92	7.93	30.531	862.428
L - 21	4:42	28.09.09	10:34	29.09.02	650	1072	36.38	36700	50324	43.76	7.38	4.797	867.225
L - 22	9:30	30.09.02	11:06	01.10.02	950	1536	37.11	37650	51860	43.56	9.85	9.358	876.583
L - 23	11:06	01.10.02	11:48	02.10.02	955	1482	38.66	38605	53342	43.42	8.48	8.098	884.681
L - 24	11:48	02.10.02	10:30	06.10.02	3200	5682	33.79	41805	59024	42.50	8.87	28.384	913.065
L - 25	10:30	06.10.02	12:27	08.10.02	1820	2997	36.44	43625	62021	42.20	8.96	16.307	929.372
L - 26	12:27	08.10.02	3:16	09.10.02	1270	1609	47.36	44895	63630	42.33	7.64	9.703	939.075
L - 27	9:40	12.10.02	3:54	13.10.02	1450	1814	47.96	46345	65444	42.49	8.76	12.702	951.777
L - 28	9:55	19.10.02	9:57	20.10.02	860	1442	35.78	47205	66886	42.35	10.10	8.686	960.463
L - 29	9:57	20.10.02	12:35	21.10.02	1170	1598	43.93	48375	68484	42.38	8.11	9.489	969.952
L - 30	12:35	21.10.02	10:42	23.10.02	2220	2767	48.14	50595	71251	42.61	6.22	13.808	983.760
L - 31	10:42	23.10.02	10:18	26.10.02	2650	4296	37.01	53245	75547	42.29	5.21	13.807	997.567
L - 32	10:18	26.10.02	12:52	27.10.02	990	1594	37.26	54235	77141	42.18	6.34	6.277	1003.843
L - 33	12:52	27.10.02	3:56	28.10.02	990	1624	36.58	55225	78765	42.07	5.05	5.000	1008.843
L - 34	3:56	28.10.02	10:00	29.10.02	745	1084	41.24	55970	79849	42.06	5.35	3.986	1012.829
L - 35	10:00	29.10.02	11:50	02.11.02	3800	5870	38.84	59770	85719	41.84	4.85	18.430	1031.259
L - 36	11:50	02.11.02	12:38	03.11.02	835	1488	33.67	60605	87207	41.70	1.11	0.927	1032.186
L - 37	12:38	03.11.02	12:40	04.11.02	1250	1442	52.01	61855	88649	41.87	1.78	2.225	1034.411
L - 38	12:40	04.11.02	3:00	05.11.02	1225	1580	46.52	63080	90229	41.95	3.12	3.822	1038.233
L - 39	3:00	05.11.02	9:56	06.11.02	865	1136	45.69	63945	91365	41.99	2.28	1.972	1040.205
L - 40	9:56	06.11.02	10:20	09.11.02	3745	4344	51.73	67690	95709	42.43	2.14	8.014	1048.219



Leachate No.	Start		End		Volume (ml)	Time (Min)	Flow Rate (ml/hr)	Cumulative volume (ml)	Cumulative Time (min)	Cumulative Flow Rate (ml/hr)	As Conc. (ppb)	Mass of As (ug)	Cumulative Mass of As (ug)
	Time	Date	Time	Date									
L - 41	10:20	09.11.02	10:50	10.11.02	895	1470	36.5306	68585	97179	42.35	2.15	1.924	1050.143
L - 42	10:50	10.11.02	9:40	12.11.02	1935	2810	41.3167	70520	99989	42.32	1.84	3.560	1053.704
L - 43	9:40	12.11.02	10:30	13.11.02	1060	1490	42.6846	71580	101479	42.32	1.25	1.325	1055.029
L - 44	10:30	13.11.02	9:55	16.11.02	3540	4285	49.5683	75120	105764	42.62	1.12	3.965	1058.993
L - 45	9:55	16.11.02	1:05	17.11.02	995	1630	36.6258	76115	107394	42.52	2.54	2.527	1061.521
L - 46	1:05	17.11.02	1:30	18.11.02	980	1465	40.1365	77095	108859	42.49	1.86	1.823	1063.344
L - 47	1:30	18.11.02	10:52	19.11.02	880	1282	41.1856	77975	110141	42.48	1.25	1.100	1064.444
L - 48	10:52	19.11.02	11:58	20.11.02	1120	1506	44.6215	79095	111647	42.51	1.22	1.366	1065.810
L - 49	11:58	20.11.02	12:38	23.11.02	2850	4360	39.2202	81945	116007	42.38	1.15	3.278	1069.087
L - 50	12:38	23.11.02	12:38	24.11.02	1105	1440	46.0417	83050	117447	42.43	1.40	1.547	1070.634
L - 51	12:38	24.11.02	12:28	25.11.02	1125	1430	47.2028	84175	118877	42.49	1.33	1.496	1072.131
L - 52	12:28	25.11.02	10:52	27.11.02	1720	2784	37.069	85895	121661	42.36	1.12	1.926	1074.057
L - 53	10:52	27.11.02	10:30	30.11.02	2530	4298	35.3188	88425	125959	42.12	1.15	2.910	1076.967
L - 54	10:30	30.11.02	2:15	01.12.02	1150	1665	41.4414	89575	127624	42.11	1.32	1.518	1078.485
L - 55	2:15	01.12.02	12:18	02.12.02	910	1323	41.2698	90485	128947	42.10	1.11	1.010	1079.495
L - 56	9:15	13.12.02	3:05	14.12.02	1300	1790	43.5754	91785	130737	42.12	0.86	1.118	1080.613
L - 57	3:05	14.12.02	12:50	15.12.02	910	1305	41.8391	92695	132042	42.12	1.11	1.010	1081.623
L - 58	12:50	15.12.02	4:02	17.12.02	1725	3072	33.6914	94420	135114	41.93	1.12	1.932	1083.555
L - 59	4:02	17.12.02	12:20	21.12.02	2985	5538	32.3402	97405	140652	41.55	1.09	3.254	1086.808
L - 60	12:20	21.12.02	12:00	22.12.02	1050	1420	44.3662	98455	142072	41.58	1.09	1.145	1087.953
L - 61	12:00	22.12.02	4:32	23.12.02	1120	1712	39.2523	99575	143784	41.55	1.08	1.210	1089.163
L - 62	4:32	23.12.02	4:44	24.12.02	1055	1452	43.595	100630	145236	41.57	1.25	1.319	1090.481

Leachate No.	Start		End		Volume (ml)	Time (Min)	Flow Rate (ml/hr)	Cumulative volume (ml)	Cumulative Time (min)	Cumulative Flow Rate (ml/hr)	As Conc. (ppb)	Mass of As (ug)	Cumulative Mass of As (ug)
	Time	Date	Time	Date									
L - 63	4:45	24.12.02	11:53	28.12.02	3750	5468	41.1485	104380	150704	41.56	1.38	5.175	1095.656
L - 64	11:53	28.12.02	1:19	29.12.02	900	1526	35.3866	105280	152230	41.50	1.02	0.918	1096.574
L - 65	1:19	29.12.02	3:21	30.12.02	850	1562	32.6504	106130	153792	41.41	<1.00		
L - 66	3:21	30.12.02	3:01	31.12.02	840	1420	35.493	106970	155212	41.35	<1.00		
L - 67	3:01	31.12.02	12:01	01.01.03	760	1260	36.1905	107730	156472	41.31	<1.00		
L - 68	12:01	01.01.03	2:55	04.01.03	3280	4494	43.7917	111010	160966	41.38	<1.00		
L - 69	2:55	04.01.03	1:12	06.01.03	1890	2777	40.8354	112900	163743	41.37	<1.00		

Column ID: C - 2; Water used: Ground Water; pH = 6.80; Initial Volume = 290 ml; Start: 25/08/2002.

Leachate No.	Start		End		Volume (ml)	Time (Min)	Flow Rate (ml/hr)	Cumulative volume (ml)	Cumulative Time (min)	Cumulative flow rate (ml/hr)	As Conc.(ppb)	Mass of As (ug)	Cumulative Mass of As (ug)
	Time	Date	Time	Date									
Initial					290			290					
L - 1	11:30	25.08.02	11:37	26.08.02	865	1447	0.00	1155	1447	47.89	57.55	16.690	16.690
L - 2	11:37	26.08.02	11:18	27.08.02	675	1423	28.46	1830	2870	38.26	57.85	50.040	66.730
L - 3	11:18	27.08.02	11:58	28.08.02	820	1480	33.24	2650	4350	36.55	47.88	32.319	99.049
L - 4	11:58	28.08.02	10:30	02.09.02	4125	7108	34.82	6775	11458	35.48	25.35	20.787	119.836
L - 5	10:30	02.09.02	12:16	03.09.02	1120	1546	43.47	7895	13004	36.43	20.78	85.718	205.553
L - 6	12:16	03.09.02	10:20	04.09.02	1000	1324	45.32	8895	14328	37.25	21.73	24.338	229.891
L - 7	10:20	04.09.02	12:31	07.09.02	2700	4451	36.40	11595	18779	37.05	19.19	19.190	249.081
L - 8	12:31	07.09.02	12:26	08.09.02	1000	1435	41.81	12595	20214	37.38	17.51	47.277	296.358
L - 9	12:26	08.09.02	9:50	11.09.02	3850	4164	55.48	16445	24378	40.48	13.58	13.580	309.938
L - 10	9:50	11.09.02	10:05	14.09.02	3700	4335	51.21	20145	28713	42.10	12.41	47.779	357.716
L - 11	10:05	14.09.02	12:32	15.09.02	1210	1587	45.75	21355	30300	42.29	10.44	38.628	396.344
L - 12	12:32	15.09.02	12:11	16.09.02	685	1419	28.96	22040	31719	41.69	10.75	13.008	409.352
L - 13	12:11	16.09.02	11:55	17.09.02	750	1424	31.60	22790	33143	41.26	10.73	7.350	416.702
L - 14	11:55	17.09.02	12:37	18.09.02	650	1482	26.32	23440	34625	40.62	12.11	9.083	425.784
L - 15	12:37	18.09.02	10:30	21.09.02	2685	4193	38.42	26125	38818	40.38	12.44	8.086	433.870
L - 16	10:30	21.09.02	3:17	22.09.02	885	1727	30.75	27010	40545	39.97	12.23	32.838	466.708
L - 17	3:17	22.09.02	3:47	23.09.02	895	1470	36.53	27905	42015	39.85	15.00	13.275	479.983
L - 18	3:47	23.09.02	4:13	24.09.02	1025	1466	41.95	28930	43481	39.92	16.51	14.776	494.759
L - 19	4:13	24.09.02	4:14	25.09.02	945	1441	39.35	29875	44922	39.90	12.74	13.059	507.818
											6.37	6.020	513.838

Leachate No.	Start		End		Volume (ml)	Time (Min)	Flow Rate (ml/hr)	Cumulative volume (ml)	Cumulative Time (min)	Cumulative flow rate (ml/hr)	As Conc.(ppb)	Mass of As (ug)	Cumulative Mass of As (ug)
	Time	Date	Time	Date									
L - 20	4:14	25.09.02	4:48	28.09.09	3710	4354	51.13	33585	49276	40.89	7.50	27.825	541.663
L - 21	4:48	28.09.02	10:36	29.09.02	870	1068	48.88	34455	50344	41.06	5.70	4.959	546.622
L - 22	10:36	29.09.02	10:50	30.09.02	1000	1454	41.27	35455	51798	41.07	5.62	5.620	552.242
L - 23	10:50	30.09.02	11:08	01.10.02	1600	1458	65.84	37055	53256	41.75	5.30	8.480	560.722
L - 24	11:08	01.10.02	11:52	02.10.02	1380	1484	55.80	38435	54740	42.13	5.34	7.369	568.091
L - 25	11:52	02.10.02	10:34	06.10.02	2550	5682	26.93	40985	60422	40.70	5.45	13.898	581.988
L - 26	10:34	06.10.02	12:30	08.10.02	1250	2996	25.03	42235	63418	39.96	6.31	7.888	589.876
L - 27	12:30	08.10.02	3:18	09.10.02	1510	1608	56.34	43745	65026	40.36	7.18	10.842	600.718
L - 28	3:18	09.10.02	9:48	12.10.02	2360	3990	35.49	46105	69016	40.08	6.18	14.585	615.302
L - 29	9:48	12.10.02	3:54	13.10.02	1250	1806	41.53	47355	70822	40.12	7.26	9.075	624.377
L - 30	9:55	19.10.02	9:58	20.10.02	450	1443	18.71	47805	72265	39.69	17.34	7.803	632.180
L - 31	9:58	20.10.02	12:40	21.10.02	1500	1602	56.18	49305	73867	40.05	6.57	9.855	642.035
L - 32	12:40	21.10.02	10:44	23.10.02	1950	2764	42.33	51255	76631	40.13	5.68	11.076	653.111
L - 33	10:44	23.10.02	10:20	26.10.02	2440	4296	34.08	53695	80927	39.81	5.97	14.567	667.678
L - 34	10:20	26.10.02	12:56	27.10.02	760	1596	28.57	54455	82523	39.59	6.35	4.826	672.504
L - 35	12:56	27.10.02	3:58	28.10.02	660	1622	24.41	55115	84145	39.30	4.27	2.818	675.322
L - 36	3:58	28.10.02	10:04	29.10.02	600	1086	33.15	55715	85231	39.22	5.32	3.192	678.514
L - 37	10:04	29.10.02	11:55	02.11.02	3660	5871	37.40	59375	91102	39.10	6.02	22.033	700.548
L - 38	11:55	02.11.02	12:40	03.11.02	780	1485	31.52	60155	92587	38.98	6.39	4.984	705.532
L - 39	12:40	03.11.02	12:42	04.11.02	800	1442	33.29	60955	94029	38.90	5.53	4.424	709.956
L - 40	12:42	04.11.02	3:02	05.11.02	1560	1580	59.24	62515	95609	39.23	6.18	9.641	719.597
L - 41	3:02	05.11.02	9:58	06.11.02	830	1136	43.84	63345	96745	39.29	6.37	5.287	724.884

Leachate No.	Start		End		Volume (ml)	Time (Min)	Flow Rate (ml/hr)	Cumulative volume (ml)	Cumulative Time (min)	Cumulative flow rate (ml/hr)	As Conc.(ppb)	Mass of As (ug)	Cumulative Mass of As (ug)
	Time	Date	Time	Date									
L - 42	9:58	06.11.02	10:24	09.11.02	2420	4342	33.44	65765	101087	39.03	4.04	9.777	734.660
L - 43	10:24	09.11.02	10:52	10.11.02	770	1468	31.47	66535	102555	38.93	3.75	2.888	737.548
L - 44	10:52	10.11.02	9:43	12.11.02	2055	2811	43.86	68590	105366	39.06	3.16	6.494	744.042
L - 45	9:43	12.11.02	10:32	13.11.02	1180	1411	50.18	69770	106777	39.21	4.04	4.767	748.809
L - 46	10:32	13.11.02	9:58	16.11.02	3060	4286	42.84	72830	111063	39.35	2.80	8.568	757.377
L - 47	9:58	16.11.02	1:08	17.11.02	1050	1630	38.65	73880	112693	39.34	2.22	2.331	759.708
L - 48	1:08	17.11.02	1:32	18.11.02	1130	1464	46.31	75010	114157	39.42	1.58	1.785	761.493
L - 49	1:32	18.11.02	10:54	19.11.02	720	1282	33.70	75730	115439	39.36	2.32	1.670	763.164
L - 50	10:54	19.11.02	12:00	20.11.02	1170	1506	46.61	76900	116945	39.45	2.38	2.785	765.948
L - 51	12:00	20.11.02	12:40	23.11.02	2150	4360	29.59	79050	121305	39.10	2.71	5.827	771.775
L - 52	12:40	23.11.02	12:40	24.11.02	950	1440	39.58	80000	122745	39.11	2.74	2.603	774.378
L - 53	12:40	24.11.02	12:30	25.11.02	1330	1430	55.80	81330	124175	39.30	2.90	3.857	778.235
L - 54	12:30	25.11.02	10:54	27.11.02	3100	2784	66.81	84430	126959	39.90	2.92	9.052	787.287
L - 55	10:54	27.11.02	10:32	30.11.02	3060	4298	42.72	87490	131257	39.99	3.85	11.781	799.068
L - 56	10:32	30.11.02	2:18	01.12.02	1150	1666	41.42	88640	132923	40.01	2.79	3.209	802.276
L - 57	2:18	01.12.02	12:24	02.12.02	750	1326	33.94	89390	134249	39.95	3.08	2.310	804.586
L - 58	9:15	11.12.02	3:07	14.12.02	3360	4672	43.15	92750	138921	40.06	5.80	19.488	824.074
L - 59	3:07	14.12.02	12:52	15.12.02	1150	1305	52.87	93900	140226	40.18	5.45	6.268	830.342
L - 60	12:52	15.12.02	4:04	17.12.02	1770	3072	34.57	95670	143298	40.06	2.91	5.151	835.493
L - 61	4:04	17.12.02	12:22	21.12.02	2420	5538	26.22	98090	148836	39.54	2.06	4.985	840.478
L - 62	12:22	21.12.02	12:02	22.12.02	1370	1420	57.89	99460	150256	39.72	2.40	3.288	843.766
L - 63	12:02	22.12.02	4:34	23.12.02	1610	1712	56.43	101070	151968	39.90	1.96	3.156	846.921

Leachate No.	Start		End		Volume (ml)	Time (Min)	Flow Rate (ml/hr)	Cumulative volume (ml)	Cumulative Time (min)	Cumulative flow rate (ml/hr)	As Conc.(ppb)	Mass of As (ug)	Cumulative Mass of As (ug)
	Time	Date	Time	Date									
L - 64	4:34	23.12.02	4:46	24.12.02	1070	1452	44.21	102140	153420	39.95	1.53	1.637	848.558
L - 65	4:46	24.12.02	11:54	28.12.02	4260	5468	46.74	106400	158888	40.18	1.15	4.899	853.457
L - 66	11:54	28.12.02	1:20	29.12.02	900	1526	35.39	107300	160414	40.13	1.97	1.773	855.230
L - 67	1:20	29.12.02	3:22	30.12.02	850	1562	32.65	108150	161976	40.06	1.80	1.530	856.760
L - 68	3:22	30.12.02	3:06	31.12.02	620	1424	26.12	108770	163400	39.94	1.60	0.992	857.752
L - 69	3:06	31.12.02	12:06	01.01.03	750	1260	35.71	109520	164660	39.91	1.14	0.855	858.607
L - 70	12:06	01.01.03	3:00	04.01.03	3560	4494	47.53	113080	169154	40.11	1.73	6.159	864.766
L - 71	3:00	04.01.03	1:17	06.01.03	3100	2777	66.98	116180	171931	40.54	1.30	4.030	868.796
L - 72	1:17	06.01.03	3:07	07.01.03	1620	1550	62.71	117800	173481	40.74	1.26	2.041	870.837
L - 73	3:07	07.01.03	3:26	08.01.03	1420	1459	58.40	119220	174940	40.89	<1.00		
L - 74	3:26	08.01.03	3:17	11.01.03	3100	4311	43.15	122320	179251	40.94	<1.00		
L - 75	9:30	12.01.03	4:27	13.01.03	1760	1857	56.87	124080	181108	41.11	<1.00		
L - 76	4:27	13.01.03	3:42	14.01.03	1450	1395	62.37	125530	182503	41.27	<1.00		
L - 77	3:42	14.01.03	11:10	15.01.03	995	1168	51.11	126525	183671	41.33	<1.00		

Column ID: C - 3; Water used: Rainwater; pH = 7.50; Initial Volume = 170 ml; Start: 25/08/2002.

Leachate No.	Start		End		Volume (ml)	Time (Min)	Flow Rate (ml/hr)	Cumulative volume (ml)	Cumulative Time (min)	Cumulative flow rate (ml/hr)	As Conc.(ppb)	Mass of As (ug)	Cumulative Mass of As (ug)
	Time	Date	Time	Date									
Initial					170			290			72.34	12.298	12.298
L - 1	11:30	25.08.02	11:45	26.08.02	830	1455	34.23	1120	1447	46.44	58.06	48.190	60.488
L - 2	11:45	26.08.02	11:25	27.08.02	890	1420	37.61	2010	2867	42.06	53.58	47.686	108.174
L - 3	11:25	27.08.02	12:04	28.08.02	795	1479	32.25	2805	4346	38.73	33.01	26.243	134.417
L - 4	12:04	28.08.02	10:20	02.09.02	4050	7096	34.24	6855	11442	35.95	9.86	39.933	174.350
L - 5	10:20	02.09.02	12:21	03.09.02	1330	1561	51.12	8185	13003	37.77	21.59	28.715	203.064
L - 6	12:21	03.09.02	10:26	04.09.02	1150	1325	52.08	9335	14328	39.09	13.41	15.422	218.486
L - 7	10:26	04.09.02	12:37	07.09.02	4700	4451	63.36	14035	18779	44.84	11.71	55.037	273.523
L - 8	12:37	07.09.02	12:30	08.09.02	1390	1433	58.20	15425	20212	45.79	10.48	14.567	288.090
L - 9	12:30	08.09.02	9:54	11.09.02	4150	4164	59.80	19575	24376	48.18	9.45	39.218	327.308
L - 10	9:54	11.09.02	10:10	14.09.02	2800	4336	38.75	22375	28712	46.76	8.45	23.660	350.968
L - 11	9:30	21.09.02	3:23	22.09.02	990	1793	33.13	23365	30505	45.96	18.41	18.226	369.194
L - 12	3:23	22.09.02	3:49	23.09.02	715	1466	29.26	24080	31971	45.19	13.41	9.588	378.782
L - 13	3:49	23.09.02	4:15	24.09.02	1150	1466	47.07	25230	33437	45.27	12.91	14.847	393.628
L - 14	4:15	24.09.02	4:16	25.09.02	1260	1441	52.46	26490	34878	45.57	8.76	11.038	404.666
L - 15	4:16	25.09.02	4:52	28.09.09	3620	4356	49.86	30110	39234	46.05	7.28	26.354	431.019
L - 16	4:52	28.09.02	10:38	29.09.02	900	1066	50.66	31010	40300	46.17	10.57	9.513	440.532
L - 17	10:38	29.09.02	10:54	30.09.02	1290	1456	53.16	32300	41756	46.41	10.27	13.248	453.781
L - 18	10:54	30.09.02	11:10	01.10.02	1150	1456	47.39	33450	43212	46.45	10.09	11.604	465.384
L - 19	11:10	01.10.02	11:55	02.10.02	1110	1485	44.85	34560	44697	46.39	9.81	10.889	476.273

Leachate No.	Start		End		Volume (ml)	Time (Min)	Flow Rate (ml/hr)	Cumulative volume (ml)	Cumulative Time (min)	Cumulative flow rate (ml/hr)	As Conc.(ppb)	Mass of As (ug)	Cumulative Mass of As (ug)
	Time	Date	Time	Date									
L - 20	11:55	02.10.02	10:38	06.10.02	3500	5683	36.95	38060	50380	45.33	9.98	34.930	511.203
L - 21	10:38	06.10.02	12:32	08.10.02	1710	2994	34.27	39770	53374	44.71	9.78	16.724	527.927
L - 22	12:32	08.10.02	3:20	09.10.02	950	1608	35.45	40720	54982	44.44	9.57	9.092	537.019
L - 23	3:20	09.10.02	9:50	12.10.02	2600	3990	39.10	43320	58972	44.08	8.41	21.866	558.885
L - 24	9:50	12.10.02	3:54	13.10.02	1280	1804	42.57	44600	60776	44.03	7.91	10.125	569.009
L - 25	9:55	19.10.02	10:00	20.10.02	980	1445	40.69	45580	62221	43.95	11.46	11.231	580.240
L - 26	10:00	20.10.02	12:42	21.10.02	1000	1602	37.45	46580	63823	43.79	8.32	8.320	588.560
L - 27	12:42	21.10.02	10:46	23.10.02	1350	2764	29.31	47930	66587	43.19	7.59	10.247	598.807
L - 28	10:46	23.10.02	10:22	26.10.02	2830	4296	39.53	50760	70883	42.97	7.13	20.178	618.985
L - 29	10:22	26.10.02	12:58	27.10.02	1180	1596	44.36	51940	72479	43.00	6.49	7.658	626.643
L - 30	12:58	27.10.02	4:00	28.10.02	1130	1622	41.80	53070	74101	42.97	6.85	7.741	634.383
L - 31	4:00	28.10.02	10:06	29.10.02	670	1086	37.02	53740	75187	42.89	6	4.020	638.403
L - 32	10:06	29.10.02	11:57	02.11.02	3660	5871	37.40	57400	81058	42.49	6.94	25.400	663.804
L - 33	11:57	02.11.02	12:57	03.11.02	430	1500	17.20	57830	82558	42.03	7.3	3.139	666.943
L - 34	12:57	12.11.02	10:34	13.11.02	910	1297	42.10	58740	83855	42.03	6.37	5.797	672.739
L - 35	10:34	13.11.02	10:00	16.11.02	2420	4286	33.88	61160	88141	41.63	5.78	13.988	686.727
L - 36	10:00	16.11.02	1:10	17.11.02	960	1630	35.34	62120	89771	41.52	4.79	4.598	691.325
L - 37	1:10	17.11.02	1:36	18.11.02	930	1466	38.06	63050	91237	41.46	3.97	3.692	695.018
L - 38	1:36	18.11.02	10:56	19.11.02	790	1280	37.03	63840	92517	41.40	3.71	2.931	697.948
L - 39	10:56	19.11.02	12:02	20.11.02	950	1566	36.40	64790	94083	41.32	3.83	3.639	701.587
L - 40	12:02	20.11.02	12:42	23.11.02	2700	4360	37.16	67490	98443	41.13	3.34	9.018	710.605
L - 41	12:42	23.11.02	12:42	24.11.02	770	1440	32.08	68260	99883	41.00	3.54	2.726	713.331



Leachate No.	Start		End		Volume (ml)	Time (Min)	Flow Rate (ml/hr)	Cumulative volume (ml)	Cumulative Time (min)	Cumulative flow rate (ml/hr)	As Conc.(ppb)	Mass of As (ug)	Cumulative Mass of As (ug)
	Time	Date	Time	Date									
L - 64	3:19	11.01.03	3:57	12.01.03	1160	1478	47.09	102527	150669	40.83	2.15	2.494	832.126
L - 65	3:57	12.01.03	4:29	13.01.03	1055	1472	43.00	103582	152141	40.85	2.82	2.975	835.101
L - 66	4:29	13.01.03	3:44	14.01.03	1250	1395	53.76	104832	153536	40.97	2.61	3.263	838.364
L - 67	4:45	19.01.03	4:36	20.01.03	2000	1431	83.86	106832	154967	41.36	1.89	3.780	842.144
L - 68	4:36	20.01.03	10:22	22.01.03	1930	2506	46.21	108762	157473	41.44	1.83	3.532	845.676
L - 69	10:22	22.01.03	4:34	25.01.03	2860	4692	36.57	111622	162165	41.30	1.86	5.320	850.995
L - 70	4:34	25.01.03	12:20	27.01.03	1400	2626	31.99	113022	164791	41.15	<1.00		
L - 71	12:20	27.01.03	3:34	28.01.03	1650	1634	60.59	114672	166425	41.34	<1.00		
L - 72	3:34	28.01.03	4:06	29.01.03	630	1472	25.68	115302	167897	41.20	<1.00		
L - 73	4:06	29.01.03	12:34	02.02.03	3850	5548	41.64	119152	173445	41.22	<1.00		
L - 74	12:34	02.02.03	11:54	04.02.03	2700	2840	57.04	121852	176285	41.47	<1.00		

Column ID: C - 4; Water used: Pond Water; pH = 7.30; Initial Volume = 120 ml; Start: 25/08/2002.

Leachate No.	Start		End		Volume (ml)	Time (Min)	Flow Rate (ml/hr)	Cumulative volume (ml)	Cumulative Time (min)	Cumulative flow rate (ml/hr)	As Conc. (ppb)	Mass of As (ug)	Cumulative Mass of As (ug)
	Time	Date	Time	Date									
Initial					120			120			68.48	8.218	8.218
L - 1	1:15	28.08.02	10:00	02.09.02	4555	7005	39.01	4675	7005	40.04	19.53	88.959	97.177
L - 2	10:00	02.09.02	12:23	03.09.02	1120	1583	42.45	5795	8588	40.49	18.54	20.765	117.942
L - 3	12:23	03.09.02	10:30	04.09.02	1120	1327	50.64	6915	9915	41.85	11.35	12.712	130.654
L - 4	10:30	04.09.02	12:45	07.09.02	2740	4455	36.90	9655	14370	40.31	12.12	33.209	163.862
L - 5	12:45	07.09.02	12:33	08.09.02	1060	1428	44.54	10715	15798	40.70	9.45	10.017	173.879
L - 6	12:33	08.09.02	9:58	11.09.02	3130	4165	45.09	13845	19963	41.61	9.05	28.327	202.206
L - 7	10:00	14.09.02	12:35	15.09.02	1465	1595	55.11	15310	21558	42.61	9.66	14.152	216.358
L - 8	12:35	15.09.02	12:15	16.09.02	975	1420	41.20	16285	22978	42.52	9.99	9.740	226.098
L - 9	12:15	16.09.02	11:58	17.09.02	1200	1423	50.60	17485	24401	42.99	6.55	7.860	233.958
L - 10	11:58	17.09.02	12:40	18.09.02	885	1482	35.83	18370	25883	42.58	4.26	3.770	237.728
L - 11	12:40	18.09.02	10:35	21.09.02	2740	4195	39.19	21110	30078	42.11	8.04	22.030	259.758
L - 12	10:35	21.09.02	3:27	22.09.02	965	1732	33.43	22075	31810	41.64	9.57	9.235	268.993
L - 13	3:27	22.09.02	3:52	23.09.02	955	1465	39.11	23030	33275	41.53	8.77	8.375	277.368
L - 14	3:52	23.09.02	4:18	24.09.02	1050	1466	42.97	24080	34741	41.59	6.73	7.067	284.435
L - 15	4:18	24.09.02	4:18	25.09.02	960	1440	40.00	25040	36181	41.52	6.04	5.798	290.233
L - 16	4:18	25.09.02	4:54	28.09.09	2510	4356	34.57	27550	40537	40.78	8.01	20.105	310.338
L - 17	4:54	28.09.02	10:40	29.09.02	680	1066	38.27	28230	41603	40.71	8.03	5.460	315.799
L - 18	10:40	29.09.02	10:58	30.09.02	870	1458	35.80	29100	43061	40.55	8.22	7.151	322.950
L - 19	10:58	30.09.02	11:12	01.10.02	900	1454	37.14	30000	44515	40.44	8.48	7.632	330.582

Leachate No.	Start		End		Volume (ml)	Time (Min)	Flow Rate (ml/hr)	Cumulative volume (ml)	Cumulative Time (min)	Cumulative flow rate (ml/hr)	As Conc. (ppb)	Mass of As (ug)	Cumulative Mass of As (ug)
	Time	Date	Time	Date									
L - 20	11:12	01.10.02	11:57	02.10.02	960	1485	38.79	30960	46000	40.38	8.43	8.093	338.675
L - 21	11:57	02.10.02	10:40	05.10.02	2180	4243	30.83	33140	50243	39.58	8.39	18.290	356.965
L - 22	10:30	06.10.02	12:34	08.10.02	1750	3004	34.95	34890	53247	39.31	9.06	15.855	372.820
L - 23	12:34	08.10.02	3:22	09.10.02	1050	1608	39.18	35940	54855	39.31	9.09	9.545	382.364
L - 24	3:22	09.10.02	9:53	12.10.02	2250	3991	33.83	38190	58846	38.94	8.68	19.530	401.894
L - 25	11:00	13.10.02	3:54	13.10.02	1250	1734	43.25	39440	60580	39.06	9.05	11.313	413.207
L - 26	9:55	19.10.02	10:01	20.10.02	860	1446	35.68	40300	62026	38.98	9.33	8.024	421.231
L - 27	10:01	20.10.02	12:45	21.10.02	1145	1604	42.83	41445	63630	39.08	8.15	9.332	430.562
L - 28	12:45	21.10.02	10:48	23.10.02	1690	2764	36.69	43135	66394	38.98	7.33	12.388	442.950
L - 29	10:48	23.10.02	10:25	26.10.02	2780	4297	38.82	45915	70691	38.97	8.01	22.268	465.218
L - 30	10:25	26.10.02	1:02	27.10.02	1345	1597	50.53	47260	72288	39.23	7.69	10.343	475.561
L - 31	1:02	27.10.02	4:02	28.10.02	1100	1620	40.74	48360	73908	39.26	6.55	7.205	482.766
L - 32	4:02	28.10.02	10:08	29.10.02	610	1086	33.70	48970	74994	39.18	6.78	4.136	486.902
L - 33	10:08	29.10.02	12:00	02.11.02	4025	5872	41.13	52995	80866	39.32	5.12	20.608	507.510
L - 34	12:00	02.11.02	12:00	03.11.02	985	1440	41.04	53980	82306	39.35	6.98	6.875	514.385
L - 35	12:00	03.11.02	12:46	04.11.02	1500	1486	60.57	55480	83792	39.73	5.76	8.640	523.025
L - 36	12:46	04.11.02	3:06	05.11.02	1280	1580	48.61	56760	85372	39.89	5.27	6.746	529.771
L - 37	3:06	05.11.02	10:00	06.11.02	910	1134	48.15	57670	86506	40.00	4.9	4.459	534.230
L - 38	10:00	06.11.02	10:27	09.11.02	3450	4347	47.62	61120	90853	40.36	3.68	12.696	546.926
L - 39	10:27	09.11.02	10:54	10.11.02	1130	1467	46.22	62250	92320	40.46	4.64	5.243	552.169
L - 40	10:54	10.11.02	9:46	12.11.02	1910	2812	40.75	64160	95132	40.47	4.19	8.003	560.172
L - 41	9:46	12.11.02	10:36	13.11.02	890	1490	35.84	65050	96622	40.39	4.54	4.041	564.212

Leachate No.	Start		End		Volume (ml)	Time (Min)	Flow Rate (ml/hr)	Cumulative volume (ml)	Cumulative Time (min)	Cumulative flow rate (ml/hr)	As Conc. (ppb)	Mass of As (ug)	Cumulative Mass of As (ug)
	Time	Date	Time	Date									
L - 42	10:36	13.11.02	10:06	16.11.02	2820	4290	39.44	67870	100912	40.35	4.5	12.690	576.902
L - 43	10:06	16.11.02	1:12	17.11.02	1055	1626	38.93	68925	102538	40.33	4.36	4.600	581.502
L - 44	1:12	17.11.02	1:38	18.11.02	1120	1466	45.84	70045	104004	40.41	3.88	4.346	585.848
L - 45	1:38	18.11.02	10:58	19.11.02	1150	1280	53.91	71195	105284	40.57	3.51	4.037	589.884
L - 46	10:58	19.11.02	12:04	20.11.02	1430	1506	56.97	72625	106790	40.80	3.46	4.948	594.832
L - 47	12:04	20.11.02	12:44	23.11.02	3550	4360	48.85	76175	111150	41.12	3.11	11.041	605.873
L - 48	12:44	23.11.02	12:44	24.11.02	970	1440	40.42	77145	112590	41.11	3.51	3.405	609.277
L - 49	12:44	24.11.02	12:34	25.11.02	900	1430	37.76	78045	114020	41.07	3.35	3.015	612.292
L - 50	12:34	25.11.02	10:58	27.11.02	1485	2784	32.00	79530	116804	40.85	3.41	5.064	617.356
L - 51	10:58	27.11.02	10:36	28.11.02	900	1418	38.08	80430	118222	40.82	4.36	3.924	621.280
L - 52	10:36	30.11.02	2:22	01.12.02	990	1666	35.65	81420	119888	40.75	5.8	5.742	627.022
L - 53	2:22	01.12.02	12:27	02.12.02	935	1325	42.34	82355	121213	40.77	4.66	4.357	631.379
L - 54	9:15	13.12.02	3:11	14.12.02	1195	1796	39.92	83550	123009	40.75	8.69	10.385	641.764
L - 55	3:11	14.12.02	12:56	15.12.02	880	1305	40.46	84430	124314	40.75	6.73	5.922	647.686
L - 56	12:56	15.12.02	4:08	17.12.02	1930	3072	37.70	86360	127386	40.68	5.45	10.519	658.205
L - 57	4:08	17.12.02	12:26	21.12.02	2800	5538	30.34	89160	132924	40.25	4.67	13.076	671.281
L - 58	12:26	21.12.02	12:06	22.12.02	895	1420	37.82	90055	134344	40.22	7.28	6.516	677.796
L - 59	12:06	22.12.02	4:38	23.12.02	1120	1712	39.25	91175	136056	40.21	7.25	8.120	685.916
L - 60	4:38	23.12.02	4:50	24.12.02	1052	1452	43.47	92227	137508	40.24	6.29	6.617	692.533
L - 61	4:50	27.12.02	1:24	29.12.02	1565	2674	35.12	93792	140182	40.14	6.36	9.953	702.487
L - 62	1:24	29.12.02	3:26	30.12.02	825	1562	31.69	94617	141744	40.05	4.46	3.680	706.166
L - 63	3:26	30.12.02	3:10	31.12.02	900	1424	37.92	95517	143168	40.03	5.43	4.887	711.053

Leachate No.	Start		End		Volume (ml)	Time (Min)	Flow Rate (ml/hr)	Cumulative volume (ml)	Cumulative Time (min)	Cumulative flow rate (ml/hr)	As Conc. (ppb)	Mass of As (ug)	Cumulative Mass of As (ug)
	Time	Date	Time	Date									
L - 64	3:10	31.12.02	12:10	01.01.03	935	1260	44.52	96452	144428	40.07	5.68	5.311	716.364
L - 65	12:10	01.01.03	3:04	04.01.03	2100	4494	28.04	98552	148922	39.71	5.73	12.033	728.397
L - 66	3:04	04.01.03	1:21	06.01.03	1985	2777	42.89	100537	151699	39.76	5.47	10.858	739.255
L - 67	1:21	06.01.03	3:11	07.01.03	1275	1550	49.35	101812	153249	39.86	3.85	4.909	744.164
L - 68	3:11	07.01.03	3:30	08.01.03	1245	1421	52.57	103057	154670	39.98	3.67	4.569	748.733
L - 69	3:30	08.01.03	3:21	11.01.03	2700	4311	37.58	105757	158981	39.91	4.06	10.962	759.695
L - 70	3:21	11.01.03	3:58	12.01.03	790	1477	32.09	106547	160458	39.84	3.95	3.121	762.815
L - 71	3:58	12.01.03	4:31	13.01.03	800	1473	32.59	107347	161931	39.78	3.86	3.088	765.903
L - 72	4:31	13.01.03	3:46	14.01.03	760	1393	32.74	108107	163324	39.72	2.41	1.832	767.735
L - 73	3:46	14.01.03	11:14	15.01.03	770	1108	41.70	108877	164432	39.73	6.07	4.674	772.409
L - 74	4:45	19.01.03	4:38	20.01.03	850	1433	35.59	109727	165865	39.69	4.31	3.664	776.072
L - 75	4:38	20.01.03	10:24	22.01.03	1650	2508	39.47	111377	168373	39.69	2.85	4.703	780.775
L - 76	10:24	22.01.03	4:36	25.01.03	3140	4692	40.15	114517	173065	39.70	1.56	4.898	785.673
L - 77	4:36	25.01.03	10:22	27.01.03	1260	2506	30.17	115777	175571	39.57	1.05	1.323	786.996
L - 78	10:22	27.01.03	10:20	28.01.03	930	1438	38.80	116707	177009	39.56	<1.00		
L - 79	10:20	28.01.03	10:25	29.01.03	840	1445	34.88	117547	178454	39.52	<1.00		
L - 80	10:25	29.01.03	10:15	01.02.03	2275	4310	31.67	119822	182764	39.34	<1.00		
L - 81	10:15	01.02.03	11:20	02.02.03	970	1505	38.67	120792	184269	39.33	<1.00		
L - 82	11:20	02.02.03	11:20	03.02.03	910	1440	37.92	121702	185709	39.32	<1.00		

Column ID: C - 5; Water used: Extraction Fluid # 1; pH = 4.81; Initial Volume = 125 ml; Start: 15/09/2002.

Leachate No.	Start		End		Volume (ml)	Time (Min)	Flow Rate (ml/hr)	Cumulative volume (ml)	Cumulative Time (min)	Cumulative flow rate (ml/hr)	As Conc. (ppb)	Mass of As (ug)	Cumulative Mass of As (ug)
	Time	Date	Time	Date									
Initial					125			125			63.15	7.894	7.894
L - 1	12:55	15.09.02	12:20	16.09.02	1120	1405	47.83	1245	1405	53.17	17.39	19.479	27.372
L - 2	12:20	16.09.02	12:00	17.09.02	850	1420	35.92	2095	2825	44.50	11.02	9.364	36.737
L - 3	12:00	17.09.02	12:42	18.09.02	1110	1482	44.94	3205	4307	44.65	11.20	12.432	49.169
L - 4	12:42	18.09.02	10:39	21.09.02	2720	4197	38.88	5925	8504	41.80	9.79	26.633	75.802
L - 5	10:39	21.09.02	3:30	22.09.02	1035	1731	35.88	6960	10235	40.80	14.17	14.663	90.464
L - 6	3:30	22.09.02	3:54	23.09.02	1005	1464	41.19	7965	11699	40.85	5.32	5.343	95.808
L - 7	3:54	23.09.02	4:20	24.09.02	910	1466	37.24	8875	13165	40.45	6.57	5.976	101.783
L - 8	4:20	24.09.02	4:20	25.09.02	820	1440	34.17	9695	14605	39.83	4.59	3.765	105.549
L - 9	4:20	25.09.02	4:48	28.09.09	2550	4348	35.19	12245	18953	38.76	4.33	11.029	116.577
L - 10	4:58	28.09.02	10:36	29.09.02	720	1058	40.83	12965	20011	38.87	4.35	3.132	119.709
L - 11	10:42	29.09.02	10:50	30.09.02	970	1448	40.19	13935	21459	38.96	5.05	4.899	124.608
L - 12	11:00	30.09.02	11:15	01.10.02	900	1455	37.11	14835	22914	38.85	5.03	4.523	129.130
L - 13	11:15	01.10.02	11:59	02.10.02	1110	1484	44.88	15945	24398	39.21	7.10	7.881	137.011
L - 14	11:59	02.10.02	10:44	06.10.02	4650	5685	49.08	20595	30083	41.08	2.38	11.044	148.055
L - 15	10:44	06.10.02	12:36	08.10.02	1850	2992	37.10	22445	33075	40.72	4.49	8.310	156.365
L - 16	12:36	08.10.02	3:24	09.10.02	1125	1608	41.98	23570	34683	40.78	5.77	6.488	162.852
L - 17	3:24	09.10.02	9:57	12.10.02	2265	3993	34.03	25835	38676	40.08	3.05	6.908	169.760
L - 18	9:57	12.10.02	3:54	13.10.02	1185	1497	47.49	27020	40173	40.36	5.67	6.715	176.475
L - 19	9:55	19.10.02	10:04	20.10.02	810	1449	33.54	27830	41622	40.12	3.67	2.970	179.445

Leachate No.	Start		End		Volume (ml)	Time (Min)	Flow Rate (ml/hr)	Cumulative volume (ml)	Cumulative Time (min)	Cumulative flow rate (ml/hr)	As Conc. (ppb)	Mass of As (ug)	Cumulative Mass of As (ug)
	Time	Date	Time	Date									
L - 20	10:04	20.10.02	12:46	21.10.02	1150	1604	43.02	28980	43226	40.23	5.20	5.980	185.425
L - 21	12:46	21.10.02	10:50	23.10.02	1660	2764	36.03	30640	45990	39.97	3.13	5.188	190.613
L - 22	9:30	26.10.02	1:04	27.10.02	1195	1714	41.83	31835	47704	40.04	6.64	7.937	198.550
L - 23	1:04	27.10.02	4:02	28.10.02	1165	1618	43.20	33000	49322	40.14	4.23	4.922	203.472
L - 24	4:02	28.10.02	10:10	29.10.02	680	1088	37.50	33680	50410	40.09	4.32	2.935	206.407
L - 25	10:10	29.10.02	12:06	02.11.02	3245	5876	33.13	36925	56286	39.36	3.88	12.574	218.981
L - 26	11:00	03.11.02	12:48	04.11.02	1220	1548	47.29	38145	57834	39.57	3.50	4.270	223.251
L - 27	12:48	04.11.02	3:08	05.11.02	945	1580	35.89	39090	59414	39.48	2.70	2.552	225.803
L - 28	3:08	05.11.02	10:02	06.11.02	770	1134	40.74	39860	60548	39.50	1.96	1.508	227.311
L - 29	10:02	06.11.02	4:02	06.11.02	280	360	46.67	40140	60908	39.54	3.85	1.078	228.389
L - 30	10:30	09.11.0	10:55	10.11.02	1080	1465	44.23	41220	62373	39.65	2.33	2.520	230.909
L - 31	10:55	10.11.02	9:50	12.11.02	1985	2825	42.16	43205	65198	39.76	5.22	10.355	241.264
L - 32	9:50	12.11.02	10:38	13.11.02	880	1488	35.48	44085	66686	39.66	3.40	2.992	244.256
L - 33	10:38	13.11.02	10:08	16.11.02	3030	4290	42.38	47115	70976	39.83	2.65	8.030	252.285
L - 34	10:08	16.11.02	1:15	17.11.02	1070	1627	39.46	48185	72603	39.82	8.05	8.614	260.899
L - 35	1:15	17.11.02	1:40	18.11.02	1320	1465	54.06	49505	74068	40.10	9.57	12.628	273.527
L - 36	11:00	19.11.02	12:06	20.11.02	750	1506	29.88	50255	75574	39.90	4.56	3.419	276.946
L - 37	12:06	20.11.02	12:46	23.11.02	2640	4360	36.33	52895	79934	39.70	11.78	31.086	308.032
L - 38	12:46	23.11.02	12:46	24.11.02	720	1440	30.00	53615	81374	39.53	9.67	6.960	314.992
L - 39	12:46	24.11.02	12:36	25.11.02	805	1430	33.78	54420	82804	39.43	9.57	7.701	322.693
L - 40	12:36	25.11.02	11:00	27.11.02	1920	2784	41.38	56340	85588	39.50	9.60	18.432	341.125
L - 41	11:00	27.11.02	10:38	30.11.02	2455	4298	34.27	58795	89886	39.25	4.56	11.191	352.316

Leachate No.	Start		End		Volume (ml)	Time (Min)	Flow Rate (ml/hr)	Cumulative volume (ml)	Cumulative Time (min)	Cumulative flow rate (ml/hr)	As Conc. (ppb)	Mass of As (ug)	Cumulative Mass of As (ug)
	Time	Date	Time	Date									
L - 42	10:38	30.11.02	2:24	01.12.02	1045	1666	37.64	59840	91552	39.22	7.85	8.203	360.519
L - 43	2:24	01.12.02	12:28	02.12.02	1100	1324	49.85	60940	92876	39.37	8.00	8.800	369.319
L - 44	9:15	13.12.02	3:13	14.12.02	1250	1798	41.71	62190	94674	39.41	2.70	3.375	372.694
L - 45	3:13	14.12.02	12:58	15.12.02	940	1305	43.22	63130	95979	39.46	3.20	3.008	375.702
L - 46	12:58	15.12.02	4:10	17.12.02	1910	3072	37.30	65040	99051	39.40	2.95	5.635	381.336
L - 47	4:10	17.12.02	12:28	21.12.02	2985	5538	32.34	68025	104589	39.02	4.15	12.388	393.724
L - 48	12:28	21.12.02	12:08	22.12.02	895	1420	37.82	68920	106009	39.01	6.00	5.370	399.094
L - 49	12:08	22.12.02	4:28	23.12.02	1385	1712	48.54	70305	107721	39.16	9.18	12.719	411.813
L - 50	9:00	28.12.02	1:26	29.12.02	1175	1706	41.32	71480	109427	39.19	4.65	5.464	417.277
L - 51	1:26	29.12.02	3:28	30.12.02	1035	1562	39.76	72515	110989	39.20	3.90	4.037	421.313
L - 52	3:28	30.12.02	3:12	31.12.02	1260	1424	53.09	73775	112413	39.38	9.00	11.340	432.653
L - 53	3:12	31.12.02	12:12	01.01.03	910	1260	43.33	74685	113673	39.42	8.67	7.887	440.540
L - 54	12:12	01.01.03	3:06	04.01.03	2590	4494	34.58	77275	118167	39.24	8.51	22.037	462.577
L - 55	3:06	04.01.03	1:23	06.01.03	2100	2777	45.37	79375	120944	39.38	7.50	15.750	478.327
L - 56	1:23	06.01.03	3:13	07.01.03	1050	1550	40.65	80425	122494	39.39	4.82	5.058	483.384
L - 57	3:13	07.01.03	3:32	08.01.03	1060	1459	43.59	81485	123953	39.44	4.96	5.256	488.640
L - 58	3:32	08.01.03	3:23	11.01.03	2960	4311	41.20	84445	128264	39.50	4.49	13.295	501.935
L - 59	3:23	11.01.03	3:59	12.01.03	1190	1476	48.37	85635	129740	39.60	5.33	6.337	508.272
L - 60	3:59	12.01.03	4:33	13.01.03	1165	1474	47.42	86800	131214	39.69	7.12	8.291	516.563
L - 61	4:33	13.01.03	3:48	14.01.03	780	1395	33.55	87580	132609	39.63	8.32	6.487	523.050
L - 62	3:48	14.01.03	11:14	15.01.03	780	1166	40.14	88360	133775	39.63	7.45	5.811	528.861
L - 63	4:45	19.01.03	4:40	20.01.03	1310	1435	54.77	89670	135210	39.79	9.26	12.128	540.989



Leachate No.	Start		End		Volume (ml)	Time (Min)	Flow Rate (ml/hr)	Cumulative volume (ml)	Cumulative Time (min)	Cumulative flow rate (ml/hr)	As Conc. (ppb)	Mass of As (ug)	Cumulative Mass of As (ug)
	Time	Date	Time	Date									
L - 64	4:40	20.01.03	10:26	22.01.03	2150	2506	51.48	91820	137716	40.00	11.27	24.223	565.213
L - 65	10:26	22.01.03	4:38	25.01.03	3290	4692	42.07	95110	142408	40.07	6.30	20.727	585.940
L - 66	4:38	25.01.03	12:24	27.01.03	1750	2626	39.98	96860	145034	40.07	10.21	17.865	603.804
L - 67	12:24	27.01.03	3:36	28.01.03	1340	1632	49.26	98200	146666	40.17	9.38	12.563	616.367
L - 68	3:36	28.01.03	4:08	29.01.03	960	1472	39.13	99160	148138	40.16	8.80	8.448	624.815
L - 69	4:08	29.01.03	12:36	02.02.03	4200	5548	45.42	103360	153686	40.35	6.28	26.390	651.205
L - 70	12:36	02.02.03	11:56	04.02.03	2300	2840	48.59	105660	156526	40.50	6.33	14.548	665.752
L - 71	11:20	22.02.03	11:20	23.02.03	1010	1440	42.08	106670	157966	40.52	6.13	6.186	671.938
L - 72	11:20	23.02.03	12:20	24.02.03	995	1500	39.80	107665	159466	40.51	5.27	5.239	677.177
L - 73	12:20	24.02.03	12:20	25.02.03	990	1440	41.25	108655	160906	40.52	5.13	5.076	682.253
L - 74	12:20	25.02.03	10:40	26.02.03	875	1340	39.18	109530	162246	40.51	4.11	3.597	685.850
L - 75	10:40	26.02.03	10:20	01.03.03	2850	4300	39.77	112380	166546	40.49	3.02	8.618	694.468
L - 76	10:20	01.03.03	10:20	02.03.03	1000	1440	41.67	113380	167986	40.50	3.22	3.224	697.692
L - 77	10:20	02.03.03	11:20	03.03.03	1035	1500	41.40	114415	169486	40.50	4.87	5.041	702.734
L - 78	11:20	03.03.03	11:20	04.03.03	985	1440	41.04	115400	170926	40.51	2.55	2.516	705.250
L - 79	11:20	04.03.03	11:20	05.03.03	960	1440	40.00	116360	172366	40.50	2.11	2.028	707.277
L - 80	11:20	05.03.03	12:40	06.03.03	1050	1520	41.45	117410	173886	40.51	2.96	3.112	710.389
L - 81	12:40	06.03.03	12:40	08.03.03	2790	4320	38.75	120200	178206	40.47	1.46	4.065	714.454
L - 82	12:40	08.03.03	12:40	09.03.03	970	1440	40.42	121170	179646	40.47	1.05	1.019	715.473
L - 83	12:40	09.03.03	9:50	10.03.03	790	1270	37.32	121960	180916	40.45	1.78	1.402	716.875
L - 84	9:50	10.03.03	9:50	11.03.03	905	1440	37.71	122865	182356	40.43	1.13	1.018	717.893
L - 85	9:50	11.03.03	9:50	12.03.03	1025	1440	42.71	123890	183796	40.44	1.08	1.102	718.995

Leachate No.	Start		End		Volume (ml)	Time (Min)	Flow Rate (ml/hr)	Cumulative volume (ml)	Cumulative Time (min)	Cumulative flow rate (ml/hr)	As Conc. (ppb)	Mass of As (ug)	Cumulative Mass of As (ug)
	Time	Date	Time	Date									
L - 86	9:50	12.03.03	11:20	15.03.03	3205	4410	43.61	127095	188206	40.52	1.22	3.913	722.908
L - 87	11:20	15.03.03	11:20	16.03.03	970	1440	40.42	128065	189646	40.52	1.05	1.017	723.925
L - 88	11:20	16.03.03	10:20	17.03.03	865	1380	37.61	128930	191026	40.50	1.03	0.887	724.812
L - 89	10:20	17.03.03	10:20	18.03.03	960	1440	40.00	129890	192466	40.49	1.10	1.051	725.863
L - 90	10:20	18.03.03	11:30	19.03.03	1050	1510	41.72	130940	193976	40.50	<1.00		
L - 91	11:30	19.03.03	11:30	22.03.03	2910	4320	40.42	133850	198296	40.50	<1.00		
L - 92	11:30	22.03.03	12:10	23.03.03	985	1480	39.93	134835	199776	40.50	<1.00		
L - 93	12:10	23.03.03	12:10	24.03.03	980	1440	40.83	135815	201216	40.50	<1.00		
L - 94	12:10	24.03.03	10:30	25.03.03	895	1340	40.07	136710	202556	40.50	<1.00		

**APPENDIX B: TCLP DATA SHEET (SOLID AND  
SEMI-SOLID SAMPLES)**

**Table 1: TCLP Data Sheet (Solid Sample)**

Serial No.	01	02	03
TCLP Extract ID	TCLP- 1A	TCLP- 1B	TCLP- 2A
Sample ID	S - 24	S - 24	S - 24
Location	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali
Type of Sample	Solid (Brick Chips)	Solid (Brick Chips)	Solid (Brick Chips)
Name of Treatment Unit	Shapla Filter	Shapla Filter	Shapla Filter
Tube (Extractor Vessel) No	C	E	B
Extraction Fluid	Distilled Water	Distilled Water	Extraction Fluid # 1
Start of Rotation	4:03 PM 17.09.2002	4:03 PM 17.09.2002	4:03 PM 17.09.2002
End of Rotation	10:03 AM 18.09.2002	10:03 AM 18.09.2002	10:03 AM 18.09.2002
Time of Rotation (hrs)	18	18	18
Raw Sample	Sample Wt. (gm)	5	5
	Adjusted Volume (ml)	500	500
	As Conc. (ppb)	388.02	388.02
	As Conc. (mg/kg)	38.802	38.802
TCLP Extract	Sample Wt. (gm)	25	25
	Adjusted Volume (ml)	1000	1000
	As Conc. (ppb)	14.33	11.53
	As Conc. (mg/kg)	0.573	0.461

Table 1: TCLP Data Sheet (Solid Sample)

Serial No.	04	05	06
TCLP Extract ID	TCLP- 2B	TCLP- 3A	TCLP- 3B
Sample ID	S - 24	S - 24	S - 24
Location	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali
Type of Sample	Solid (Brick Chips)	Solid (Brick Chips)	Solid (Brick Chips)
Name of Treatment Unit	Shapla Filter	Shapla Filter	Shapla Filter
Tube (Extractor Vessel) No	E	I	G
Extraction Fluid	Extraction Fluid # 1	Ground Water	Ground Water
Start of Rotation	4:05 PM 22.09.2002	4:03 PM 17.09.2002	4:05 PM 22.09.2002
End of Rotation	10:05 AM 23.09.2002	10:03 AM 18.09.2002	10:05 AM 23.09.2002
Time of Rotation (hrs)	18	18	18
Raw Sample	Sample Wt. (gm)	5	5
	Adjusted Volume (ml)	500	500
	As Conc. (ppb)	388.02	388.02
	As Conc. (mg/kg)	38.802	38.802
TCLP Extract	Sample Wt. (gm)	25	25
	Adjusted Volume (ml)	1000	1000
	As Conc. (ppb)	10.08	12.69
	As Conc. (mg/kg)	0.403	0.508

**Table 1: TCLP Data Sheet (Solid Sample)**

Serial No.	07	08	09
TCLP Extract ID	TCLP- 4A	TCLP- 4B	TCLP- 5A
Sample ID	S - 24	S - 24	S - 24
Location	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali
Type of Sample	Solid (Brick Chips)	Solid (Brick Chips)	Solid (Brick Chips)
Name of Treatment Unit	Shapla Filter	Shapla Filter	Shapla Filter
Tube (Extractor Vessel) No	A	B	C
Extraction Fluid	Rain Water	Rain Water	Pond Water
Start of Rotation	4:30 PM 21.09.2002	4:30 PM 21.09.2002	4:30 PM 21.09.2002
End of Rotation	10:30 AM 22.09.2002	10:30 AM 22.09.2002	10:30 AM 22.09.2002
Time of Rotation (hrs)	18	18	18
Raw Sample	Sample Wt. (gm)	5	5
	Adjusted Volume (ml)	500	500
	As Conc. (ppb)	388.02	388.02
	As Conc. (mg/kg)	38.802	38.802
TCLP Extract	Sample Wt. (gm)	25	25
	Adjusted Volume (ml)	1000	1000
	As Conc. (ppb)	16.65	19.17
	As Conc. (mg/kg)	0.666	0.767

Table 1: TCLP Data Sheet (Solid Sample)

Serial No.	10	11	12
TCLP Extract ID	TCLP- 5B	TCLP- 6A	TCLP- 6B
Sample ID	S – 24	S – 08	S – 08
Location	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali
Type of Sample	Solid (Brick Chips)	Solid (Brick Chips)	Solid (Brick Chips)
Name of Treatment Unit	Shapla Filter	Shapla Filter	Shapla Filter
Tube (Extractor Vessel) No	I	B	A
Extraction Fluid	Pond Water	Extraction Fluid # 1	Extraction Fluid # 1
Start of Rotation	4:05 PM 22.09.2002	4:05 PM 22.09.2002	4:05 PM 23.09.2002
End of Rotation	10:05 AM 23.09.2002	10:05 AM 23.09.2002	10:05 AM 24.09.2002
Time of Rotation (hrs)	18	18	18
Raw Sample	Sample Wt. (gm)	5	5
	Adjusted Volume (ml)	500	500
	As Conc. (ppb)	388.02	181.29
	As Conc. (mg/kg)	38.802	18.129
TCLP Extract	Sample Wt. (gm)	25	25
	Adjusted Volume (ml)	1000	1000
	As Conc. (ppb)	13.50	7.83
	As Conc. (mg/kg)	0.540	0.313

**Table 1: TCLP Data Sheet (Solid Sample)**

Serial No.	13	14	15
TCLP Extract ID	TCLP- 7A	TCLP- 7B	TCLP- 8A
Sample ID	S - 06	S - 06	S - 21
Location	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali
Type of Sample	Solid (Brick Chips)	Solid (Brick Chips)	Solid (Brick Chips)
Name of Treatment Unit	Shapla Filter	Shapla Filter	Shapla Filter
Tube (Extractor Vessel) No	B	C	E
Extraction Fluid	Extraction Fluid # 1	Extraction Fluid # 1	Extraction Fluid # 1
Start of Rotation	4:05 PM 23.09.2002	4:05 PM 23.09.2002	4:05 PM 23.09.2002
End of Rotation	10:05 AM 24.09.2002	10:05 AM 24.09.2002	10:05 AM 24.09.2002
Time of Rotation (hrs)	18	18	18
Raw Sample	Sample Wt. (gm)	5	5
	Adjusted Volume (ml)	500	500
	As Conc. (ppb)	80.28	80.28
	As Conc. (mg/kg)	8.028	8.028
TCLP Extract	Sample Wt. (gm)	25	25
	Adjusted Volume (ml)	1000	1000
	As Conc. (ppb)	4.01	5.84
	As Conc. (mg/kg)	0.160	0.234



Table 1: TCLP Data Sheet (Solid Sample)

Serial No.	16	17	18
TCLP Extract ID	TCLP- 8B	TCLP- 9A	TCLP- 9B
Sample ID	S - 21	SIDKO - Raw	SIDKO - Raw
Location	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Betha Manikganj Pourasava Manikganj	Vill: Betha Manikganj Pourasava Manikganj
Type of Sample	Solid (Brick Chips)	Solid (Soil)	Solid (Soil)
Name of Treatment Unit	Shapla Filter	SIDKO	SIDKO
Tube (Extractor Vessel) No	B	C	G
Extraction Fluid	Extraction Fluid # 1	Extraction Fluid # 2	Extraction Fluid # 2
Start of Rotation	4:04 PM 03.11.2002	4:04 PM 03.11.2002	4:04 PM 03.11.2002
End of Rotation	10:04 AM 04.11.02	10:04 AM 04.11.02	10:04 AM 04.11.02
Time of Rotation (hrs)	18	18	18
Raw Sample	Sample Wt. (gm)	5	5
	Adjusted Volume (ml)	500	500
	As Conc. (ppb)	378.98	7977.36
	As Conc. (mg/kg)	37.898	797.736
TCLP Extract	Sample Wt. (gm)	25	25
	Adjusted Volume (ml)	1000	1000
	As Conc. (ppb)	7.89	17.82
	As Conc. (mg/kg)	0.316	0.713

Table 1: TCLP Data Sheet (Solid Sample)

Serial No.	19	20	21
TCLP Extract ID	TCLP- 10A	TCLP- 10B	TCLP- 11A
Sample ID	SIDKO – Stabilized	SIDKO – Stabilized	S – 16
Location	Vill: Betha Manikganj Poursava Manikganj	Vill: Betha Manikganj Poursava Manikganj	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali
Type of Sample	Solid (Soil)	Solid (Soil)	Solid (Brick Chips)
Name of Treatment Unit	SIDKO	SIDKO	Shapla Filter
Tube (Extractor Vessel) No	H	I	C
Extraction Fluid	Extraction Fluid # 2	Extraction Fluid # 2	Extraction Fluid # 1
Start of Rotation	4:04 PM 03.11.2002	4:04 PM 03.11.2002	4:15 PM 24.09.2002
End of Rotation	10:04 AM 04.11.02	10:04 AM 04.11.02	10:15 AM 25.09.2002
Time of Rotation (hrs)	18	18	18
Raw Sample	Sample Wt. (gm)	5	5
	Adjusted Volume (ml)	500	500
	As Conc. (ppb)	7077.48	7077.48
	As Conc. (mg/kg)	707.748	707.748
TCLP Extract	Sample Wt. (gm)	25	25
	Adjusted Volume (ml)	1000	1000
	As Conc. (ppb)	25.14	24.23
	As Conc. (mg/kg)	1.006	0.969

**Table 1: TCLP Data Sheet (Solid Sample)**

Serial No.	22	23	24
TCLP Extract ID	TCLP- 11B	TCLP- 12A	TCLP- 12B
Sample ID	S - 16	S - 20	S - 20
Location	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali
Type of Sample	Solid (Brick Chips)	Solid (Brick Chips)	Solid (Brick Chips)
Name of Treatment Unit	Shapla Filter	Shapla Filter	Shapla Filter
Tube (Extractor Vessel) No	E	G	I
Extraction Fluid	Extraction Fluid # 1	Extraction Fluid # 1	Extraction Fluid # 1
Start of Rotation	4:15 PM 24.09.2002	4:15 PM 24.09.2002	4:15 PM 24.09.2002
End of Rotation	10:15 AM 25.09.2002	10:15 AM 25.09.2002	10:15 AM 25.09.2002
Time of Rotation (hrs)	18	18	18
Raw Sample	Sample Wt. (gm)	5	5
	Adjusted Volume (ml)	500	500
	As Conc. (ppb)	147.33	251.01
	As Conc. (mg/kg)	14.733	25.101
TCLP Extract	Sample Wt. (gm)	25	25
	Adjusted Volume (ml)	1000	1000
	As Conc. (ppb)	5.86	17.25
	As Conc. (mg/kg)	0.234	0.690

**Table 1: TCLP Data Sheet (Solid Sample)**

Serial No.	25	26	27
TCLP Extract ID	TCLP- 13A	TCLP- 13B	TCLP- 14A
Sample ID	S - 14	S - 14	S - 30
Location	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali
Type of Sample	Solid (Brick Chips)	Solid (Brick Chips)	Solid (Brick Chips)
Name of Treatment Unit	Shapla Filter	Shapla Filter	Shapla Filter
Tube (Extractor Vessel) No	A	B	C
Extraction Fluid	Extraction Fluid # 1	Extraction Fluid # 1	Extraction Fluid # 1
Start of Rotation	4:00 PM 19.10.2002	4:00 PM 19.10.2002	4:00 PM 19.10.2002
End of Rotation	10:15 AM 10.10.2002	10:15 AM 20.10.2002	10:15 AM 20.10.2002
Time of Rotation (hrs)	18:15	18:15	18:15
Raw Sample	Sample Wt. (gm)	5	5
	Adjusted Volume (ml)	500	500
	As Conc. (ppb)	131.75	131.75
	As Conc. (mg/kg)	13.175	13.175
TCLP Extract	Sample Wt. (gm)	25	25
	Adjusted Volume (ml)	1000	1000
	As Conc. (ppb)	7.89	5.53
	As Conc. (mg/kg)	0.316	0.221

**Table 1: TCLP Data Sheet (Solid Sample)**

Serial No.	28	29	30
TCLP Extract ID	TCLP- 14B	TCLP- 15A	TCLP- 15B
Sample ID	S – 30	S – 03	S – 03
Location	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali
Type of Sample	Solid (Brick Chips)	Solid (Brick Chips)	Solid (Brick Chips)
Name of Treatment Unit	Shapla Filter	Shapla Filter	Shapla Filter
Tube (Extractor Vessel) No	G	G	I
Extraction Fluid	Extraction Fluid # 1	Extraction Fluid # 1	Extraction Fluid # 1
Start of Rotation	4:00 PM 19.10.2002	4:00 PM 19.10.2002	4:00 PM 19.10.2002
End of Rotation	10:15 AM 20.10.2002	10:15 AM 20.10.2002	10:15 AM 20.10.2002
Time of Rotation (hrs)	18:15	18:15	18:15
Raw Sample	Sample Wt. (gm)	5	5
	Adjusted Volume (ml)	500	500
	As Conc. (ppb)	302.09	141.87
	As Conc. (mg/kg)	30.201	14.187
TCLP Extract	Sample Wt. (gm)	25	25
	Adjusted Volume (ml)	1000	1000
	As Conc. (ppb)	8.45	5.20
	As Conc. (mg/kg)	0.338	0.208

**Table 1: TCLP Data Sheet (Solid Sample)**

Serial No.	31	32	33
TCLP Extract ID	TCLP-16A	TCLP-16B	TCLP-17A
Sample ID	S-18	S-18	S-22
Location	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali
Type of Sample	Solid (Brick Chips)	Solid (Brick Chips)	Solid (Brick Chips)
Name of Treatment Unit	Shapla Filter	Shapla Filter	Shapla Filter
Tube (Extractor Vessel) No	A	B	C
Extraction Fluid	Extraction Fluid # 1	Extraction Fluid # 1	Extraction Fluid # 1
Start of Rotation	4:20 PM 20.10.2002	4:20 PM 20.10.2002	4:20 PM 20.10.2002
End of Rotation	10:05 AM 21.10.2002	10:05 AM 21.10.2002	10:05 AM 21.10.2002
Time of Rotation (hrs)	17:45	17:45	17:45
Raw Sample	Sample Wt. (gm)	5	5
	Adjusted Volume (ml)	500	500
	As Conc. (ppb)	97.3	97.3
	As Conc. (mg/kg)	9.730	9.730
TCLP Extract	Sample Wt. (gm)	25	25
	Adjusted Volume (ml)	1000	1000
	As Conc. (ppb)	6.67	9.45
	As Conc. (mg/kg)	0.267	0.378

**Table 1: TCLP Data Sheet (Solid Sample)**

Serial No.	34	35	36	
TCLP Extract ID	TCLP- 17B	TCLP- 18A	TCLP- 18B	
Sample ID	S – 22	S – 29	S – 29	
Location	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	
Type of Sample	Solid (Brick Chips)	Solid (Brick Chips)	Solid (Brick Chips)	
Name of Treatment Unit	Shapla Filter	Shapla Filter	Shapla Filter	
Tube (Extractor Vessel) No	G	H	I	
Extraction Fluid	Extraction Fluid # 1	Extraction Fluid # 1	Extraction Fluid # 1	
Start of Rotation	4:20 PM 20.10.2002	4:20 PM 20.10.2002	4:20 PM 20.10.2002	
End of Rotation	10:05 AM 21.10.2002	10:05 AM 21.10.2002	10:05 AM 21.10.2002	
Time of Rotation (hrs)	17:45	17:45	17:45	
Raw Sample	5	5	5	
	500	500	500	
	As Conc. (ppb)	225.29	244.85	244.85
	As Conc. (mg/kg)	22.529	24.485	24.485
TCLP Extract	Sample Wt. (gm)	25	25	25
	Adjusted Volume (ml)	1000	1000	1000
	As Conc. (ppb)	4.57	12.02	8.75
	As Conc. (mg/kg)	0.183	0.481	0.350

**Table 1: TCLP Data Sheet (Solid Sample)**

Serial No.	37	38	39	
TCLP Extract ID	TCLP- 19A	TCLP- 19B	TCLP- 20A	
Sample ID	S – 23	S – 23	S – 12	
Location	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	
Type of Sample	Solid (Brick Chips)	Solid (Brick Chips)	Solid (Brick Chips)	
Name of Treatment Unit	Shapla Filter	Shapla Filter	Shapla Filter	
Tube (Extractor Vessel) No	A	B	C	
Extraction Fluid	Extraction Fluid # 1	Extraction Fluid # 1	Extraction Fluid # 1	
Start of Rotation	4:15 PM 26.10.2002	4:15 PM 26.10.2002	4:15 PM 26.10.2002	
End of Rotation	10:15 AM 27.10.2002	10:15 AM 27.10.2002	10:15 AM 27.10.2002	
Time of Rotation (hrs)	18	18	18	
Raw Sample	5	5	5	
	500	500	500	
	As Conc. (ppb)	196.7	196.7	126.71
	As Conc. (mg/kg)	19.670	19.670	12.671
TCLP Extract	Sample Wt. (gm)	25	25	25
	Adjusted Volume (ml)	1000	1000	1000
	As Conc. (ppb)	4.23	5.52	5.30
	As Conc. (mg/kg)	0.169	0.221	0.212



**Table 1: TCLP Data Sheet (Solid Sample)**

Serial No.	40	41	42	
TCLP Extract ID	TCLP- 20B	TCLP- 21A	TCLP- 21B	
Sample ID	S - 12	S - 13	S - 13	
Location	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	Vill: Badarpur Union: Ashwadia Thana: Noakhali Sadar District: Noakhali	
Type of Sample	Solid (Brick Chips)	Solid (Brick Chips)	Solid (Brick Chips)	
Name of Treatment Unit	Shapla Filter	Shapla Filter	Shapla Filter	
Tube (Extractor Vessel) No	G	H	I	
Extraction Fluid	Extraction Fluid # 1	Extraction Fluid # 1	Extraction Fluid # 1	
Start of Rotation	4:15 PM 26.10.2002	4:15 PM 26.10.2002	4:15 PM 26.10.2002	
End of Rotation	10:15 AM 27.10.2002	10:15 AM 27.10.2002	10:15 AM 27.10.2002	
Time of Rotation (hrs)	18	18	18	
Raw Sample	5	5	5	
	500	500	500	
	As Conc. (ppb)	126.71	247.86	247.86
	As Conc. (mg/kg)	12.671	24.786	24.786
TCLP Extract	Sample Wt. (gm)	25	25	25
	Adjusted Volume (ml)	1000	1000	1000
	As Conc. (ppb)	4.94	14.25	16.71
	As Conc. (mg/kg)	0.198	0.570	0.668

**Table 1: TCLP Data Sheet (Solid Sample)**

Serial No.	43	44	45	
TCLP Extract ID	TCLP- 22A	TCLP- 22B	TCLP- 23A	
Sample ID	Iron Coated Sand – 2	Iron Coated Sand - 2	Iron Coated Sand – 1	
Location	Vill: Adda Union: Adda Thana: Barura District: Comilla	Vill: Adda Union: Adda Thana: Barura District: Comilla	Vill: Adda Union: Adda Thana: Barura District: Comilla	
Type of Sample	Solid (Sand)	Solid (Sand)	Solid (Sand)	
Name of Treatment Unit	Iron Coated Sand Based ARU	Iron Coated Sand Based ARU	Iron Coated Sand Based ARU	
Tube (Extractor Vessel) No	G	H	I	
Extraction Fluid	Extraction Fluid # 2	Extraction Fluid # 2	Extraction Fluid # 2	
Start of Rotation	4:00 PM 28.10.2002	4:00 PM 28.10.2002	4:00 PM 28.10.2002	
End of Rotation	10:00 AM 29.10.2002	10:00 AM 29.10.2002	10:00 AM 29.10.2002	
Time of Rotation (hrs)	18	18	18	
Raw Sample	5	5	5	
	500	500	500	
	As Conc. (ppb)	369.54	369.54	191.5
	As Conc. (mg/kg)	36.954	36.954	19.150
TCLP Extract	Sample Wt. (gm)	25	25	25
	Adjusted Volume (ml)	1000	1000	1000
	As Conc. (ppb)	6.54	7.64	1.85
	As Conc. (mg/kg)	0.262	0.306	0.074

**Table 1: TCLP Data Sheet (Solid Sample)**

Serial No.	46	47	48
TCLP Extract ID	TCLP- 23B		
Sample ID	Iron Coated Sand - 1		
Location	Vill: Adda Union: Adda Thana: Barura District: Comilla		
Type of Sample	Solid (Sand)		
Name of Treatment Unit	Iron Coated Sand Based ARU		
Tube (Extractor Vessel) No	A		
Extraction Fluid	Extraction Fluid # 2		
Start of Rotation	4:04 PM 03.11.2002		
End of Rotation	10:04 AM 04.11.2002		
Time of Rotation (hrs)	18		
Raw Sample	Sample Wt. (gm)	5	
	Adjusted Volume (ml)	500	
	As Conc. (ppb)	191.5	
	As Conc. (mg/kg)	19.150	
TCLP Extract	Sample Wt. (gm)	25	
	Adjusted Volume (ml)	1000	
	As Conc. (ppb)	2.67	
	As Conc. (mg/kg)	0.109	

**Table 2: TCLP Data Sheet (Liquid Sample)**

Serial No.	01	02	03
TCLP Extract ID	TCLP- 24	TCLP- 25	TCLP- 26
Sample ID	R - 17	R - 56	R - 61
Location	Vill: Modhupur Pourasava: Raipur Thana: Raipur Dist: Laksmipur	Vill: Modhupur Pourasava: Raipur Thana: Raipur Dist: Laksmipur	Vill: Modhupur Pourasava: Raipur Thana: Raipur Dist: Laksmipur
Type of Sample	Sludge (Multiphasic)	Sludge (Multiphasic)	Sludge (Multiphasic)
Name of Treatment Unit	STAR Filter	STAR Filter	STAR Filter
% Solids	8.82	16.62	9.17
Tube (Extractor Vessel) No	A	I	C
Extraction Fluid	Extraction Fluid # 2	Extraction Fluid # 2	Extraction Fluid # 2
Start of Rotation	4:45 PM 11.01.03	4:45 PM 11.01.03	4:45 PM 11.01.03
End of Rotation	9:30 AM 12.01.03	9:30 AM 12.01.03	9:30 AM 12.01.03
Time of Rotation (hrs)	16:45	16:45	16:45
Raw Sample	Volume (ml)	50	50
	Adjusted Volume (ml)	500	500
	As Conc. (ppb)	1294.87	134.98
	As Conc. (mg/L)	12.949	1.350
TCLP Extract	Volume (ml)	540	370
	Adjusted Volume (ml)	1000	1000
	As Conc. (ppb)	18.80	3.94
	As Conc. (mg/L)	0.035	0.011

**Table 2: TCLP Data Sheet (Liquid Sample)**

Serial No.	04	05	06
TCLP Extract ID	TCLP- 27	TCLP- 28	TCLP- 29
Sample ID	R – 50	R – 58	R – 70
Location	Vill: Modhupur Pourasava: Raipur Thana: Raipur Dist: Laksmipur	Vill: Modhupur Pourasava: Raipur Thana: Raipur Dist: Laksmipur	Vill: Modhupur Pourasava: Raipur Thana: Raipur Dist: Laksmipur
Type of Sample	Sludge (Multiphasic)	Sludge (Multiphasic)	Sludge (Multiphasic)
Name of Treatment Unit	STAR Filter	STAR Filter	STAR Filter
% Solids	5.23	3.05	2.47
Tube (Extractor Vessel) No	H	G	B
Extraction Fluid	Extraction Fluid # 2	Extraction Fluid # 2	Extraction Fluid # 2
Start of Rotation	4:45 PM 11.01.03	4:45 PM 11.01.03	4:45 PM 11.01.03
End of Rotation	9:30 AM 12.01.03	9:30 AM 12.01.03	9:30 AM 12.01.03
Time of Rotation (hrs)	16:45	16:45	16:45
Raw Sample	Volume (ml)	50	50
	Adjusted Volume (ml)	500	500
	As Conc. (ppb)	1089.92	169.12
	As Conc. (mg/L)	10.899	1.691
TCLP Extract	Volume (ml)	485	460
	Adjusted Volume (ml)	1000	1000
	As Conc. (ppb)	44.93	183.24
	As Conc. (mg/L)	0.093	0.398

**Table 2: TCLP Data Sheet (Liquid Sample)**

Serial No.	07	08	09
TCLP Extract ID	TCLP- 30	TCLP- 31	TCLP- 32
Sample ID	R – 60	R – 62	R – 81
Location	Vill: Modhupur Pourasava: Raipur Thana: Raipur Dist: Laksmipur	Vill: Modhupur Pourasava: Raipur Thana: Raipur Dist: Laksmipur	Vill: Modhupur Pourasava: Raipur Thana: Raipur Dist: Laksmipur
Type of Sample	Sludge (Multiphasic)	Sludge (Multiphasic)	Sludge (Multiphasic)
Name of Treatment Unit	STAR Filter	STAR Filter	STAR Filter
% Solids	20.44	8.25	16.56
Tube (Extractor Vessel) No	B	G	H
Extraction Fluid	Extraction Fluid # 2	Extraction Fluid # 2	Extraction Fluid # 2
Start of Rotation	4:45 PM 12.01.03	4:45 PM 12.01.03	4:45 PM 12.01.03
End of Rotation	9:30 AM 13.01.03	9:30 AM 13.01.03	9:30 AM 13.01.03
Time of Rotation (hrs)	16:45	16:45	16:45
Raw Sample	Volume (ml)	50	50
	Adjusted Volume (ml)	500	500
	As Conc. (ppb)	1707.91	1080.51
	As Conc. (mg/L)	17.079	10.805
TCLP Extract	Volume (ml)	360	425
	Adjusted Volume (ml)	1000	1000
	As Conc. (ppb)	37.52	29.56
	As Conc. (mg/L)	0.104	0.070

**Table 2: TCLP Data Sheet (Liquid Sample)**

Serial No.	10	11	12
TCLP Extract ID	TCLP- 33	TCLP- 34	TCLP- 35
Sample ID	R – 88	BTU - 1	BTU – 4
Location	Vill: Modhupur Pourasava: Raipur Thana: Raipur Dist: Laksmipur	Vill: Adda Union: Adda Thana: Barura Dist: Comilla	Vill: Adda Union: Adda Thana: Barura Dist: Comilla
Type of Sample	Sludge (Multiphasic)	Sludge (Multiphasic)	Sludge (Multiphasic)
Name of Treatment Unit	STAR Filter	BTU	BTU
% Solids	16.07	2.56	2.41
Tube (Extractor Vessel) No	C	A	I
Extraction Fluid	Extraction Fluid # 2	Extraction Fluid # 2	Extraction Fluid # 2
Start of Rotation	4:45 PM 12.01.03	4:45 PM 12.01.03	4:45 PM 12.01.03
End of Rotation	9:30 AM 13.01.03	9:30 AM 13.01.03	9:30 AM 13.01.03
Time of Rotation (hrs)	16:45	16:45	16:45
Raw Sample	Volume (ml)	50	50
	Adjusted Volume (ml)	500	500
	As Conc. (ppb)	1854.66	90.74
	As Conc. (mg/L)	18.547	0.907
TCLP Extract	Volume (ml)	300	600
	Adjusted Volume (ml)	1000	1000
	As Conc. (ppb)	93.56	114.28
	As Conc. (mg/L)	0.312	0.190

**Table 2: TCLP Data Sheet (Liquid Sample)**

Serial No.	13	14	15	
TCLP Extract ID	TCLP- 36	TCLP- 37	TCLP- 38	
Sample ID	R – 15	R – 16	R – 68	
Location	Vill: Modhupur Pourasava: Raipur Thana: Raipur Dist: Laksmipur	Vill: Modhupur Pourasava: Raipur Thana: Raipur Dist: Laksmipur	Vill: Modhupur Pourasava: Raipur Thana: Raipur Dist: Laksmipur	
Type of Sample	Sludge (Multiphasic)	Sludge (Multiphasic)	Sludge (Multiphasic)	
Name of Treatment Unit	STAR Filter	STAR Filter	STAR Filter	
% Solids	6.41	10.80	14.98	
Tube (Extractor Vessel) No	A	B	C	
Extraction Fluid	Extraction Fluid # 2	Extraction Fluid # 2	Extraction Fluid # 2	
Start of Rotation	5:00 PM 13.01.03	5:00 PM 13.01.03	5:00 PM 13.01.03	
End of Rotation	9:45 AM 14.01.03	9:45 AM 14.01.03	9:45 AM 14.01.03	
Time of Rotation (hrs)	16:45	16:45	16:45	
Raw Sample	Volume (ml)	50	50	50
	Adjusted Volume (ml)	500	500	500
	As Conc. (ppb)	119.56	2450.89	329.01
	As Conc. (mg/L)	1.196	24.510	3.290
TCLP Extract	Volume (ml)	350	250	250
	Adjusted Volume (ml)	1000	1000	1000
	As Conc. (ppb)	157.56	35.79	37.84
	As Conc. (mg/L)	0.450	0.143	0.151



**Table 2: TCLP Data Sheet (Liquid Sample)**

Serial No.	16	
TCLP Extract ID	TCLP- 39	
Sample ID	R – 99	
Location	Vill: Modhupur Pourasava: Raipur Thana: Raipur District: Laksmipur	
Type of Sample	Sludge (Multiphasic)	
Name of Treatment Unit	STAR Filter	
% Solids	18.22	
Tube (Extractor Vessel) No	G	
Extraction Fluid	Extraction Fluid # 2	
Start of Rotation	5:00 PM 13.01.03	
End of Rotation	9:45 AM 14.01.03	
Time of Rotation (hrs)	16:45	
Raw Sample	Volume (ml)	50
	Adjusted Volume (ml)	500
	As Conc. (ppb)	2615.31
	As Conc. (mg/L)	26.153
TCLP Extract	Volume (ml)	250
	Adjusted Volume (ml)	1000
	As Conc. (ppb)	89.36
	As Conc. (mg/L)	0.357

## **APPENDIX C: GRAPHS**

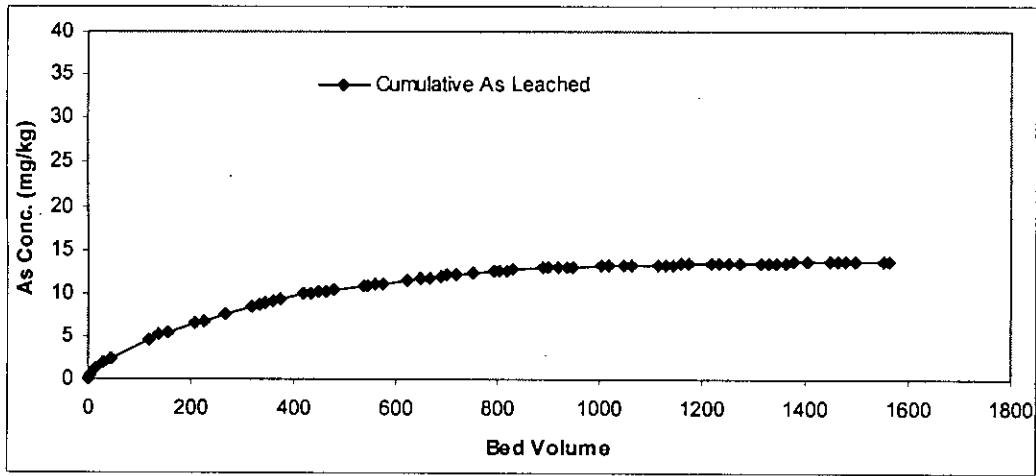


Figure 1: Cumulative arsenic leached as a function of bed volume of fluid passed through the column (Column ID: C-1, Fluid: Distilled Water)

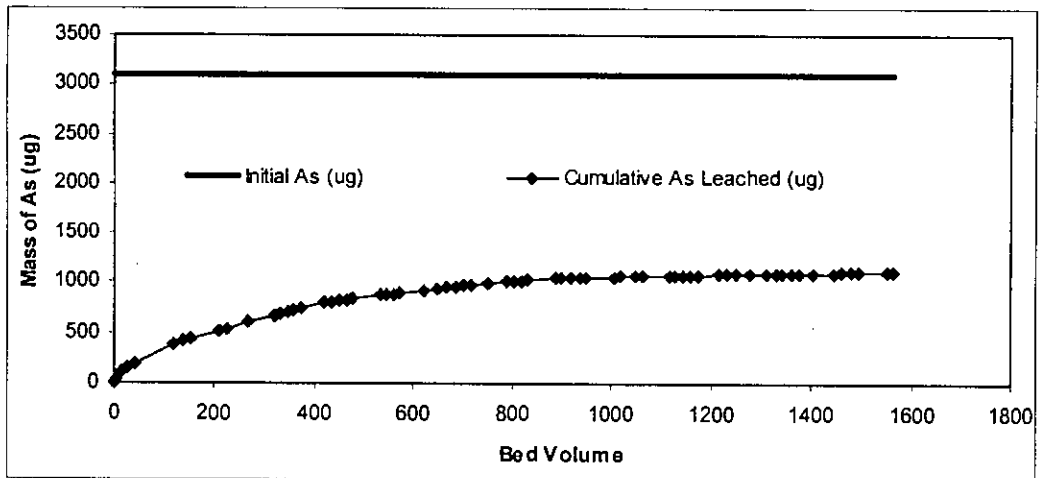


Figure 2: Initial arsenic and Cumulative arsenic leached as a function of bed volume of fluid passed through the column (Column ID: C-1, Fluid: Distilled Water).

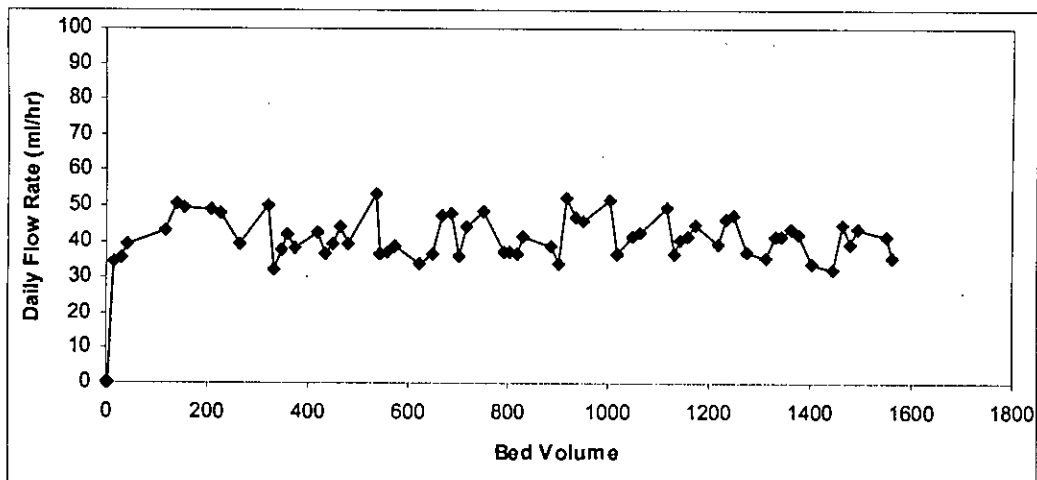


Figure 3: Daily flow rate as a function of bed volume of fluid passed through the column (Column ID: C-1, Fluid: Distilled Water).

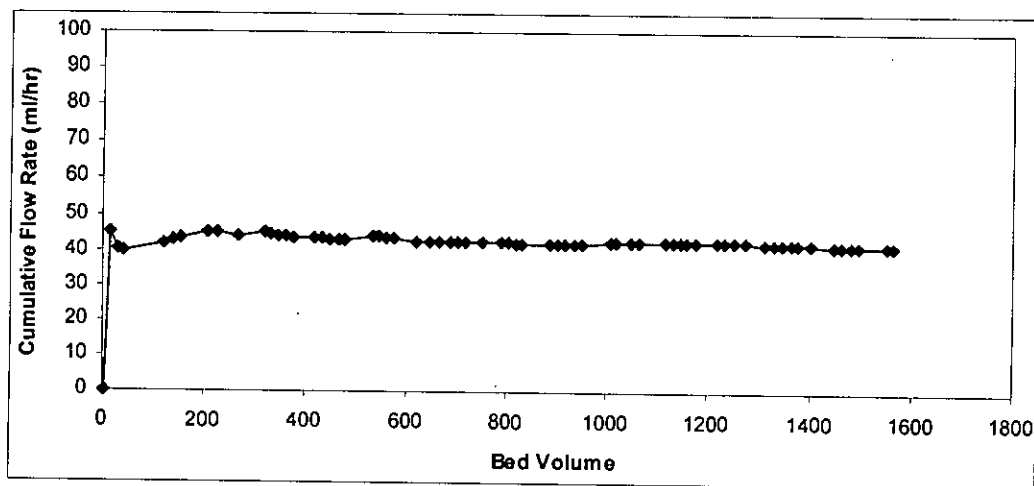


Figure 4: Cumulative flow rate as a function of bed volume of fluid passed through the column (Column ID: C-1, Fluid: Distilled Water).

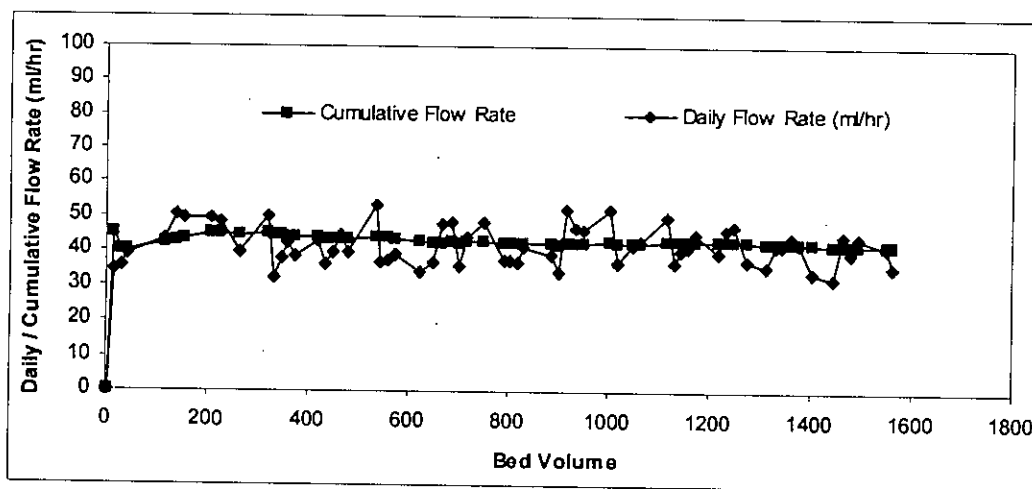


Figure 5: Cumulative and Daily flow rate as a function of bed volume of fluid passed through the column (Column ID: C-1, Fluid: Distilled Water).

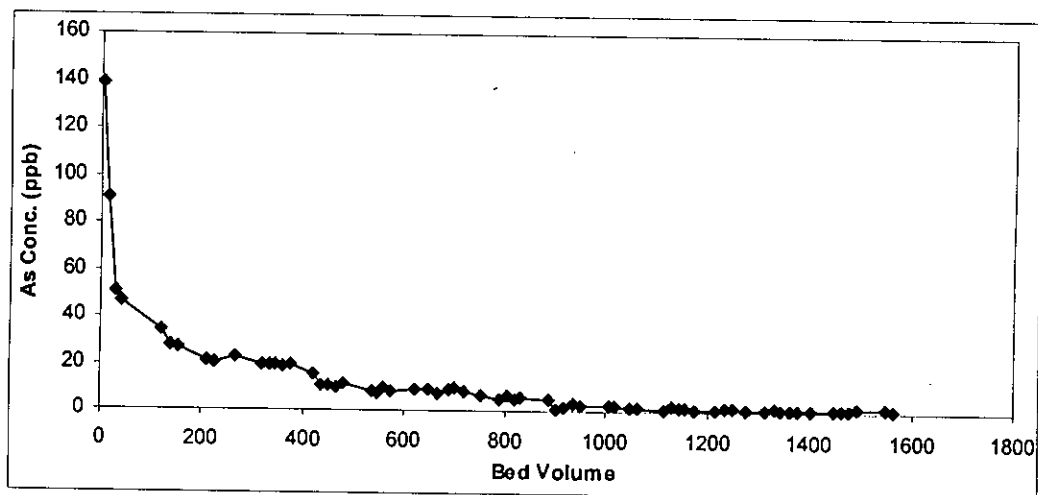


Figure 6: Arsenic in column effluent as a function of bed volume of fluid passed through the column (Column ID: C-1, Fluid: Distilled Water).

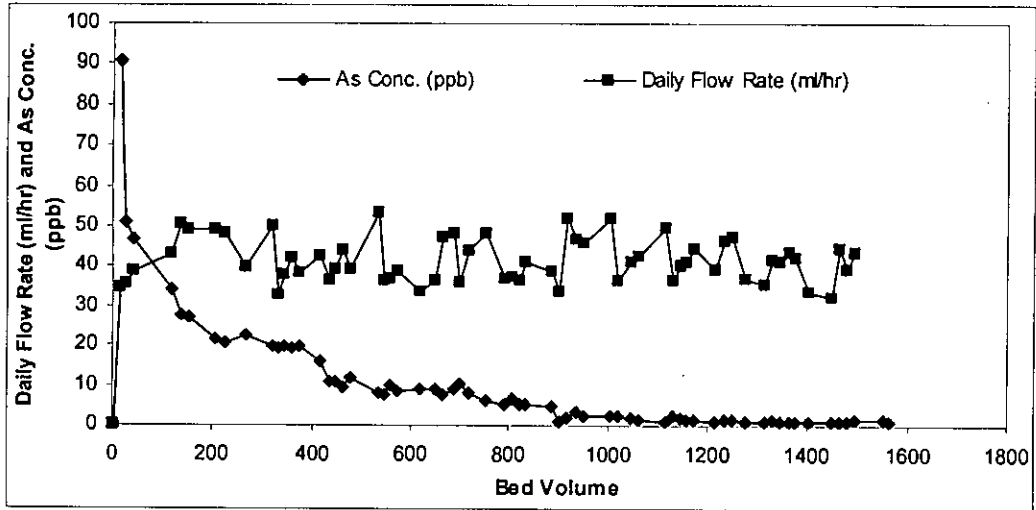


Figure 7: Daily flow rate and Arsenic in column effluent as a function of bed volume of fluid passed through the column (Column ID: C-1, Fluid: Distilled Water).

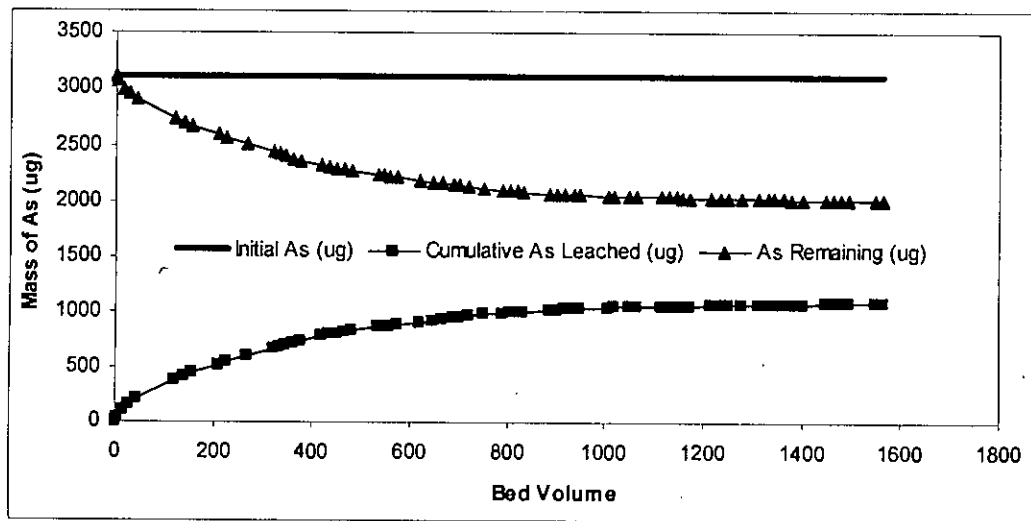


Figure 8: Initial arsenic, arsenic leached and arsenic remaining as a function of bed volume of fluid passed through the column (Column ID: C-1, Fluid: Distilled Water).

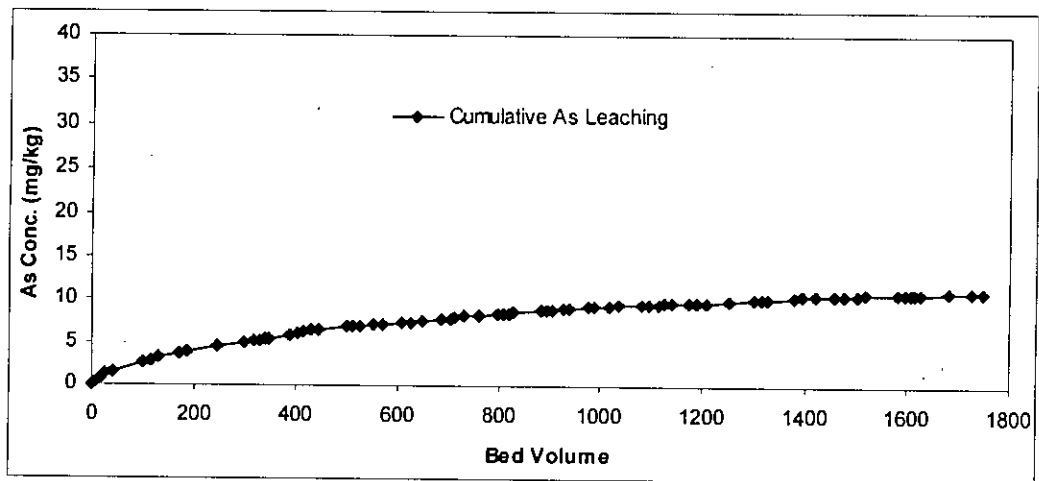


Figure 9: Cumulative arsenic leached as a function of bed volume of fluid passed through the column (Column ID: C-2, Fluid: Ground Water).

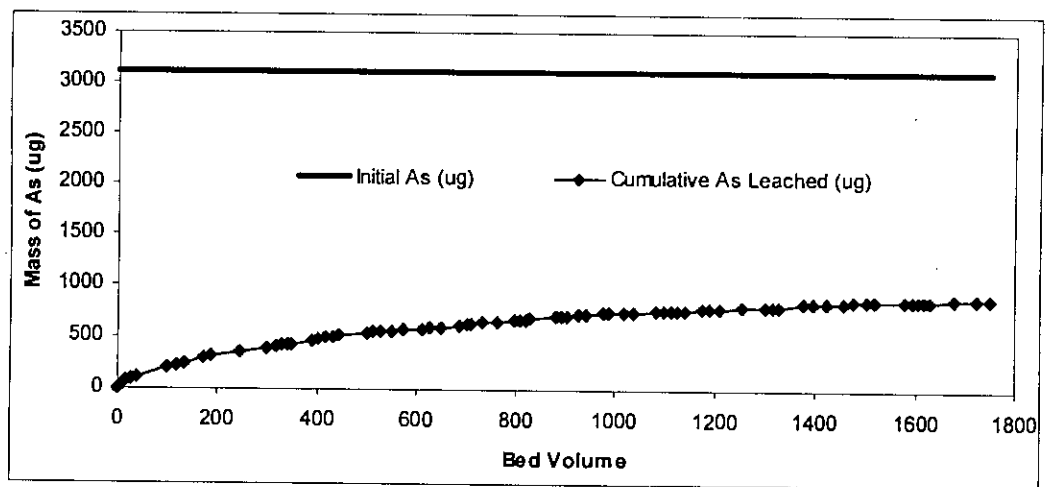


Figure 10: Initial arsenic and Cumulative arsenic leached as a function of bed volume of fluid passed through the column (Column ID: C-2, Fluid: Ground Water).

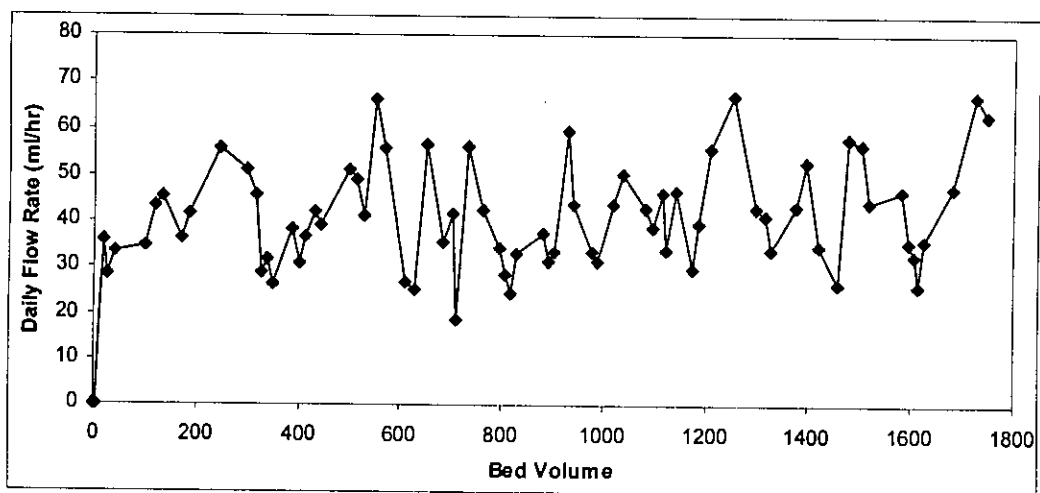


Figure 11: Daily flow rate as a function of bed volume of fluid passed through the column (Column ID: C-2, Fluid: Ground Water).

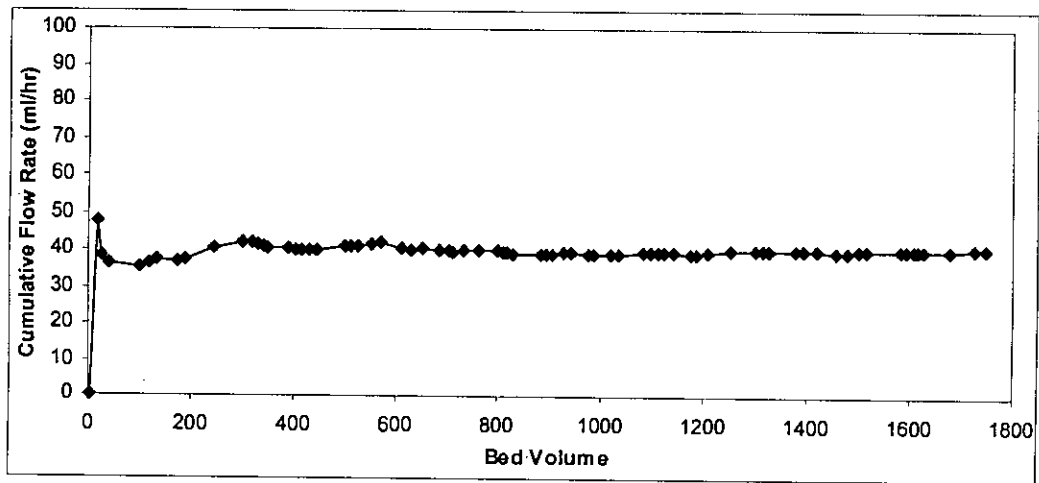


Figure 12: Cumulative flow rate as a function of bed volume of fluid passed through the column (Column ID: C-2, Fluid: Ground Water).

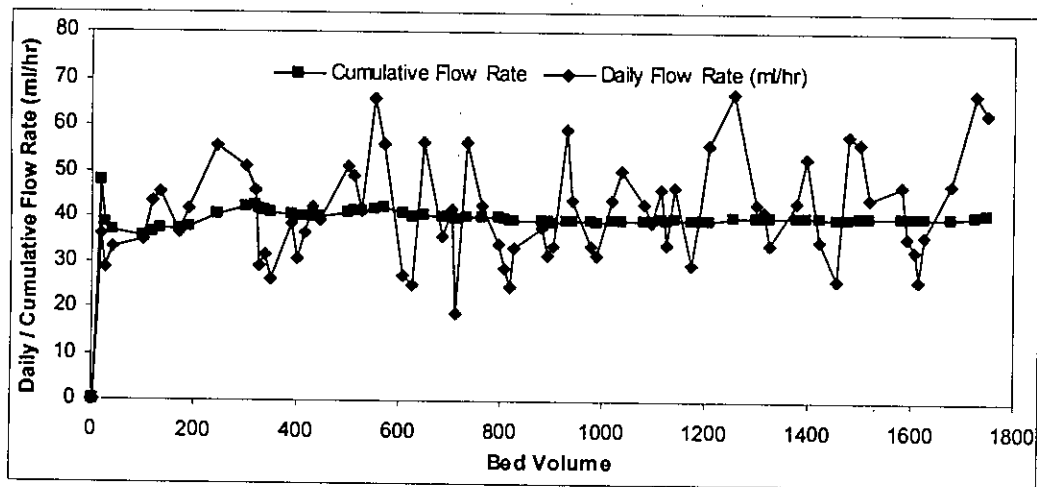


Figure 13: Cumulative and Daily flow rate as a function of bed volume of fluid passed through the column (Column ID: C-2, Fluid: Ground Water).

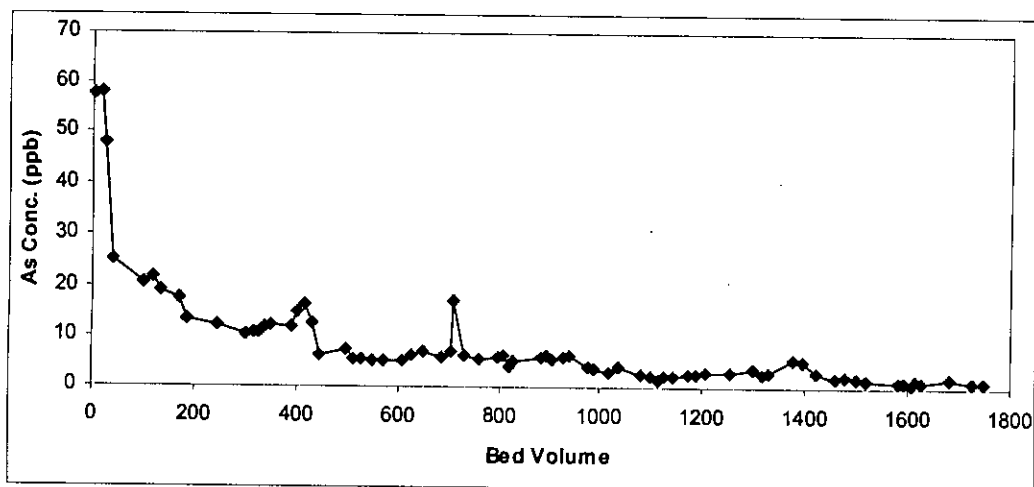


Figure 14: Arsenic in column effluent as a function of bed volume of fluid passed through the column (Column ID: C-2, Fluid: Ground Water).

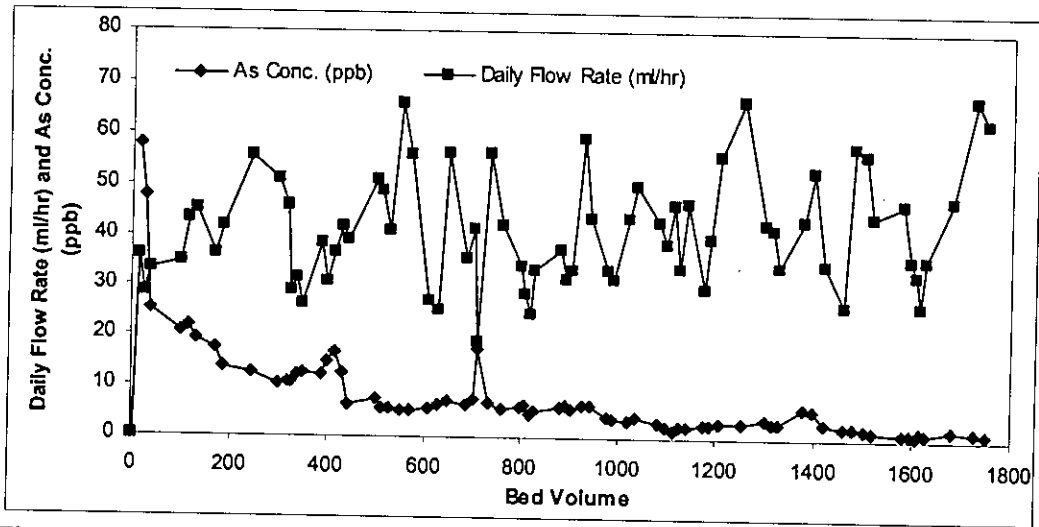


Figure 15: Daily flow rate and Arsenic in column effluent as a function of bed volume of fluid passed through the column (Column ID: C-2, Fluid: Ground Water).

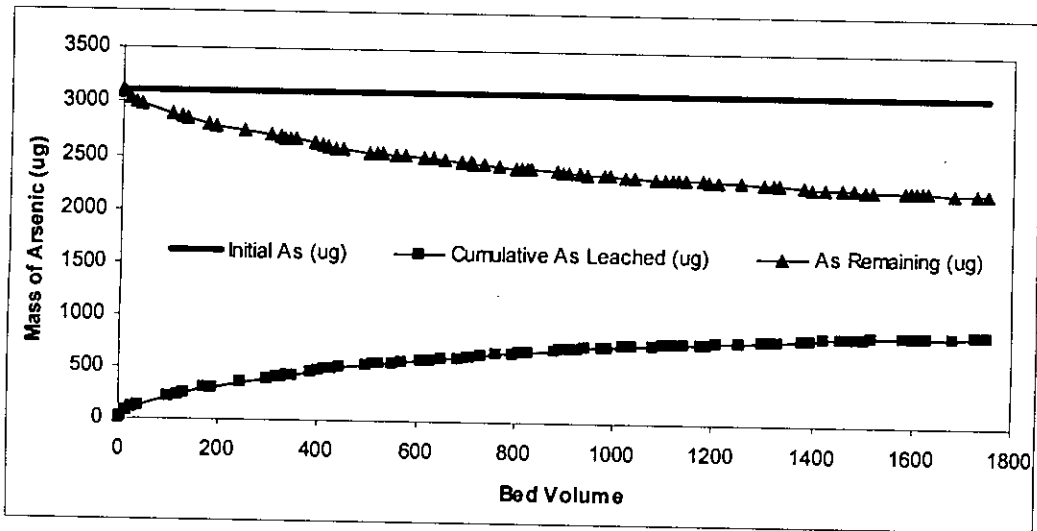


Figure 16: Initial arsenic, arsenic leached and arsenic remaining as a function of bed volume of fluid passed through the column (Column ID: C-2, Fluid: Ground Water).



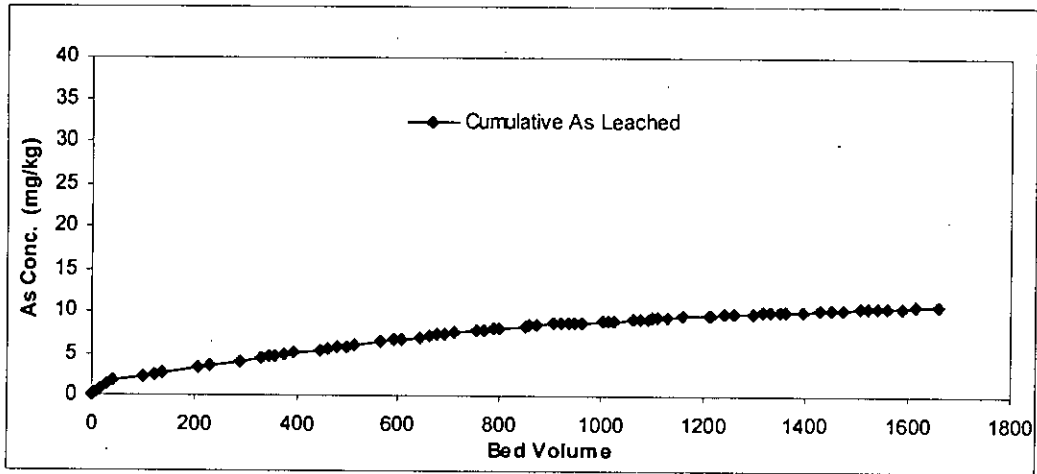


Figure 17: Cumulative arsenic leached as a function of bed volume of fluid passed through the column (Column ID: C-3, Fluid: Rain Water).

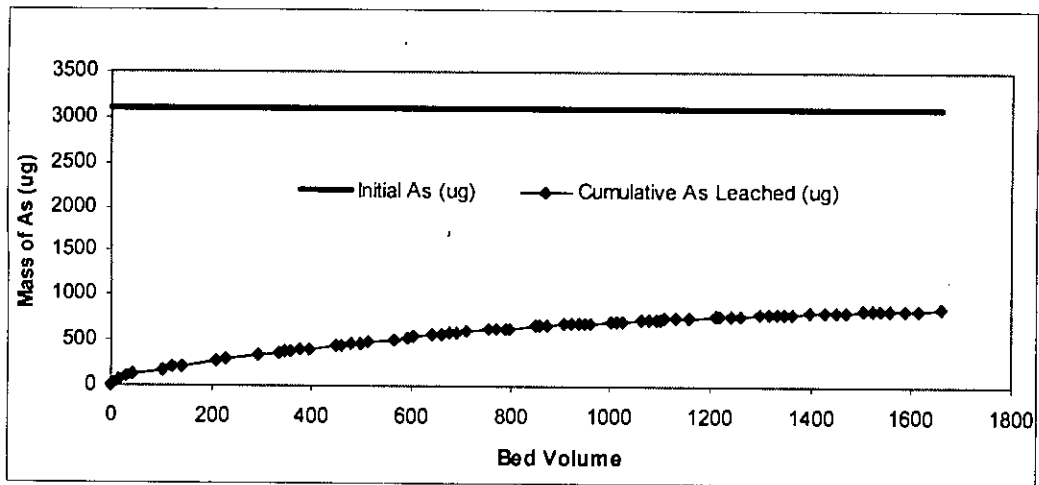


Figure 18: Initial arsenic and Cumulative arsenic leached as a function of bed volume of fluid passed through the column (Column ID: C-3, Fluid: Rain Water).

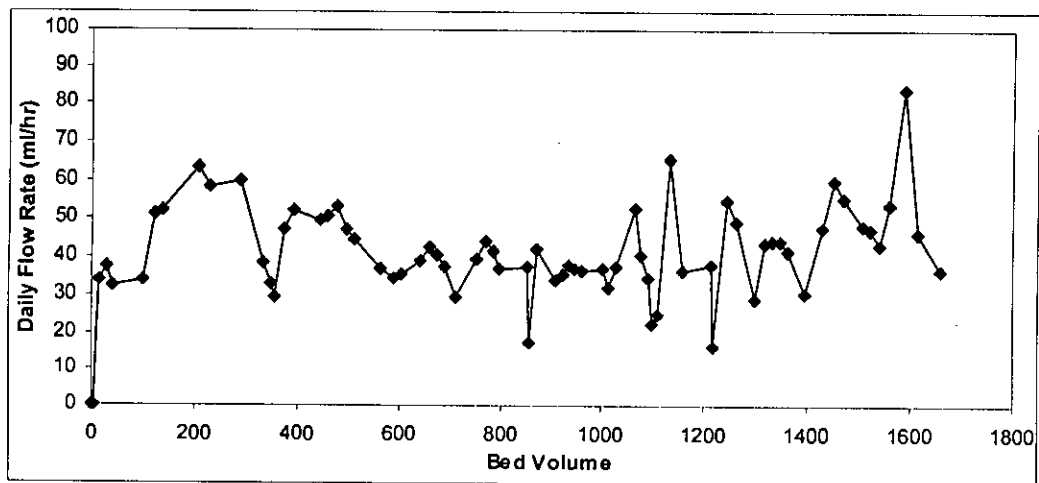


Figure 19: Daily flow rate as a function of bed volume of fluid passed through the column (Column ID: C-3, Fluid: Rain Water).

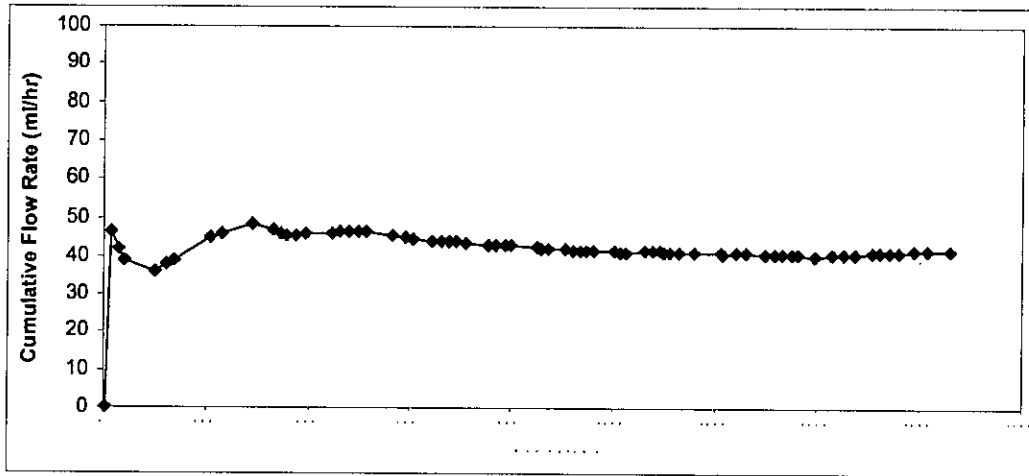


Figure 20: Cumulative flow rate as a function of bed volume of fluid passed through the column (Column ID: C-3, Fluid: Rain Water).

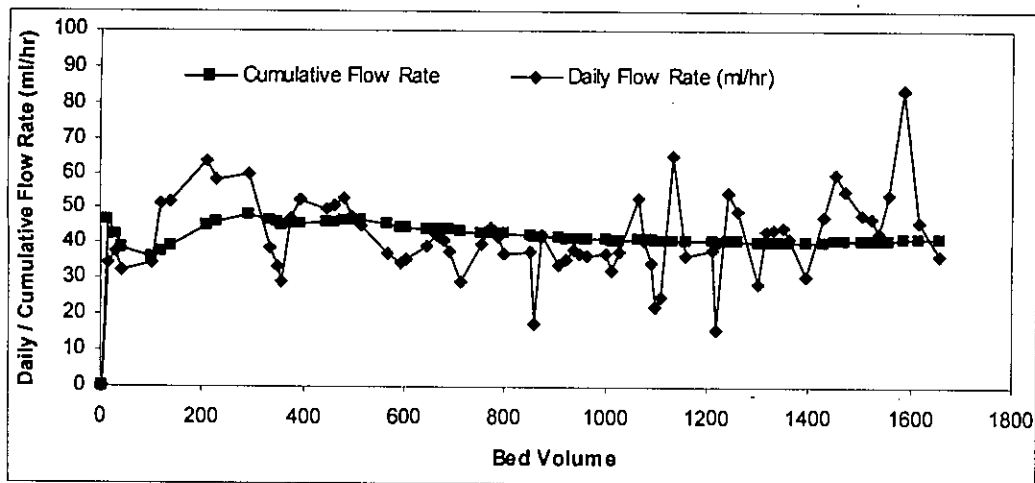


Figure 21: Cumulative and Daily flow rate as a function of bed volume of fluid passed through the column (Column ID: C-3, Fluid: Rain Water).

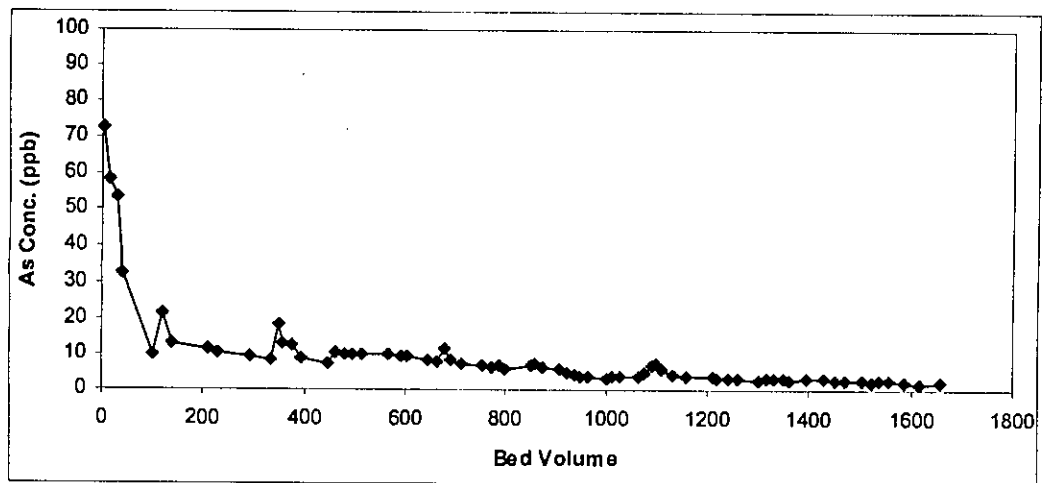


Figure 22: Arsenic in column effluent as a function of bed volume of fluid passed through the column (Column ID: C-3, Fluid: Rain Water).

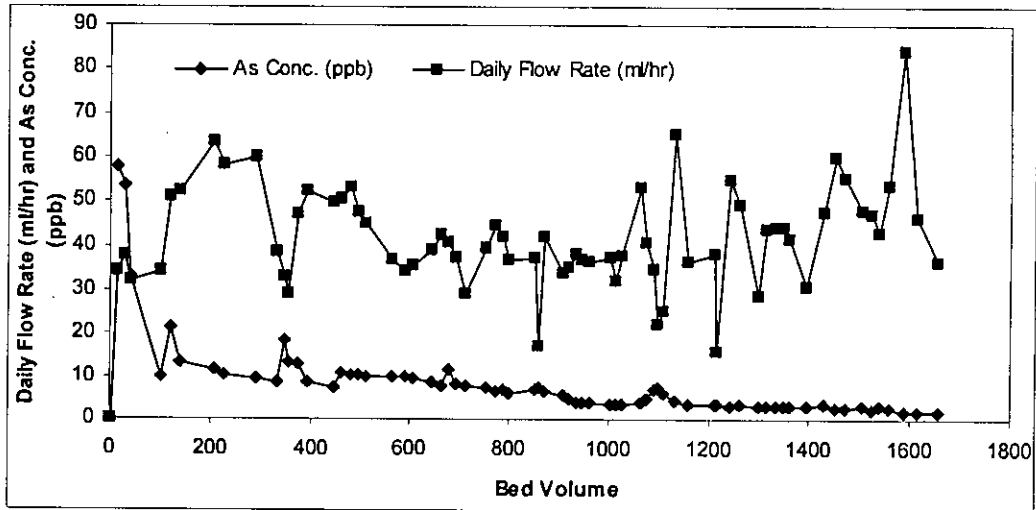


Figure 23: Daily flow rate and Arsenic in column effluent as a function of bed volume of fluid passed through the column (Column ID: C-3, Fluid: Rain Water).

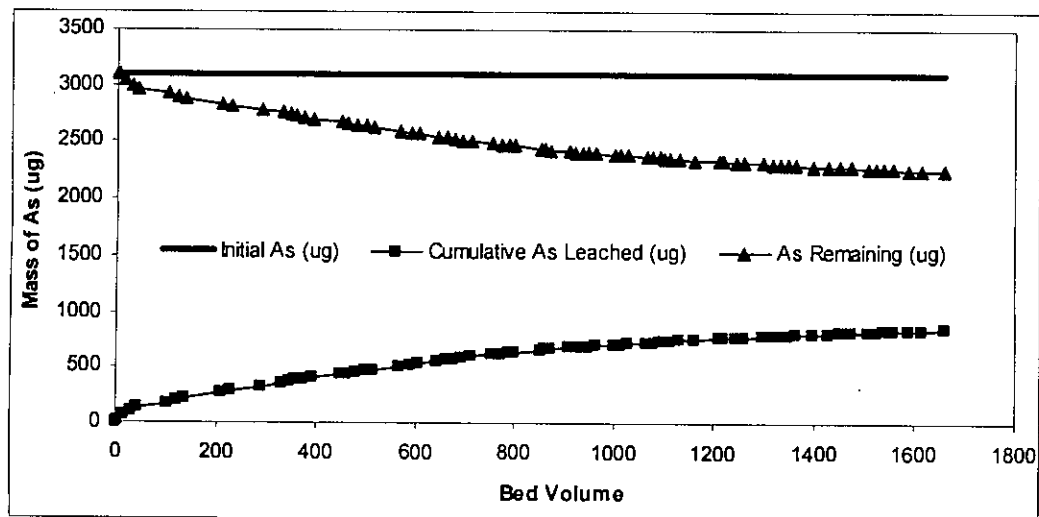


Figure 24: Initial arsenic, arsenic leached and arsenic remaining as a function of bed volume of fluid passed through the column (Column ID: C-3, Fluid: Rain Water).

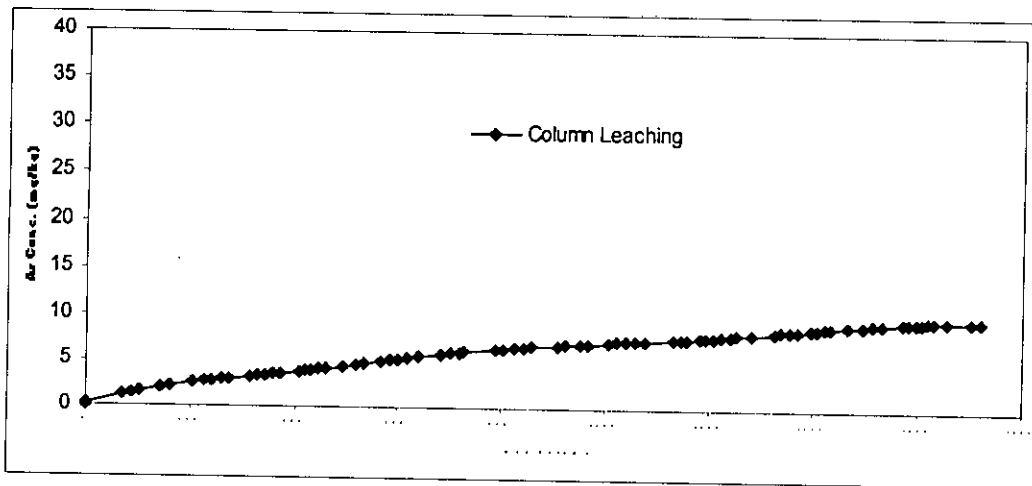


Figure 25: Cumulative arsenic leached as a function of bed volume of fluid passed through the column (Column ID: C-4, Fluid: Pond Water).

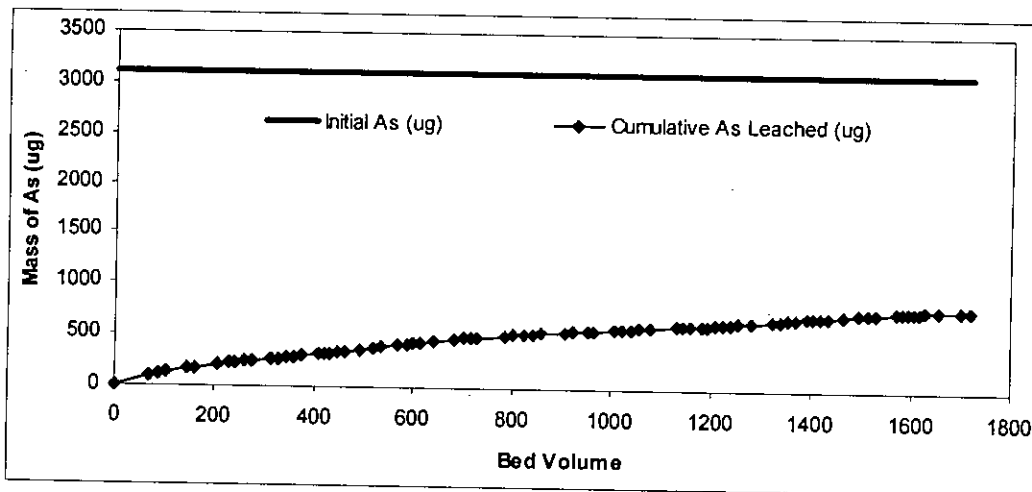


Figure 26: Initial arsenic and Cumulative arsenic leached as a function of bed volume of fluid passed through the column (Column ID: C-4, Fluid: Pond Water).

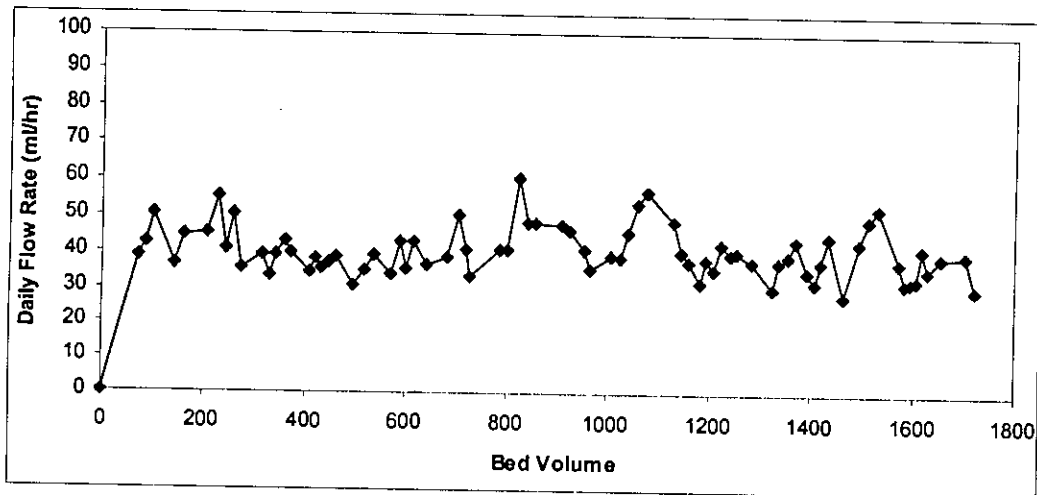


Figure 27: Daily flow rate as a function of bed volume of fluid passed through the column (Column ID: C-4, Fluid: Pond Water).

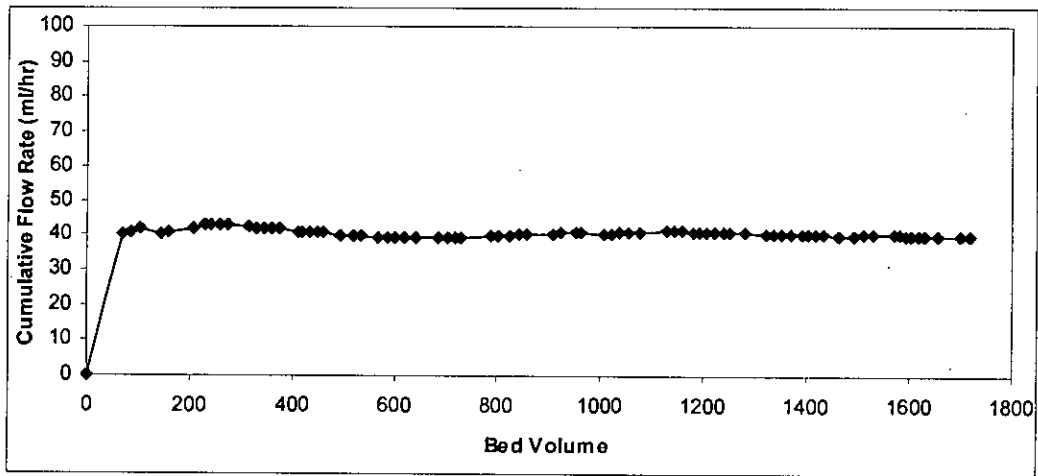


Figure 28: Cumulative flow rate as a function of bed volume of fluid passed through the column (Column ID: C-4, Fluid: Pond Water).

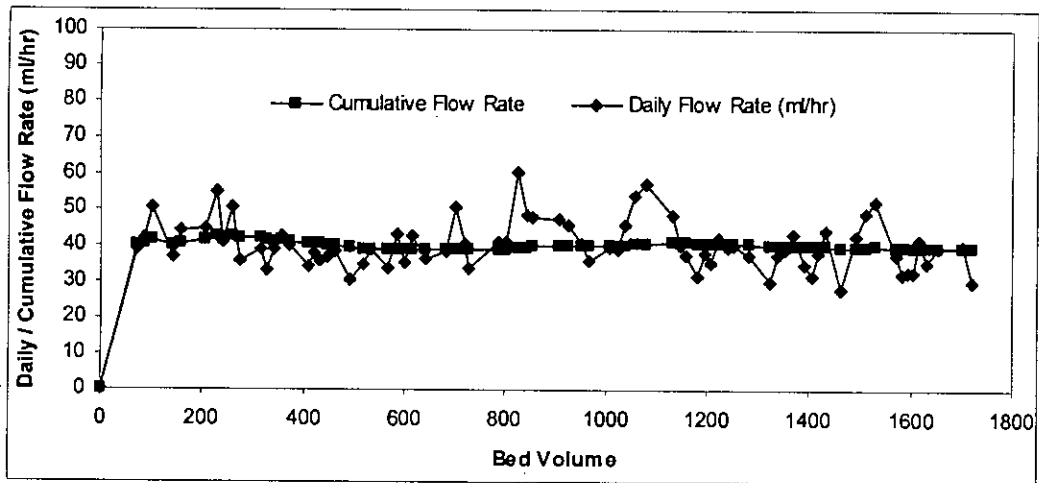


Figure 29: Cumulative and Daily flow rate as a function of bed volume of fluid passed through the column (Column ID: C-4, Fluid: Pond Water).

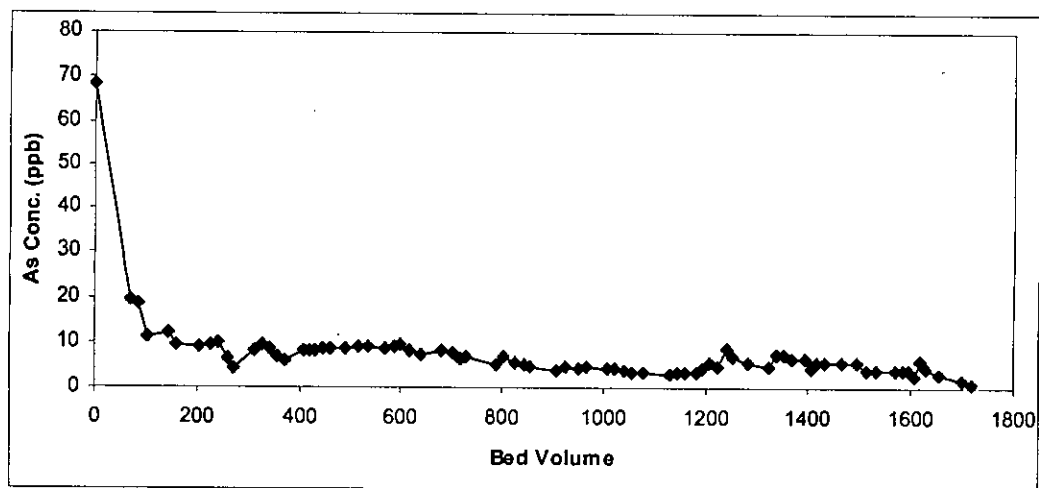


Figure 30: Arsenic in column effluent as a function of bed volume of fluid passed through the column (Column ID: C-4, Fluid: Pond Water).

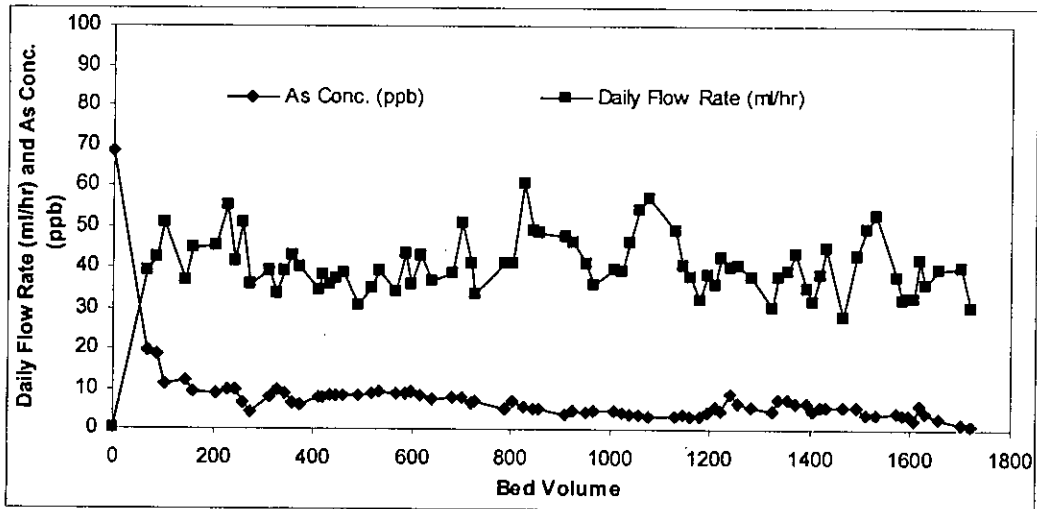


Figure 31: Daily flow rate and Arsenic in column effluent as a function of bed volume of fluid passed through the column (Column ID: C-4, Fluid: Pond Water).

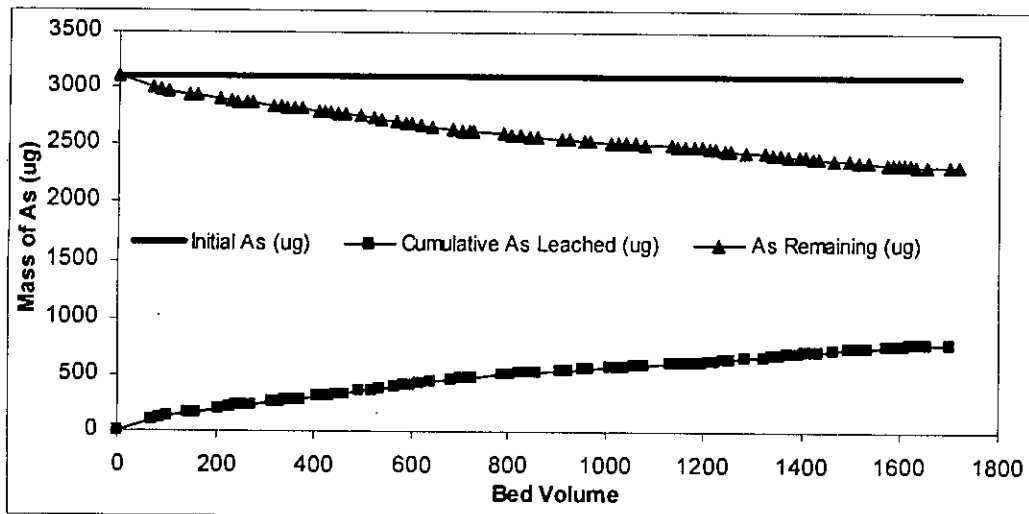


Figure 32: Initial arsenic, arsenic leached and arsenic remaining as a function of bed volume of fluid passed through the column (Column ID: C-4, Fluid: Pond Water).

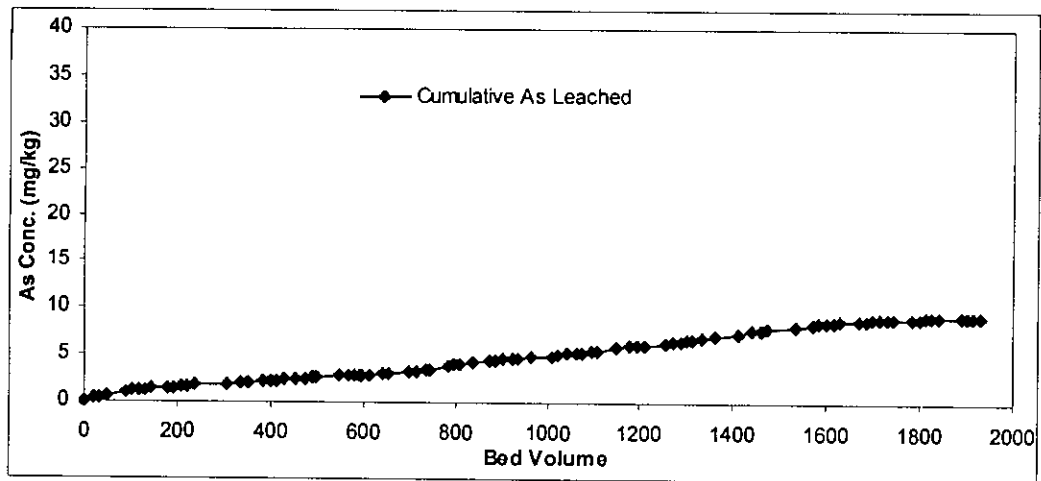


Figure 33: Cumulative arsenic leached as a function of bed volume of fluid passed through the column (Column ID: C-5, Fluid: Extraction Fluid # 1).

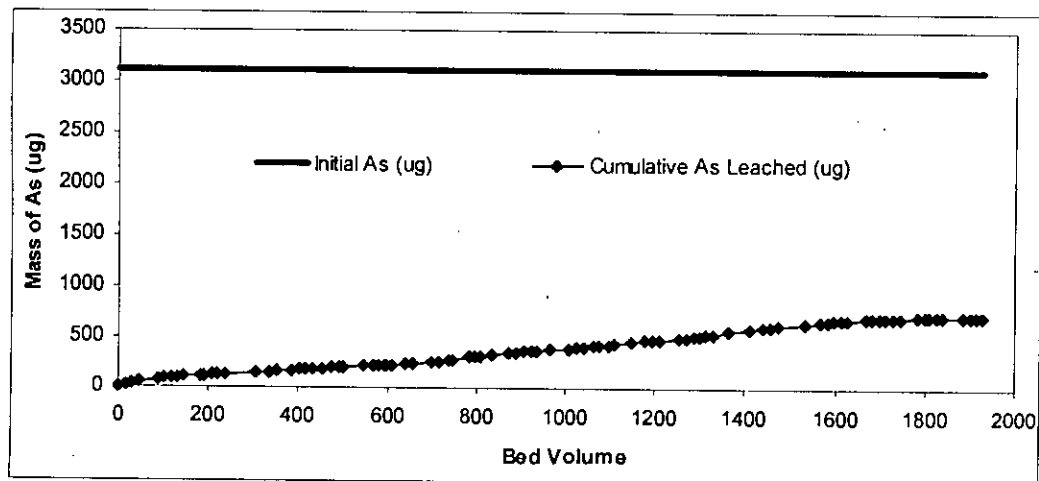


Figure 34: Initial arsenic and Cumulative arsenic leached as a function of bed volume of fluid passed through the column (Column ID: C-5, Fluid: Extraction Fluid # 1).

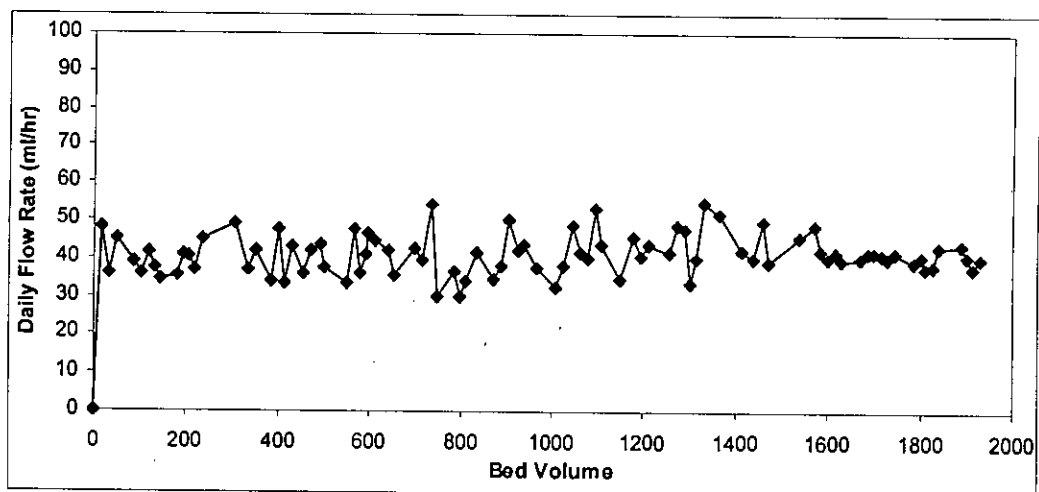


Figure 35: Daily flow rate as a function of bed volume of fluid passed through the column (Column ID: C-5, Fluid: Extraction Fluid # 1).

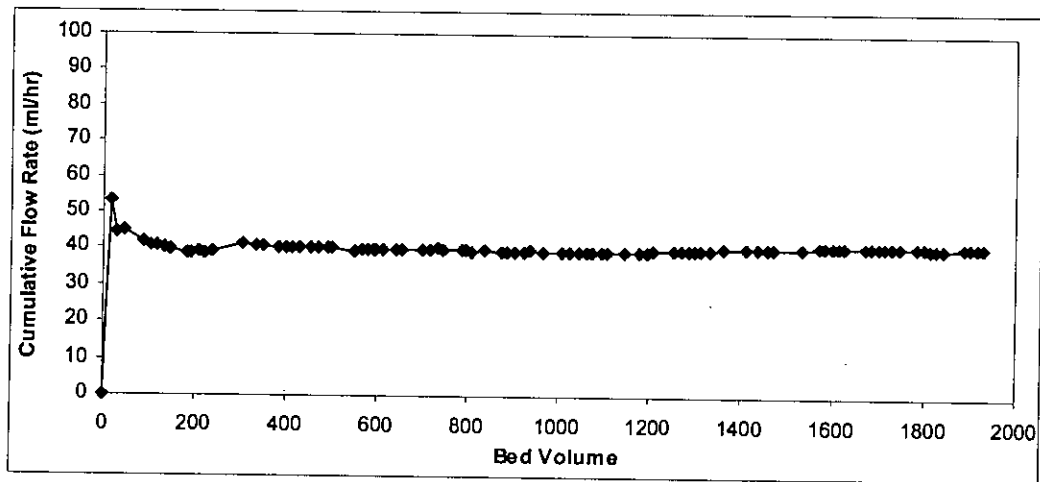


Figure 36: Cumulative flow rate as a function of bed volume of fluid passed through the column (Column ID: C-5, Fluid: Extraction Fluid # 1).

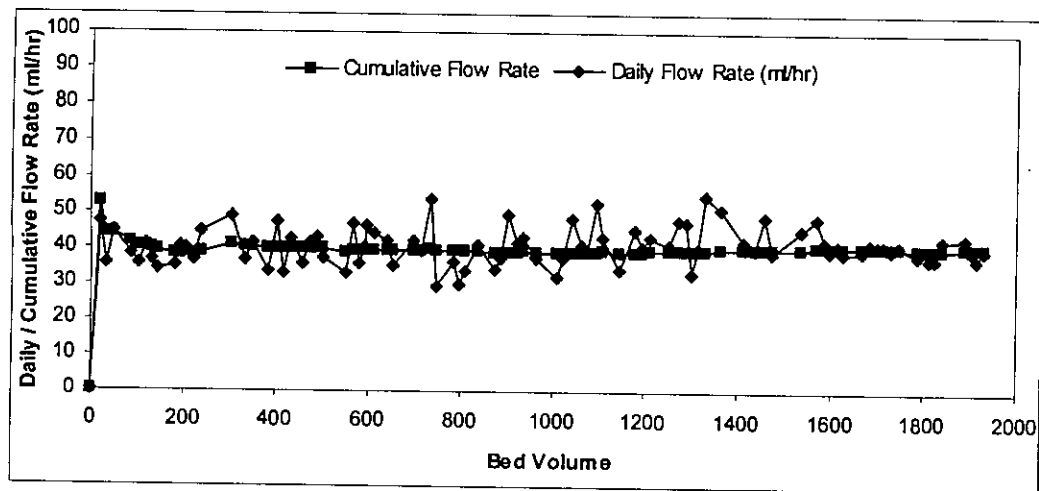


Figure 37: Cumulative and Daily flow rate as a function of bed volume of fluid passed through the column (Column ID: C-5, Fluid: Extraction Fluid # 1).

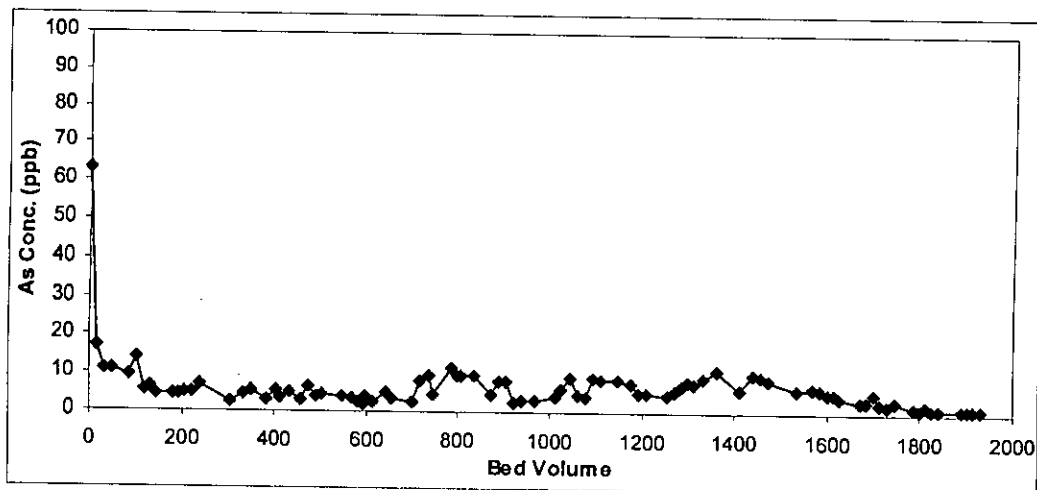
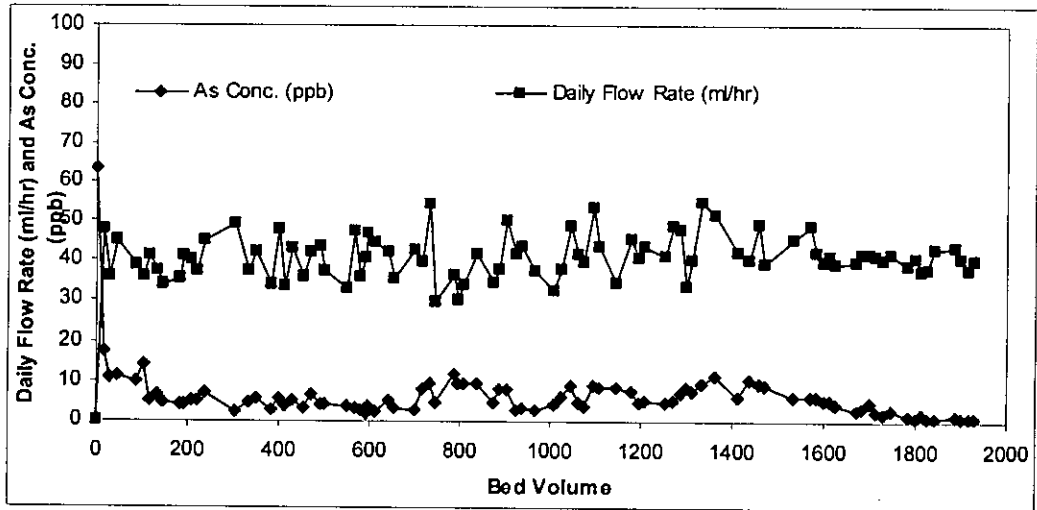
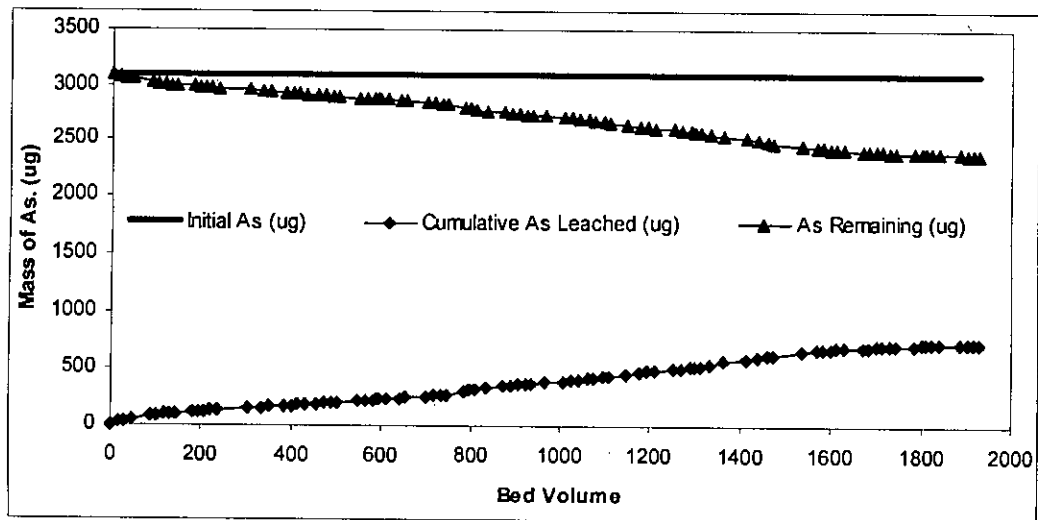


Figure 38: Arsenic in column effluent as a function of bed volume of fluid passed through the column (Column ID: C-5, Fluid: Extraction Fluid # 1).





**Figure 39:** Daily flow rate and Arsenic in column effluent as a function of bed volume of fluid passed through the column (Column ID: C-5, Fluid: Extraction Fluid # 1).



**Figure 40:** Initial arsenic, arsenic leached and arsenic remaining as a function of bed volume of fluid passed through the column (Column ID: C-5, Fluid: Extraction Fluid # 1).

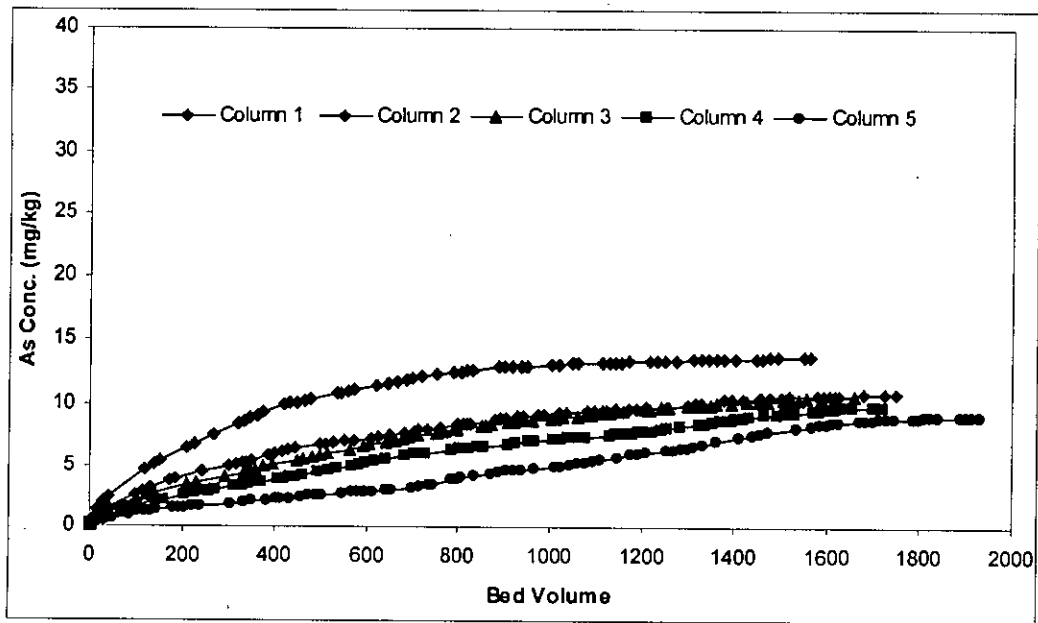


Figure 41: Cumulative arsenic leached as a function of bed volume of fluid passed through the column (All columns).

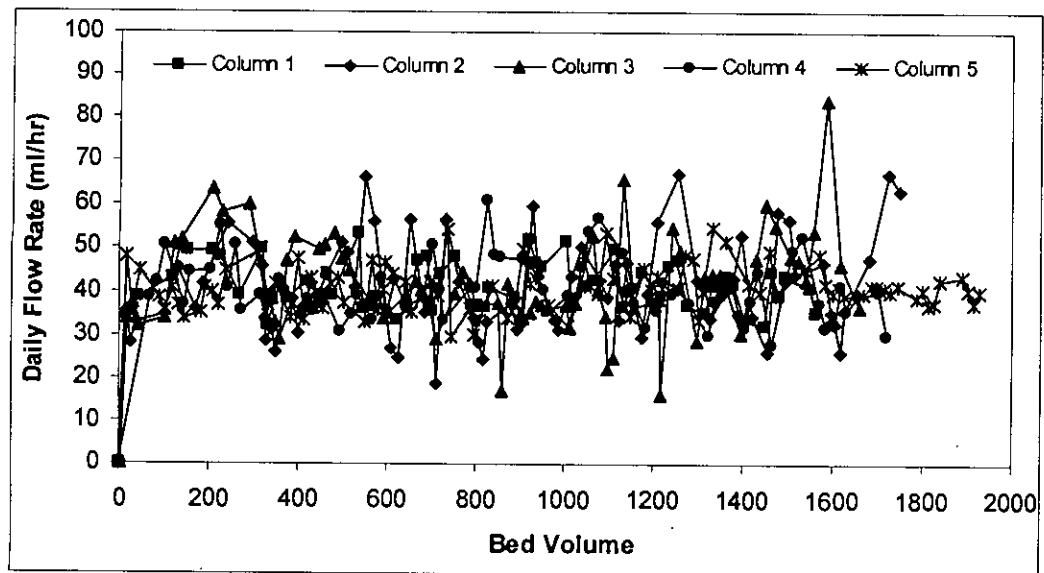


Figure 42: Daily flow rate as a function of bed volume of fluid passed through the column (All columns).

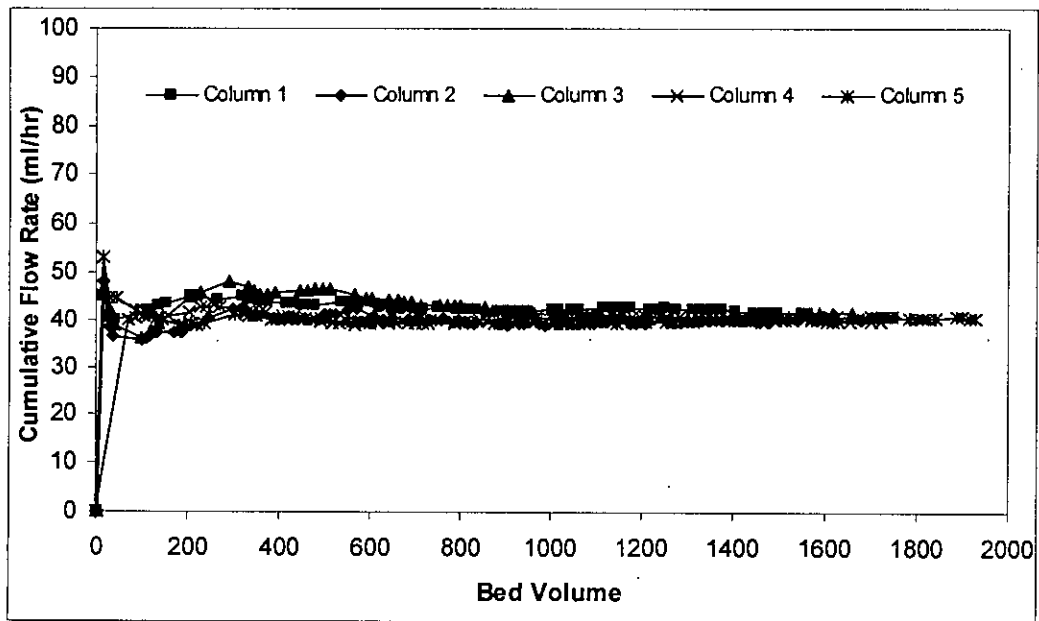


Figure 43: Cumulative flow rate as a function of bed volume of fluid passed through the column (All columns).

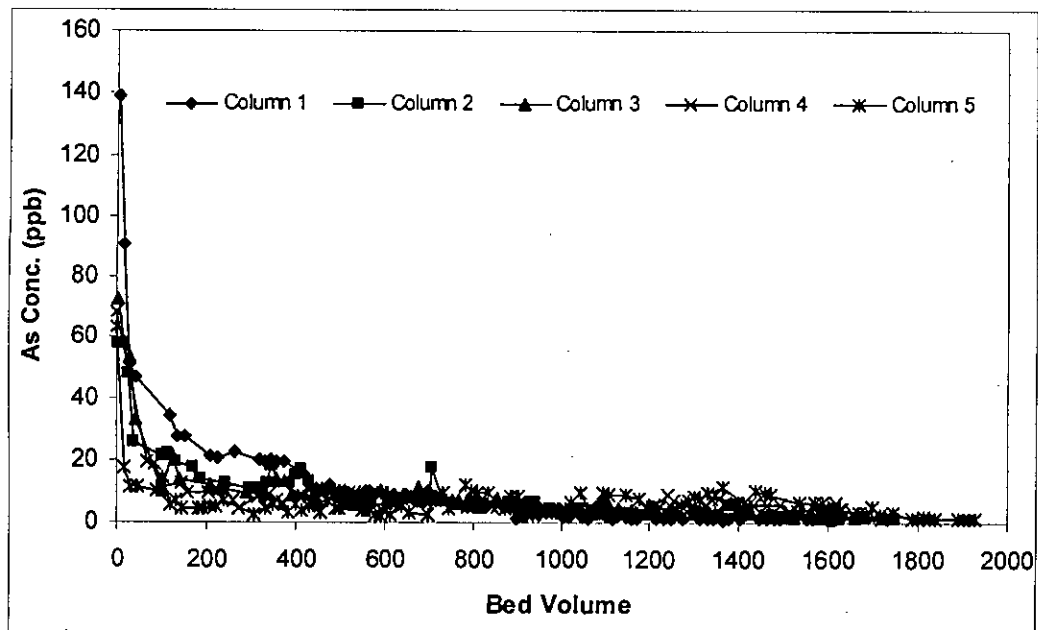


Figure 44: Arsenic in column effluent as a function of bed volume of fluid passed through the column (All columns).

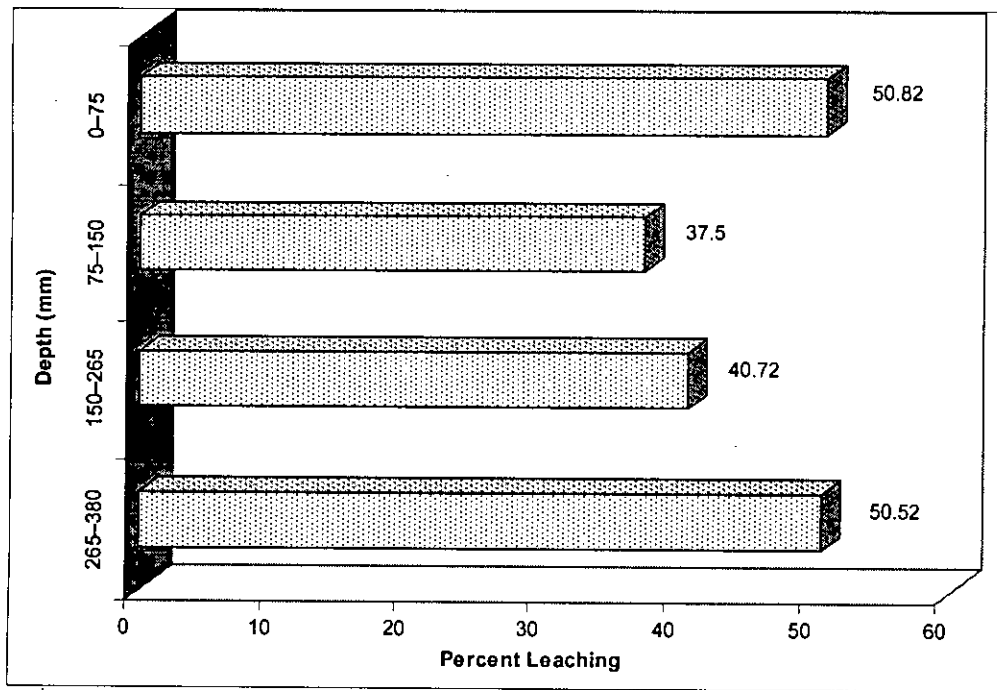


Figure 45: Percent leaching of arsenic from various segments of column 1 (Column ID: C-, Fluid: Distilled Water)

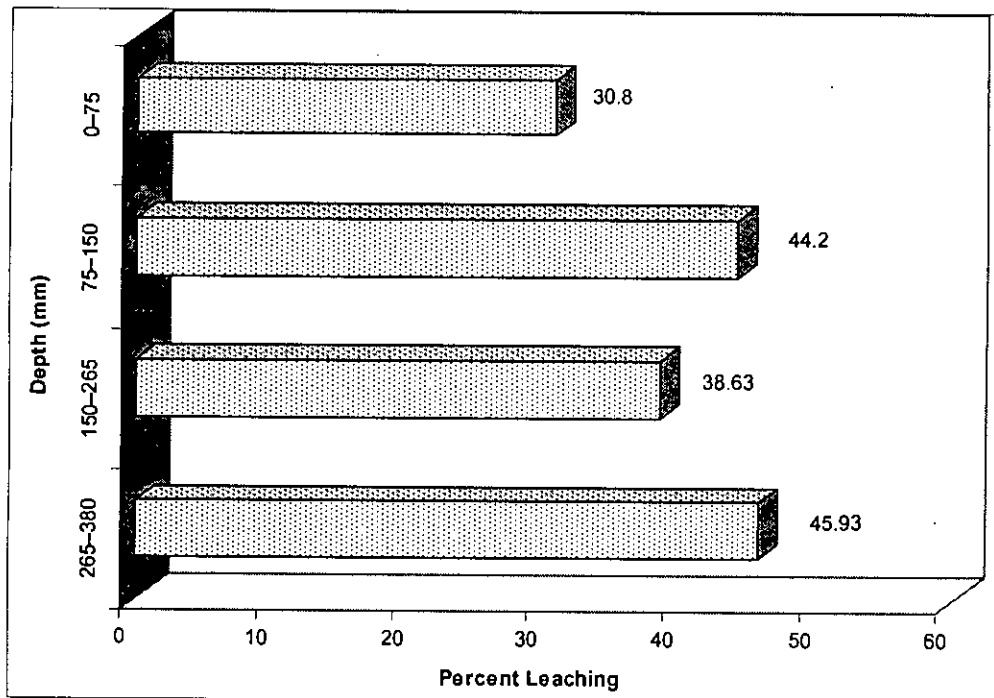


Figure 46: Percent leaching of arsenic from various segments of column 2 (Column ID: C-2, Fluid: Ground Water)

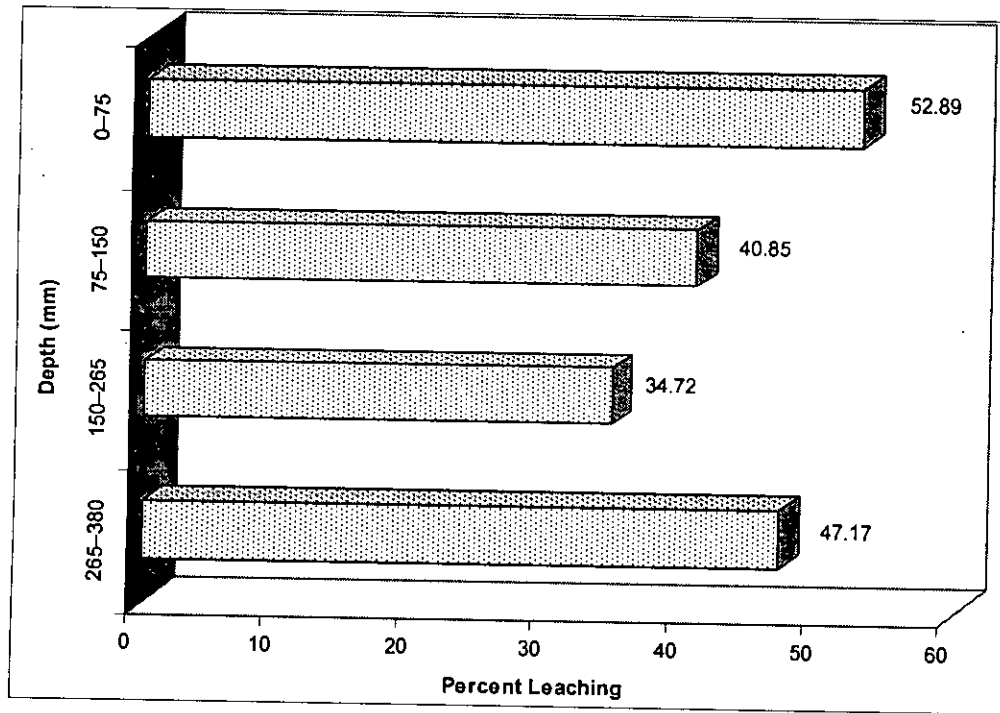


Figure 47: Percent leaching of arsenic from various segments of column 3 (Column ID: C-3, Fluid: Rainwater)

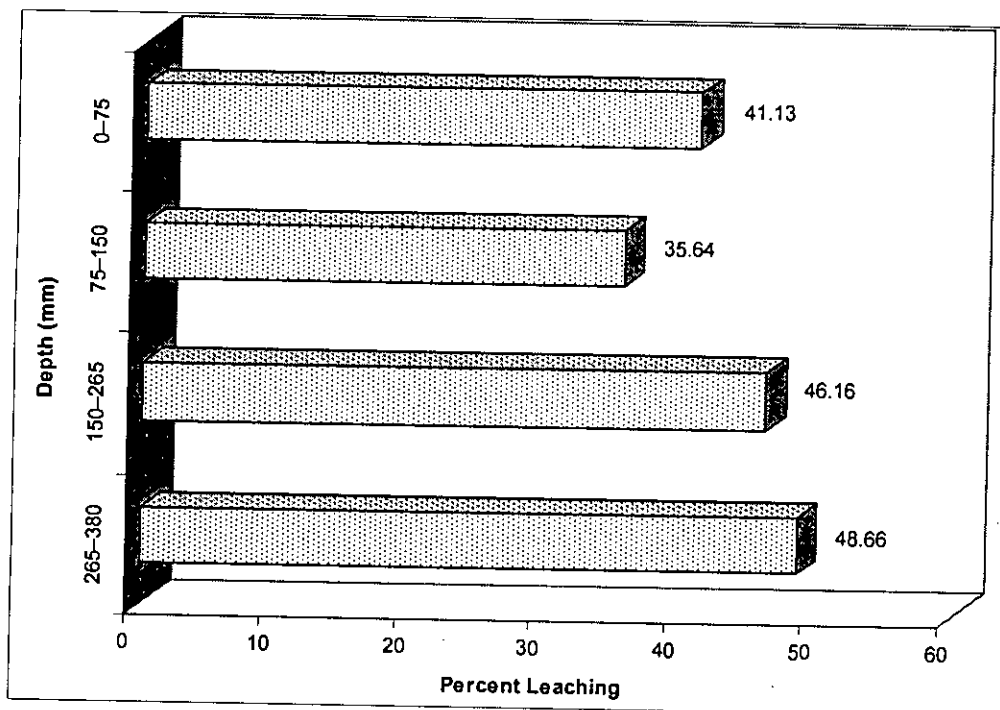


Figure 48: Percent leaching of arsenic from various segments of column 4 (Column ID: C-4, Fluid: Pond Water)

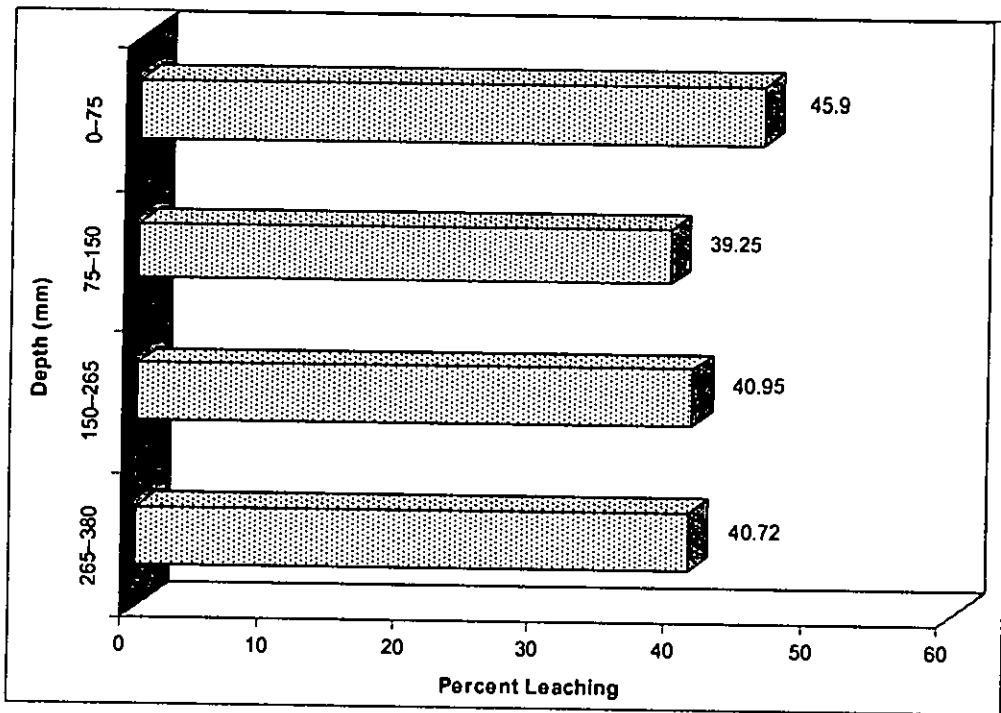


Figure 49: Percent leaching of arsenic from various segments of column 5 (Column ID: C-5, Fluid: Extraction Fluid # 1)

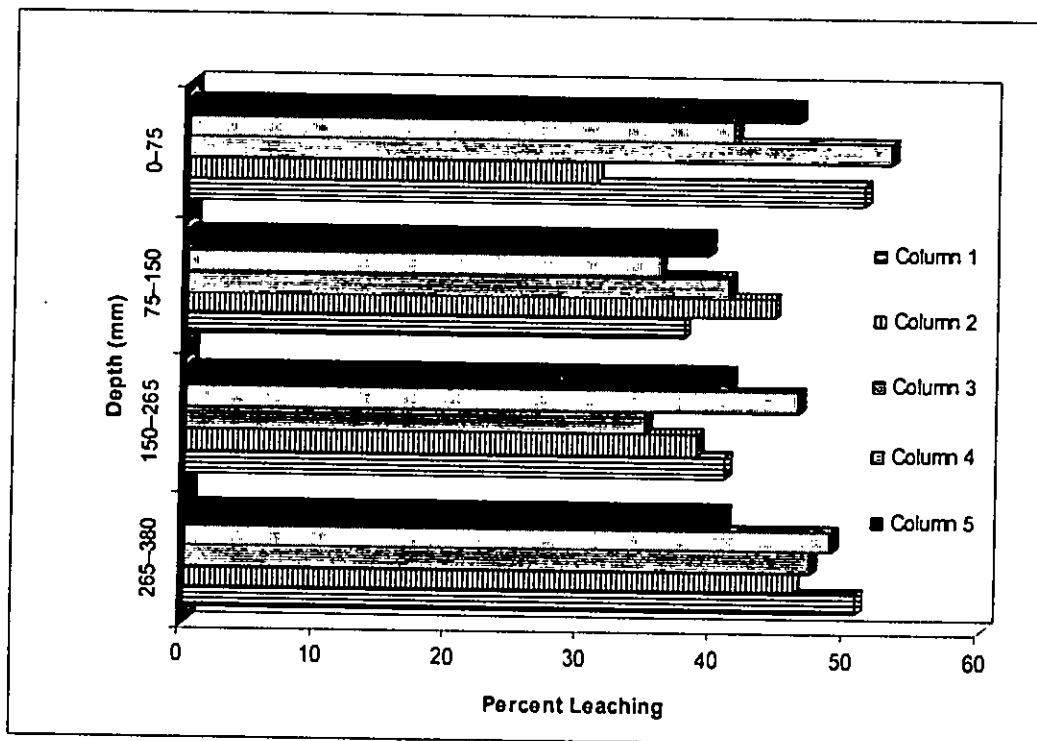


Figure 50: Percent leaching of arsenic from various segments of all columns

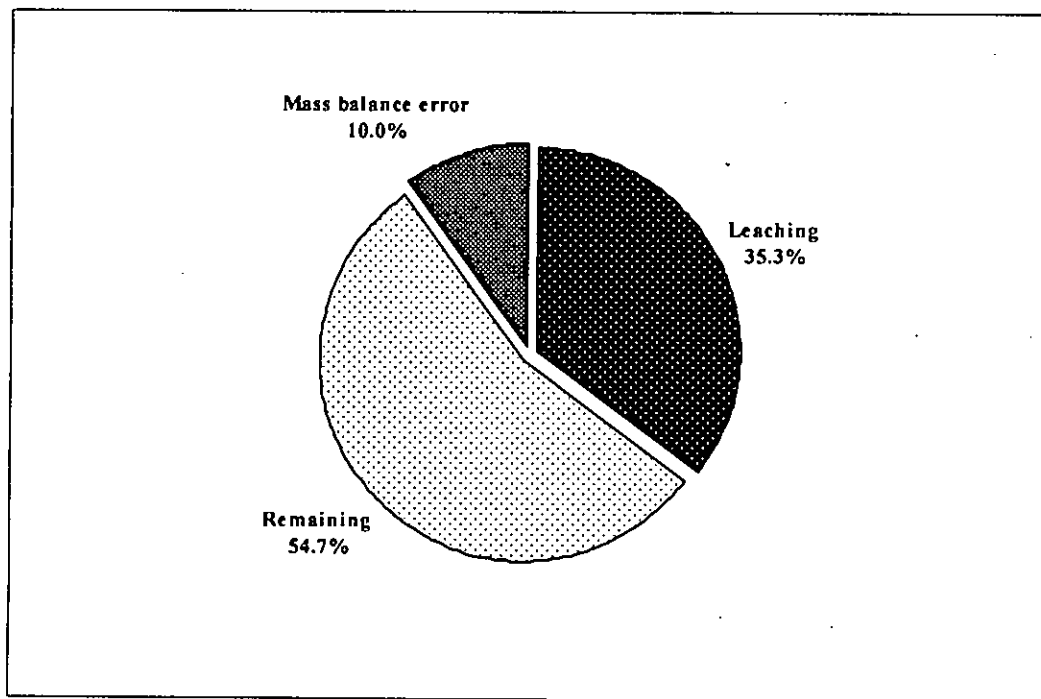


Figure 51: Total amount of arsenic leached, arsenic remaining and mass balance error of arsenic in column 1 (Column ID: C-1, Fluid: Distilled Water)

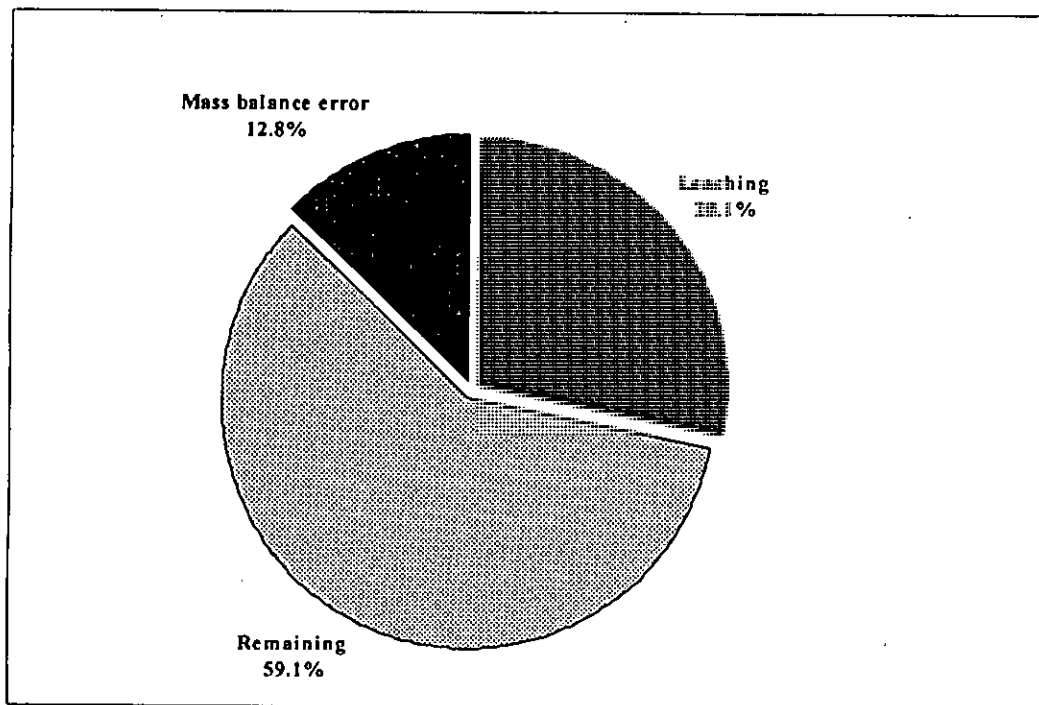
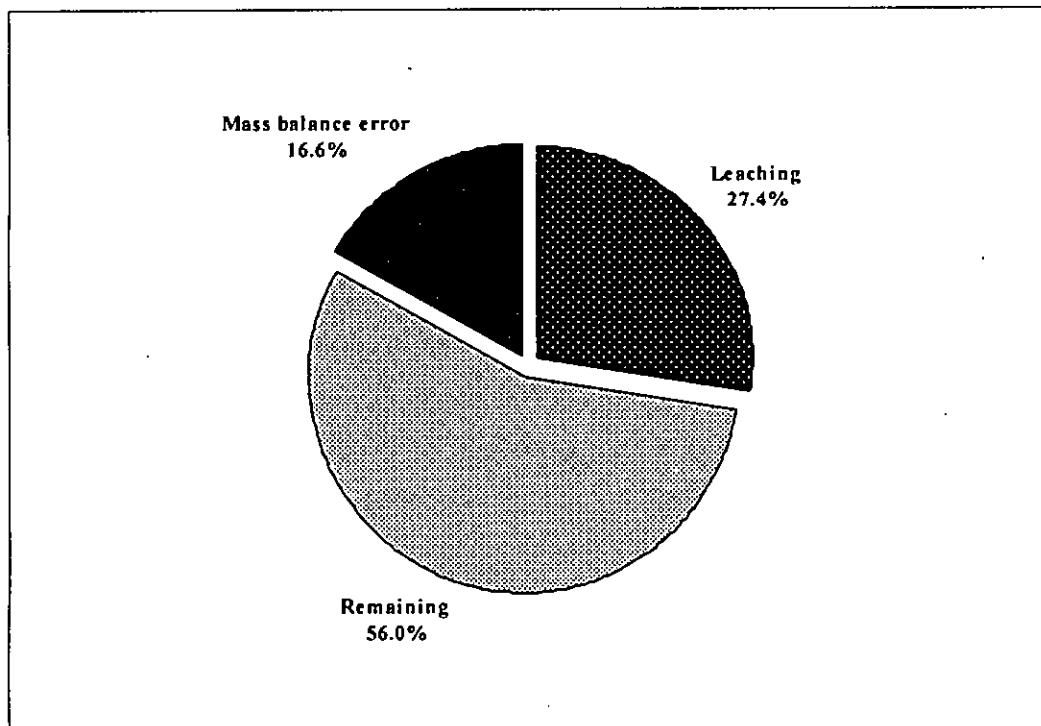
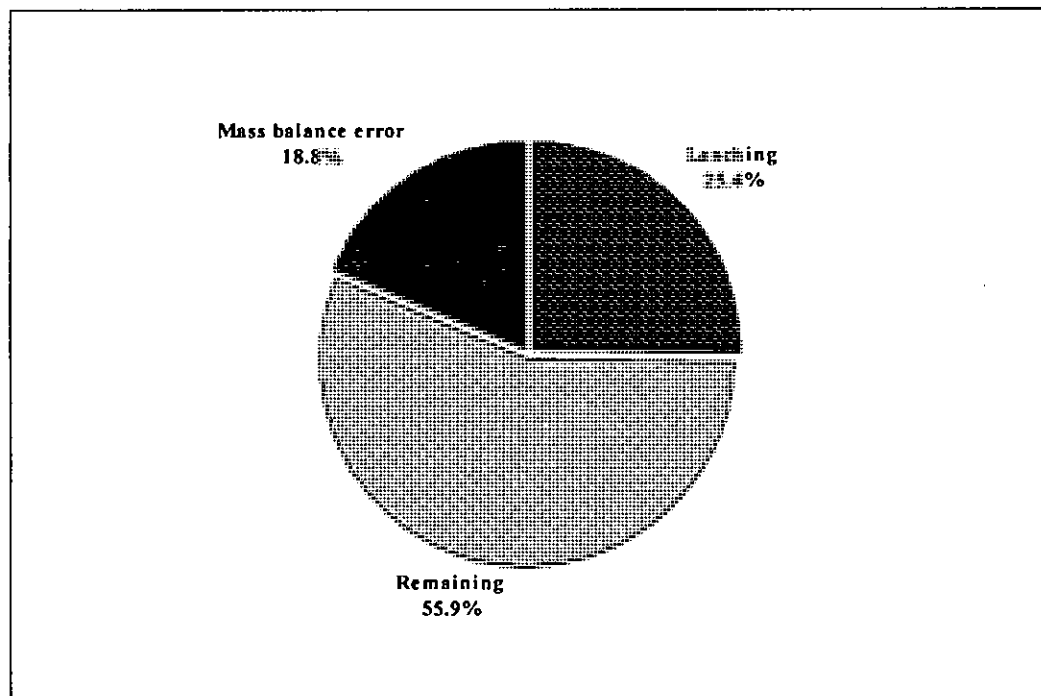


Figure 52: Total amount of arsenic leached, arsenic remaining and mass balance error of arsenic in column 2 (Column ID: C-2, Fluid: Ground Water)

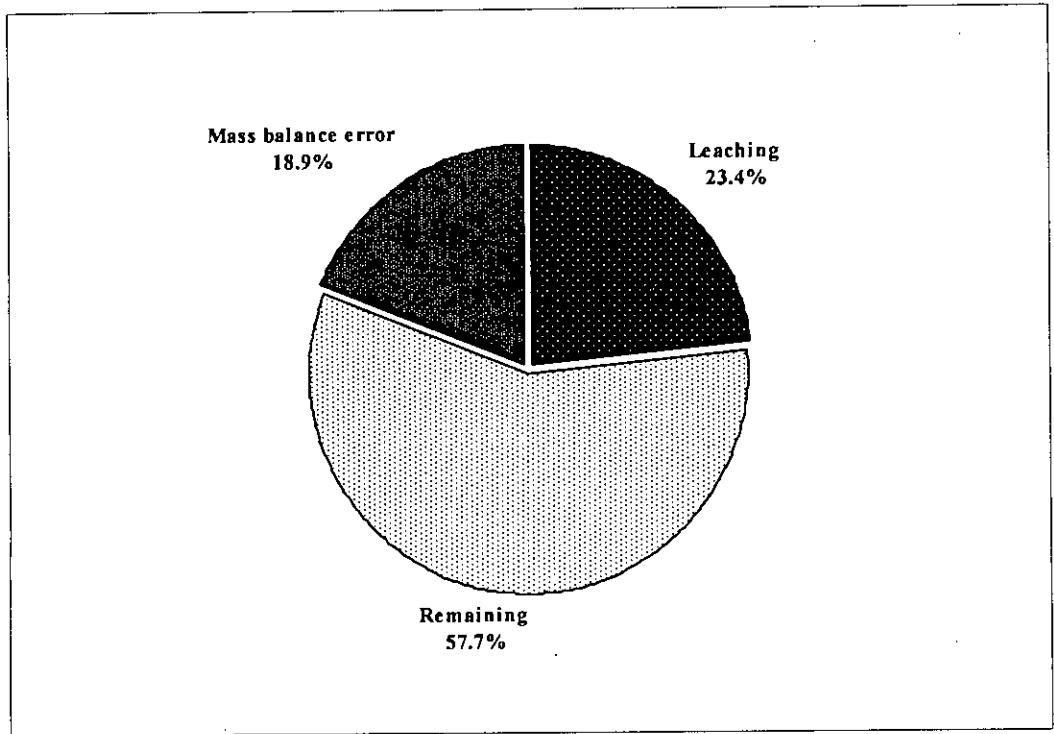


**Figure 53:** Total amount of arsenic leached, arsenic remaining and mass balance error of arsenic in column 3 (Column ID: C-3, Fluid: Rainwater)



**Figure 54:** Total amount of arsenic leached, arsenic remaining and mass balance error of arsenic in column 4 (Column ID: C-4, Fluid: Pond Water)





**Figure 55:** Total amount of arsenic leached, arsenic remaining and mass balance error of arsenic in column 5 (Column ID: C-5, Fluid: Extraction Fluid # 1)

**APPENDIX D: TABLES**

**Table 1: Total time required, bed volume passed, avg. flow rate, no. of leachate samples collected etc. before stabilization of the waste sample in different columns.**

Column	Fluid used	Total time (days)	Total volume (liter)	Bed volume	Avg. flow rate (ml/hr)	No of leachate sample collected
Column 1	Distilled Water	105.72	105.28	1563.64	41.37	64
Column 2	Groud water	120.47	117.8	1749.59	40.74	72
Column 3	Rainwater	112.62	111.62	1657.84	41.3	69
Column 4	Pond water	121.92	115.78	1719.55	39.57	77
Column 5	Extraction Fluid # 1	133.66	129.89	1929.16	40.49	89

**Table 2: Comparison of short-term and long-term leaching of arsenic from the waste collected from 'Shapla' filter using different fluids.**

Column	Fluid used	Initial As Conc. (mg/kg)	Long term leaching (mg/kg)	Short term leaching (mg/kg)	% Long term leaching	% Short term leaching
Column 1	Distilled Water	38.80	13.71	0.52	35.3	1.33
Column 2	Groud water	38.80	10.89	0.54	28.1	1.39
Column 3	Rainwater	38.80	10.64	0.72	27.4	1.85
Column 4	Pond water	38.80	9.84	0.59	25.4	1.53
Column 5	Extraction Fluid #1	38.80	9.07	0.46	22.7	1.19

**Table 3: Leaching of arsenic through column experiment, remaining arsenic in the waste sample after stabilization, shortage of arsenic etc. of different columns.**

Column ID	Leaching of As ( $\mu\text{g}$ )	Remaining ( $\mu\text{g}$ )	Total ( $\mu\text{g}$ )	Initial arsenic ( $\mu\text{g}$ )	Shortage ( $\mu\text{g}$ )	Mass balance error (%)
Column 1	1097	1698	2795	3104	309.9	9.98
Column 2	871	1836	2707	3104	397.4	12.80
Column 3	851	1737	2588	3104	515.6	16.61
Column 4	787	1735	2522	3104	582.1	18.75
Column 5	726	1792	2518	3104	586.0	18.88

**Table 4: Segment wise depth, weight, arsenic concentration, arsenic leaching etc. of Column 1 (Column ID: C-1, Fluid: Distilled Water)**

Segment No.	Depth (mm)	Weight (gm)	As Conc. (mg/kg)	Total As. ( $\mu\text{g}$ )	Initial As ( $\mu\text{g}$ )	As Leached ( $\mu\text{g}$ )	% As Leached
1	0-75	15.618	19.08	297.99	605.98	307.99	50.82
2	75-150	16.028	24.25	388.68	621.89	233.21	37.50
3	150-265	24.130	23.00	554.99	936.24	381.25	40.72
4	265-380	23.747	19.2	455.94	921.38	465.44	50.52
Total	-	79.523	-	1697.60	3085.49	1387.89	44.98

**Table 5: Segment wise depth, weight, arsenic concentration, arsenic leaching etc. of Column 2 (Column ID: C-2, Fluid: Ground Water)**

Segment No.	Depth (mm)	Weight (gm)	As Conc. (mg/kg)	Total As. ( $\mu\text{g}$ )	Initial As ( $\mu\text{g}$ )	As Leached ( $\mu\text{g}$ )	% As Leached
1	0-75	16.103	26.85	432.37	624.8	192.43	30.80
2	75-150	15.269	21.65	330.57	592.44	261.87	44.20
3	150-265	24.043	23.81	572.46	932.87	360.41	38.63
4	265-380	23.849	20.98	500.35	925.34	424.99	45.93
Total	-	79.264	-	1835.76	3075.45	1239.69	40.31

**Table 6: Segment wise depth, weight, arsenic concentration, arsenic leaching etc. of Column 3 (Column ID: C-3, Fluid: Rainwater)**

Segment No.	Depth (mm)	Weight (gm)	As Conc. (mg/kg)	Total As. (µg)	Initial As (µg)	As Leached (µg)	% As Leached
1	0-75	15.441	18.28	282.26	599.11	316.85	52.89
2	75-150	16.195	22.95	371.68	628.37	256.69	40.85
3	150-265	23.659	25.33	599.28	917.97	318.69	34.72
4	265-380	23.620	20.5	484.21	916.46	432.25	47.17
Total	-	78.915	-	1737.43	3061.91	1324.48	43.26

**Table 7: Segment wise depth, weight, arsenic concentration, arsenic leaching etc. of Column 4 (Column ID: C-4, Fluid: Pond Water)**

Segment No.	Depth (mm)	Weight (gm)	As Conc. (mg/kg)	Total As at the end of column experiment (µg)	Initial As (µg)	Calculated As Leached (µg)	% As Leached
1	0-75	18.144	22.84	414.41	703.99	289.58	41.13
2	75-150	16.945	24.97	423.12	657.47	234.35	35.64
3	150-265	23.515	20.89	491.23	912.38	421.15	46.16
4	265-380	20.390	19.92	406.17	791.13	384.96	48.66
Total	-	78.994	-	1734.92	3064.97	1330.05	43.40

**Table 8: Segment wise depth, weight, arsenic concentration, arsenic leaching etc. of Column 5 (Column ID: C-5, Fluid: Extraction Fluid # 1)**

Segment No.	Depth (mm)	Weight (gm)	As Conc. (mg/kg)	Total As at the end of column experiment (µg)	Initial As (µg)	Calculated As Leached (µg)	% As Leached
1	0-75	16.960	20.99	355.99	658.05	302.06	45.90
2	75-150	14.321	23.57	337.55	555.65	218.10	39.25
3	150-265	22.248	22.91	509.70	863.22	353.52	40.95
4	265-380	25.605	23	588.92	993.47	404.56	40.72
Total	-	79.134	-	1792.15	3070.39	1278.24	41.63

